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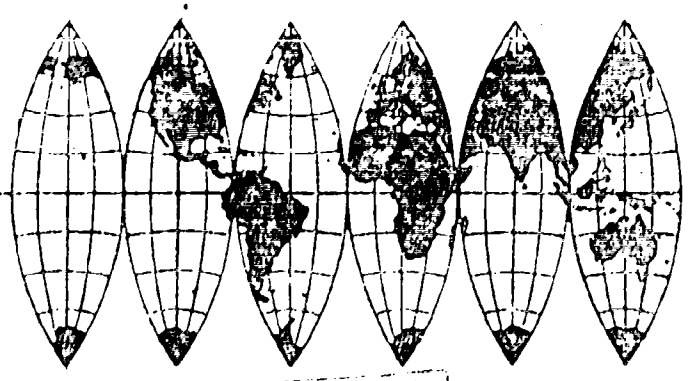
ALL-WEATHER FLIGHT MANUAL



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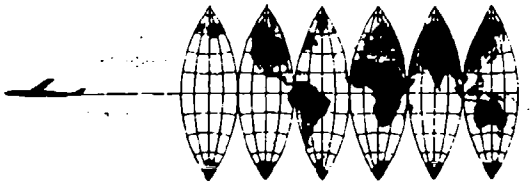

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Foreword

The All-Weather Flight Manual is an excellent reference dealing with instrument flying and advanced pilot training. Although this manual was originally issued by the Office of the Chief of Naval Operations for use by Naval Aviators, civilian airmen will find a large portion of its contents valuable for study and reference purposes.

In a continuing effort to promote aviation safety through increased airman competency, the Federal Aviation Agency has reproduced the All-Weather Flight Manual and made it available to the aviation public. The Examination and Records Division of the Bureau of Flight Standards recommends this publication to those preparing for Instrument Pilot, Airline Transport Pilot, Instrument Flight Instructor and other FAA certificates and ratings.

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CHAPTER 1

INSTRUMENT TRAINERS

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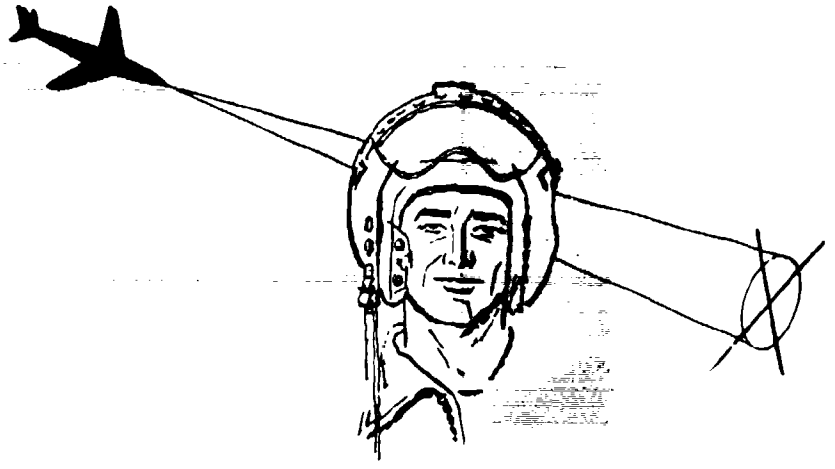

CHAPTER 1

INSTRUMENT TRAINERS

THE key to all-weather flying is pilot proficiency, and the key to pilot proficiency is effective training and practice. In this training, you will find that simulated flight trainers can help you tremendously because they let you practice the procedures you want under ideal conditions without the distractions and dangers of actual flight.

This does not mean that the simulated flight trainers are unrealistic. On the contrary, they are so realistic that sometimes students forget they are in a trainer and break out in a cold sweat at the supposed imminent danger of a crash. The realism of the trainers is due to the careful attention paid to every detail in their design. In many cases the trainer cockpit is the actual cockpit obtained from the plane manufacturer. The stick forces are pretty accurate, so the "feel" of the controls is lifelike. The instrument panel indications are what you would see in actual flight under similar circumstances. Even the cockpit sounds are duplicated, as are lightning, cloud formations, and rain. This fairly complete realism results in effective training and makes it easier for you to carry over into actual flight the skills you learn in the trainer.

Time-wise and cost-wise, too, the simulated flight trainer has advantages. A trainer is available for a greater percentage of time than an aircraft is because the trainer is not subject to the problems of weather and general unavailability of aircraft. In addition, trainer costs per hour

are one-tenth to one-fortieth of aircraft costs per hour.

However, useful as the simulated flight trainers are for training in instrument procedures, they are even more useful and necessary for training in emergency procedures. With simulated flight trainers, the instructor can set up problems, such as engine-out approach, flame-outs and intercept problems at close range, that would not be possible in actual aircraft. The instructor can create emergency situations by introducing such malfunctions as icing of wings, engine fire, fuel or boost pump failure, excessive oil pressure or temperature, failure of landing gear, flaps, and so on. In this way you learn not only to recognize causes of trouble, but also how to combat them effectively. Similarly, the instructor can introduce instrument problems, so that you learn to meet abnormal situations when the instruments become unreliable or fail to function at all.

Aside from the factors of safety and economy, the trainers have another important advantage for training in emergency procedures. The emergency can be repeated over and over until you have completely mastered the proper recovery procedure. You learn to meet emergencies of all kinds with automatic reactions of the proper kind.

Furthermore, all Operational Flight Trainers (OFTs) have a "freeze button" which enables the instructor to "freeze" a flight problem at any time. If you become involved in a flight problem to which you see no apparent solution and become tense, perhaps even panicky about your inability to meet the situation, the instructor can "freeze" the problem and give you time to analyze your predicament. You can review the problem or discuss it with the instructor, so that you can locate your mistake and plan corrective action. Once you find the solution, the instructor can flick a switch either to continue the training flight or to reset the entire flight back to take-off time and permit you to begin again. Thus, in an OFT you can get the necessary time to think through your more serious flight problems at the time you are most conscious of it.

In short, simulated flight trainers offer you a remarkable means for learning the fundamental techniques of all-weather flying effectively and safely. Although they can't provide *all* the experience you need to become an instrument pilot—you can gain that essential experience and "final polish" only in actual flight—the trainers do speed your learning greatly and enable you to start actual instrument flying with far greater skill, knowledge and confidence than otherwise.

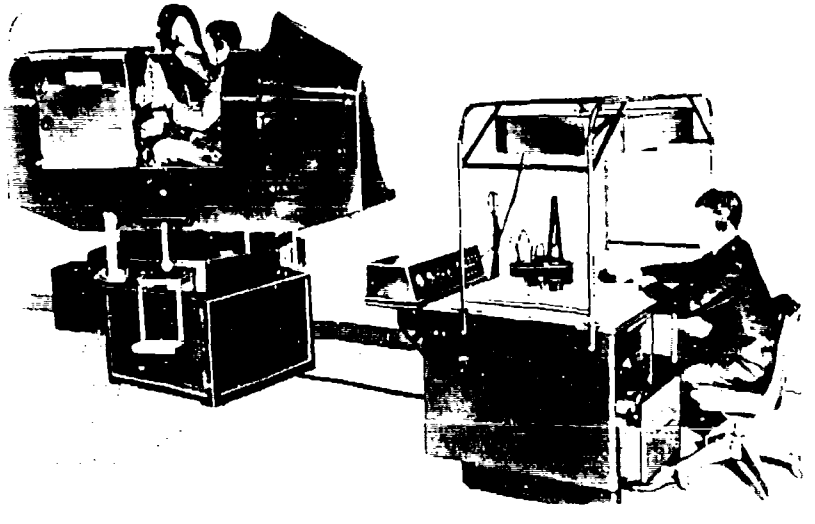

Figure 1–1. Device 1–CA–1, known as the Link Trainer

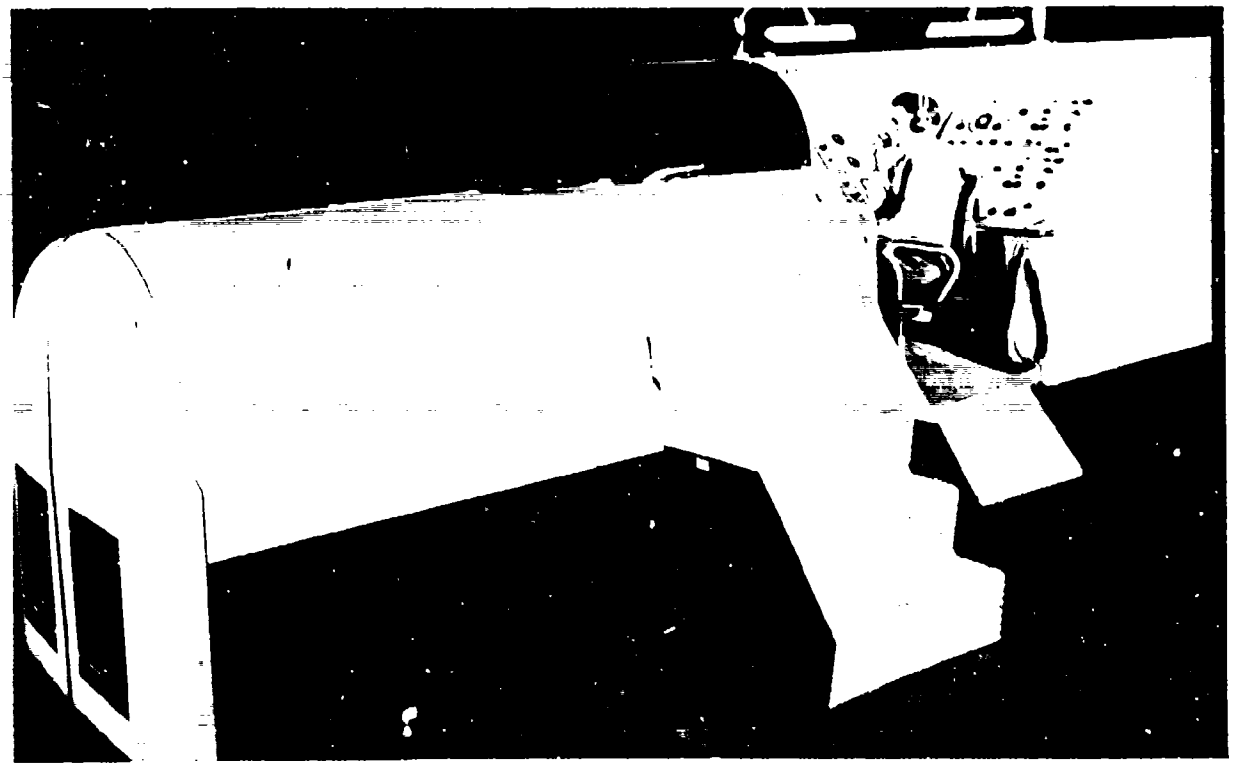

Figure 1-2. Device 2-F-23 jet instrument trainer

The types of simulated flight trainers used in all-weather flight training are the Link Trainer, properly called Device 1-CA-1, Navy Basic Instrument Trainer (NAVBIT); the Twin-Engine Instrument Trainer, Device 2-F-25; the Jet Instrument Trainer, Device 2-F-23; and a variety of Operational Flight Trainers (OFTs) for different model aircraft.

NAVY BASIC INSTRUMENT TRAINER DEVICE 1-CA-1

The Navy Basic Instrument Trainer (Fig. 1-1) is used in teaching all phases of elementary and advanced instrument flying, including radio navigation, radio range and loop orientation, instrument landing systems, voice procedure, and flight and engine instrument familiarization. The complete unit contains the controls, switches, instruments, and mechanisms necessary to reproduce generally the flight characteristics of a single-place reciprocating aircraft. The basic instruments are standard and are interconnected and inter-related to give the same readings as if they were positioned in an actual airplane. They are so grouped that you can practice scan patterns. Range work, including use of fan markers, holding ADF, MDF, GCA, and stacking can be easily simulated.

The controls are of the conventional stick or wheel type. Additional controls are included for the throttle, flaps, landing gear, controllable or constant speed propellers, and so on.

Mounted on a universal joint, the trainer fuselage pitches and banks in accordance with your movement of the controls, and these motions transmit flight instrument indications corresponding to those received in actual flight.

The instructor can simulate failure of instruments by use of controls at his desk, and he can introduce, with or without the student's knowledge, factors of turbulence and wind velocity from any point of the compass up to 60 miles an hour. The instructor's desk houses a simulated radio, automatically or manually operated, radio range equipment, facilities for automatic radio compass and "loop" direction finding, and a keying device to produce station identification and range signals.

The primary purpose of the Link Trainer Course is to teach the navigational procedures before they are encountered in the actual flight syllabus. Link time is preflight briefing time, and it pays off in terms of faster learning when you are aloft. That's why Link instruction must be closely coordinated with flight instruction to insure that procedures and techniques are taught identically in both programs.

Still, Link instruction can readily be adjusted to fit your individual rate of learning. An automatic recorder crab traces the course of the flight, and the results on the recorded track can be reviewed and evaluated. When you receive instrument flight training on the NAVBIT, you can get the most out of the training by seeing that your Link work stays ahead of your work in the air. If unusual circumstances cause your air work to get ahead of the Link, be sure to inform your instructor. Remember, too, that the Link is a synthetic trainer. You cannot fly pressures, and you must keep the Link trimmed.

JET INSTRUMENT TRAINER DEVICE 2-F-23

The Jet Instrument Trainer, Device 2-F-23 (Fig. 1-2) consists of a mock-up of an aircraft cockpit, an instructor's console, and a computer section. Although it is a generalized jet instrument trainer, its cockpit is esentially a mock-up of the F-80A aircraft. It is used for jet instrument training of both cadets and fleet pilots.

The outstanding feature of this trainer is its complete radio-navigation equipment. Besides the usual engine and flight instruments, the trainer has simulated navigational instruments such as the Type ID-249 Course Indicator, B-1 Attitude Gyro Indicator, and controls for various types of radios. With this trainer, you can train in VOR/DME, GCA letdowns, ILS approach and landing, power settings, unusual attitude recovery, and simulated weather conditions.

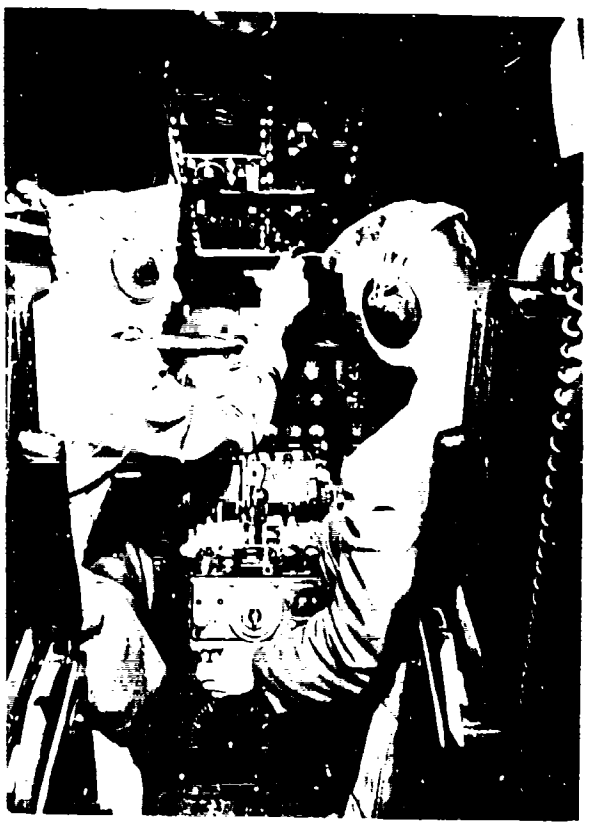

Figure 1-3. Device 2-F-25, showing side-by-side seating and instruments of this twin-engine instrument trainer

The Twin-Engine Instrument Flight Trainer, Device 2-F-25, like the Jet Instrument Trainer, is used for instrument training and for training in control of the powerplant. It is a "general" trainer—that is, it is used in training for a "class" of aircraft rather than for any one specific plane. The planes it may be considered to typify include,

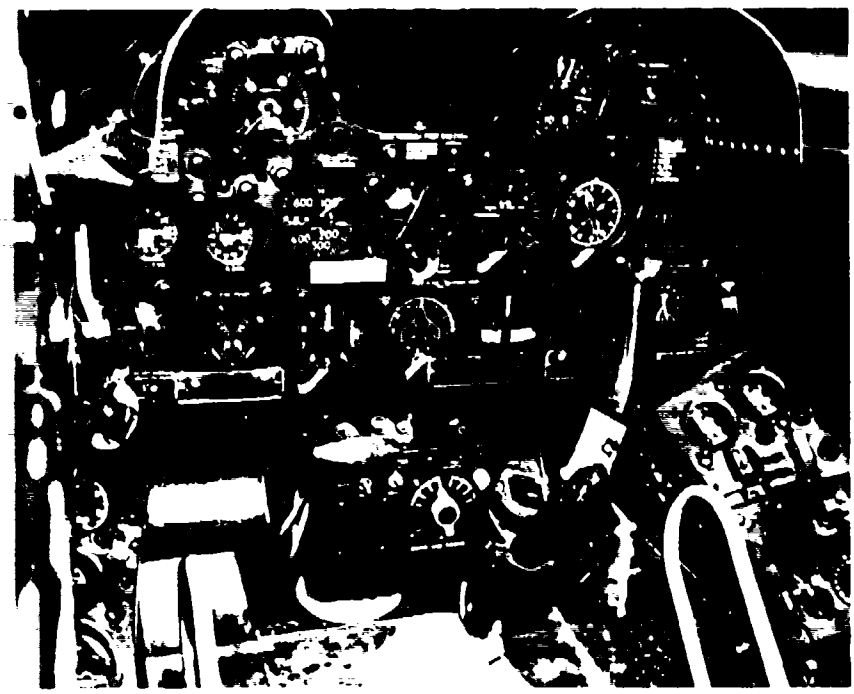

Figure 1-4. Instrument panel of the Operational Flight Trainer for the F2H-2 airplane, device 2-F-15

among others, the P2V, R4D-8, and SNB. The Twin-Engine Instrument Flight Trainer is designed primarily to overcome the hazards of learning twin-engine instrument flying in the air. It has twin-engine controls similar to those of a large, twin-engine conventional airplane. It also has a side-by-side dual cockpit and dual instrumentation and permits the training of two pilots to operate together as a pilot and co-pilot team. Thus, it helps prevent accidents which might occur from misinterpretation of signals or confusion of procedure between two pilots learning instrument flying of multi-engine aircraft.

The 2-F-25 may be used for training in the fine points of maneuvers, flight planning, instrument flying, radio navigation, and direction-finding for multi-engine planes. With this trainer you can get practice in GCA, ILS, omni-range, standard radio communications, radio compass, and radio range.

It permits realistic cross-country flight simulations with a maximum range of 2000 nautical miles. Various instrument and system malfunctions can be introduced as well as weather problems. Since the Flight Path Recorder automatically computes and records the ground position of the trainer from the starting position, you can look at your recorded flight path and recorded elevation at the end of the problem and see what errors you made.

OPERATIONAL FLIGHT TRAINERS (OFTS)

OFTs, unlike the trainers discussed up to now, are designed to simulate specific types of

aircraft. Their cockpits are generally exact replicas of the cockpits of the actual aircraft they represent. Their controls and instruments are made to react as closely as possible to the way the controls and instruments do in actual flight. In

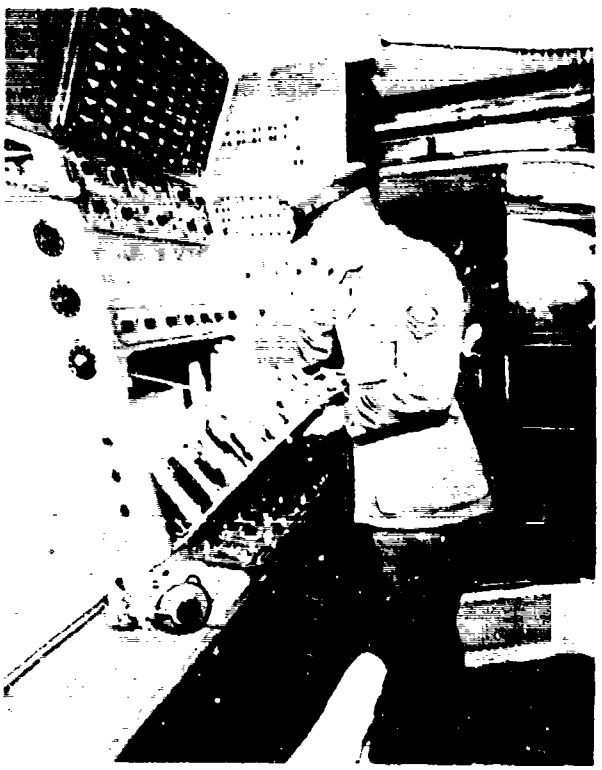

Figure 1–5. Flight instruments duplicating for the twin-engine trainer operator those on the pilots' instrument panel are checked by equipment maintenance Chief

fact, the OFTs are designed so that their characteristics are as nearly identical as possible to those of the aircraft.

As an example of how far this simulation goes, just look at the following list of the flight characteristics simulated in one OFT.

1. Taxiing—take-off—landing.
2. Bank—pitch—turn.
3. Nose heaviness during turn.
4. Indicated bank with turn.
5. Automatic turn with bank.
6. Trim-tab controls.
7. Control loading.
8. "Crash" conditions.
9. Longitudinal and directional stability.
10. Rough air.
11. Stalling.
12. Main hydraulic system.
13. Landing gear and wing flaps.
14. Engine noise.
15. Control quadrant.
16. Power effect on turning.
17. Engine starting.
18. Radio.
19. Cross-country navigation.

This realistic simulation of the flight characteristics of specific types of aircraft makes the OFT's particularly suitable for transition or

Figure 1–6. Photo shows the twin-engine instrument trainer components through which flight conditions are set up on the cockpit instrument panel for the pilots. Note "crab" at left which traces flight path

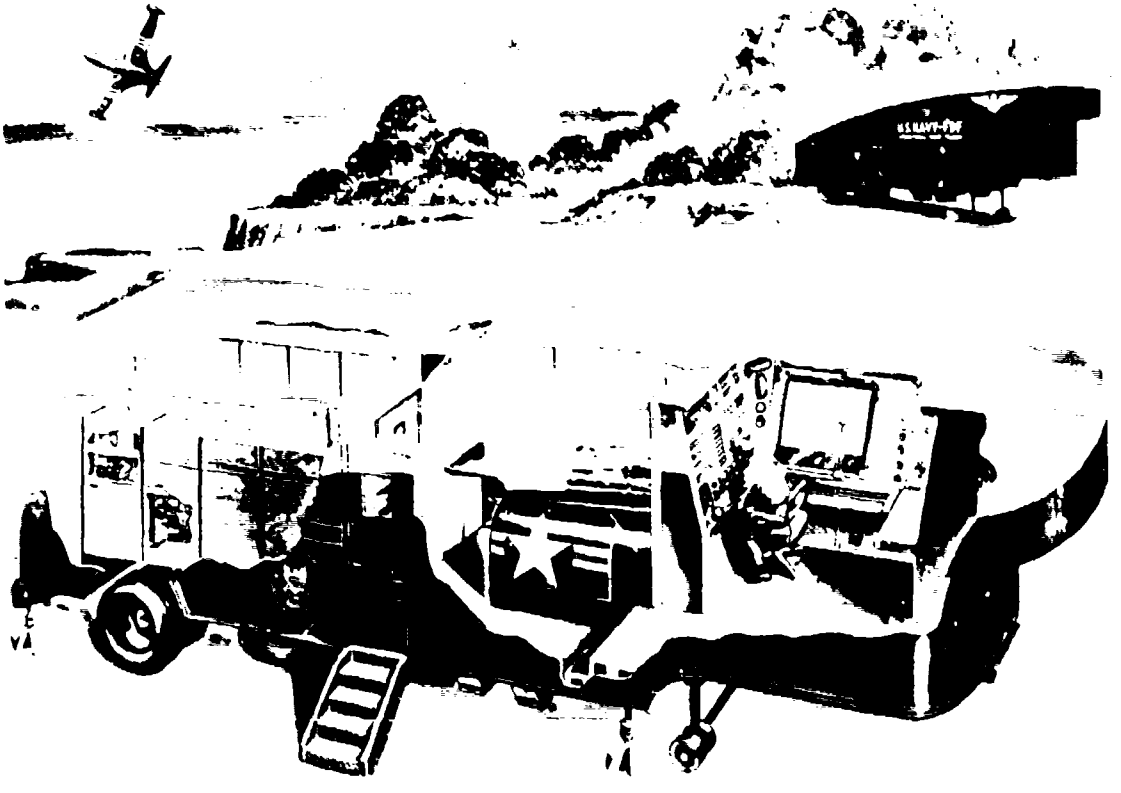

Figure 1-7. Cutaway view of trailer-installed Operational Flight Trainer, device 2-F-13 for F9F airplane, shows (from left to right) electronic components, cockpit installation with student "flying", and trainer operator.

refresher training of pilots who will use those specific aircraft. Perhaps the most distinctive factor of some OFTs and their associate tactics trainer is the ability to create problems in which "enemy" contacts are made by the student, so that he can simulate realistic combat or ASW exercises. Such trainers permit the instructor to control the "enemy" and to maneuver it to give the best possible training.

With respect to training in instrument procedures and emergency procedures, the OFTs, of course, perform like the other trainers -the instructor can introduce weather, malfunctions, and special problems so that the student can learn the proper reactions and procedures for every situation.

You can also rehearse flights in these OFTs. If you are faced with a flight involving certain unfavorable conditions, such as high winds, icing conditions, complex cruise control problems, the OFT enables you to run through a rehearsal of the flight during which you can duplicate the conditions you anticipate in actual flight. You can then practice handling these problems and approach the flight with greater assurance of your ability to meet the challenge. OFT rehearsal flights can be equally helpful following a flight in which you have made an error of judgment. The OFT enables you to recreate your flight and master the procedure before the next take-off.

The OFTs now available include the F2H-1 OFT, F2H-2 OFT, F2H-3 OFT, F9F-2 OFT, F9F-5 OFT, F4D OFT and F2V-3 OFT.

CHAPTER 2

SENSATIONS OF INSTRUMENT FLYING

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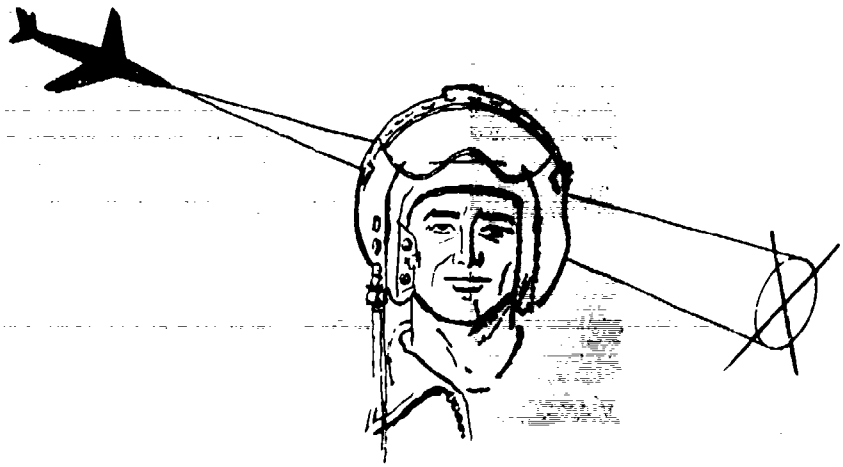


CHAPTER 2

SENSATIONS OF INSTRUMENT FLYING

YOUR primary problem in instrument flight is making judgments and taking action entirely on the basis of reports from your instruments instead of reports from your senses. In visual flight you orient yourself largely on the basis of what your eyes, inner ears, and postural senses tell you. In instrument flight, you can't see—and your inner ears and postural senses often give you misleading information. So you have to ignore your normal sensations and depend entirely on your instruments, interpreting their readings almost subconsciously and acting on them as automatically as you would on the information you get from your own senses. This takes a lot of effort on your part, for it is contrary to your lifelong habits. But it's worth the effort, for your sensations in instrument flight can mislead you dangerously.

OPTICAL ILLUSIONS

When your eyes have enough information to go by, they give you reliable reports of your situation. However, when they can't get enough information, as in instrument conditions, they can mislead you. A common example of this occurs when the horizon is not visible. Pilots sometimes take the line of a cloud bank for the horizon and bank the plane to conform to the slope of the clouds. It's an optical illusion due to insufficient visual data.

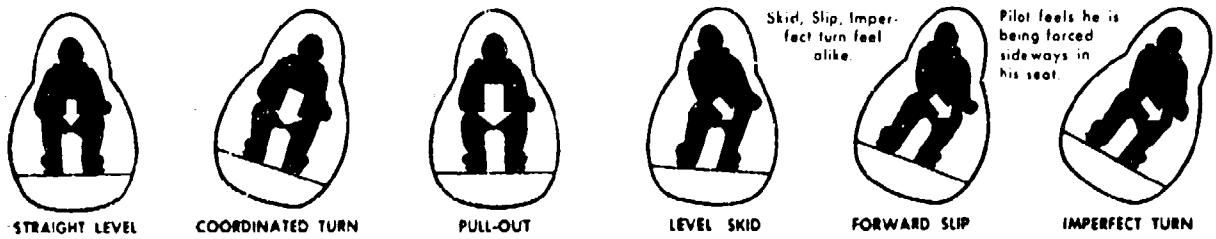


Figure 2–1. Sensations caused by centrifugal force

Another optical illusion, called an *autokinetic illusion*, occurs when you concentrate on a single light and can't see any other objects around it. Often, under these circumstances, you will see the light moving when it is actually stationary. The reason for this illusion is that the muscles which control your eyeballs continually make involuntary movements of which you are not conscious. Consequently, your eyeballs move and the light stimulates different points on your retina. Normally, you are not aware of this because the other reference points in your field of vision let you know that there is no actual motion. However, when you concentrate on a single light and no other reference points are visible, the small movements of the eyeballs make it seem as if the light is moving.

Autokinetic illusions do not happen every time to everyone. They are unpredictable, and, therefore, at any given time when you are looking out at a single light in the darkness, you cannot be sure whether it is actually moving or whether you are suffering from an illusion.

Autokinetic illusions used to cause many accidents in the days when planes had only a single light. In fact, it was primarily because of this danger that blinking tail and wingtip lights were added. Even today, there is still the danger that a pilot flying night formation with his eyes fixed on the wingtip lights of his leader may get the

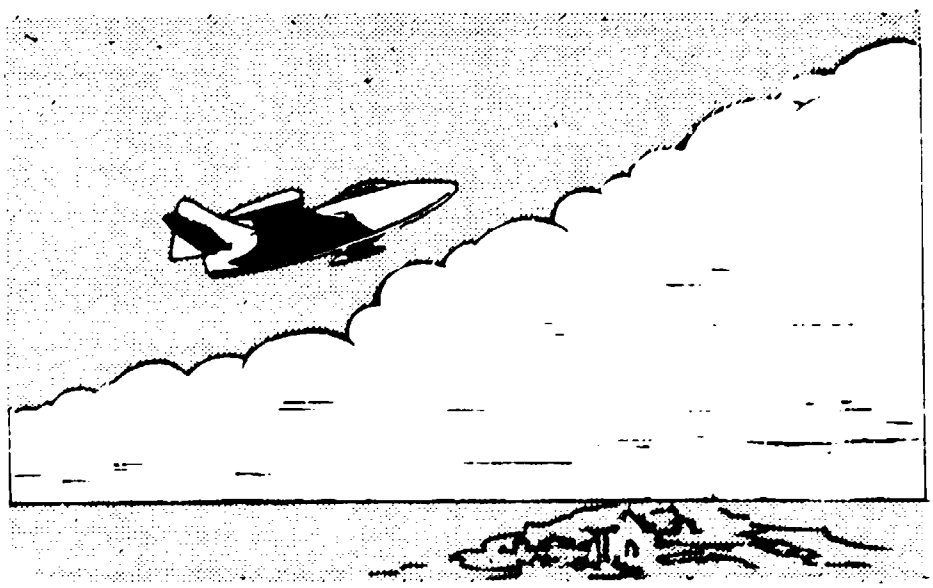


Figure 2–2. Flying up a cloud bank

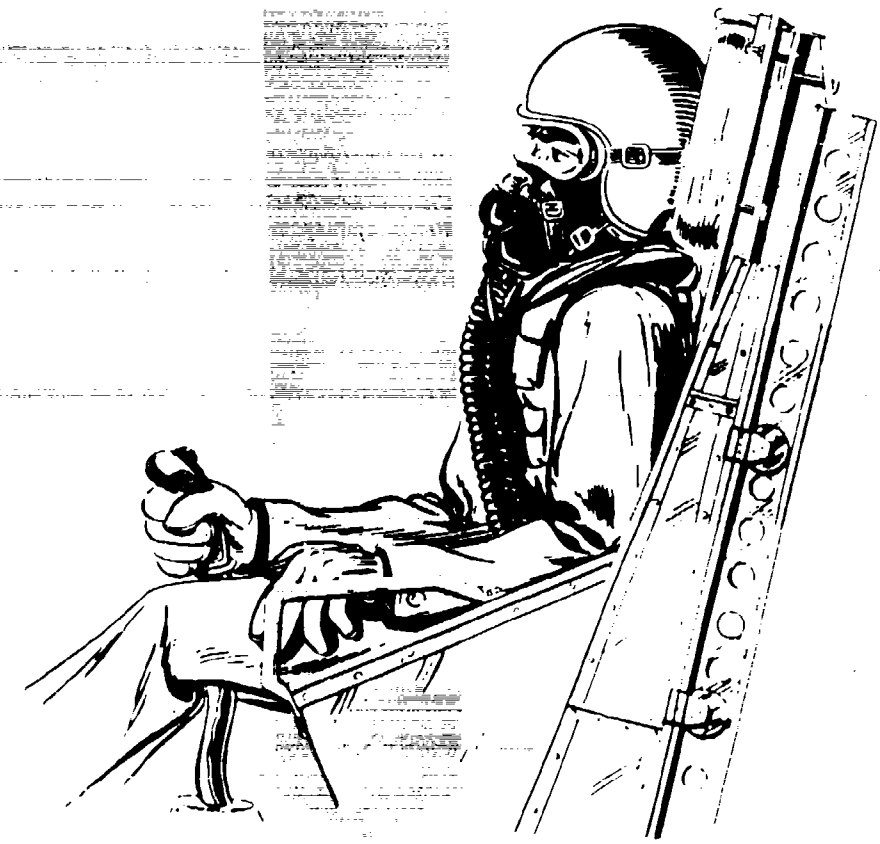


Figure 2-3. In both dive pull-out and steep turn, sensation is of being pushed down in seat

illusion that the leader is peeling off when he is doing nothing of the sort.

EQUILIBRIAL ILLUSIONS

The danger of misinformation from your equilibrium senses is greater than the danger of misinformation from your eyes, because your equilibrium senses are designed to act primarily on the basis of gravity. This is fine on the ground, but in the air acceleration affects them in exactly the same way gravity does, and your equilibrium sense can mislead you completely. As a simple example: in a properly executed steep turn—except while entering or leaving the turn—the only physical sensation is one of being pulled down into the seat. In a pull-out, the sensation is the same. Blindfolded you could not tell the difference, and you could be completely misled. It's all the result of the way your inner ear is constructed.

Your Inner Ear

Your inner ear is the source of most of your non-visual sensations of balance. It is composed of two parts—the static (or otolith) organ and the semi-circular canals. The static organ tells you the direction of the forces acting on you, and the semi-circular canals tell you whether you are turning or rotating and in which direction. Of course, you have two inner ears—one on the left and the other on the right side of your head—two static organs and two sets of semi-circular canals.

Illusions Due to Static Organ

Each static organ is a small, hollow sphere lined with sensitive hairs. Poised on these hairs

are small bony crystals. The weight of the crystals bend the hairs directly beneath them and causes them to send a message to the brain. When you tilt your head, the bony crystals change their position and cause other hairs within the static organ to be bent. These give the brain a message of what the new position is.

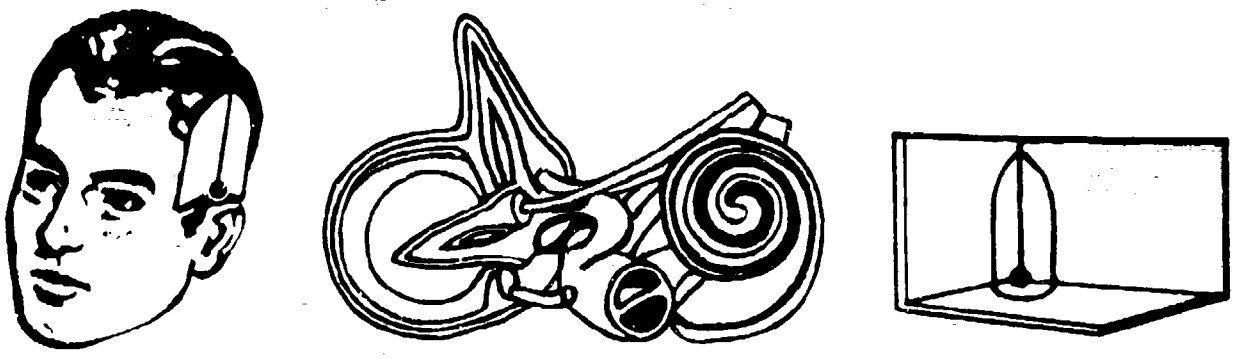
The system works very well on the ground, but in the air the fact that acceleration also affects the position of the crystals can cause trouble. Take the example of a sharply banked turn. When the plane banks, there is a force of positive acceleration on you in a head-to-foot direction. As a result, the crystals in your static organ are pulled toward your feet. In other words, even though you are almost lying on your side, you get the same sensation as if you were upright.

In this respect, the static organ acts very much like the turn-and-bank indicator in the airplane. In a perfect turn, the ball of the instrument is centered. Similarly, your static organ records only that a force is acting directly downward on you. Under such conditions you might easily interpret the increased positive acceleration to mean that you're in a pull-out when you're really in a banked turn. When the visibility is good, you can see that you are really making a turn and you can discount the report from your static organ. When you can't see, though, you have no way of telling unless you check your aircraft instruments.

Illusions Due to Semi-Circular Canals

The other part of your vestibular organ or inner ear is the set of semi-circular canals. There are three canals, each at right angles to the other. One lies in the horizontal plane in your head, another in a vertical plane from side to side, and the third in a vertical plane from front to back. The canals are filled with fluid, and at the end of each canal there is a little bay into which project small sensory hairs. There are extremely fine and light, and bend with any movement of the fluid. The fluid, of course, is displaced slightly (moves

Figure 2–4. Location and shape of the inner ear



The inner ear is located in the head approximately as shown and is about the size of the black dot. Enlarged, the actual structure is shaped as drawn. The semicircular canals are circular tubes lying at right angles to each other in the planes shown.

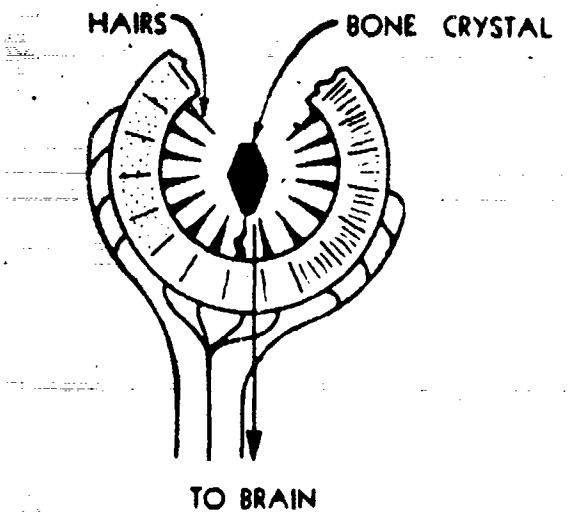


Figure 2–5. Construction of the static organ

slightly) whenever your head turns. Since each canal is at right angles to the other, the fluid is displaced with your movements in any of the three dimensions. The hairs transmit messages to the brain telling which way they are bent, and the brain figures out the direction of your rotation.

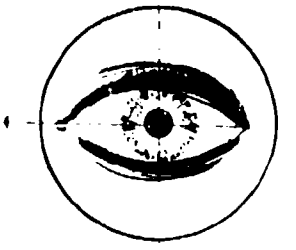
It's an excellent system, and it works well; but it has weaknesses because the whole system depends on the slight displacement of the fluid within the canal. In the first place, the sensitivity of the semi-circular canals is limited. A slow entry into a turn may not get over the threshold of stimulation and may not give the sensation of entry into a turn at all. Secondly, when there are sensations, they may be misleading. You can readily see how illusions arise if you compare the displacement of the fluid in the semi-circular canals to the movement of water in a glass. If you turn the glass rapidly, the water will tend to stand still. If you stop the glass quickly after turning it rapidly, the water will tend to remain in motion.

The same type of thing happens in the semi-circular canals, only on a very much smaller scale, of course. The displacement of the liquid in the canals corresponds to the movements of your head only if the rotation is relatively slow and lasts only for a short time. In the long turn or in a sudden stop, the liquid behaves almost independently of the movement of the head, and the hairs transmit false messages to your brain. Consider now how this can produce illusions in flight.

Suppose you are flying blind and start making a turn to the right. If the turn is slow, the fluid in the canals catches up with the motion of your body. The fluid ceases to move, stops affecting the sensory hairs, and you have the illusion that you have stopped turning. If you act on that information alone and still want to go to the right, you will swing right again, get into a much tighter turn, and may start a dangerous spiral.

On the other hand, if you stop a relatively sharp turn, the fluid in your semi-circular canals, like the water in the glass, will continue to be displaced even after you and the plane have stopped rotating. This will give you the impression that you're turning in the opposite direction. Again, you see that if you depend on your equilibrium senses alone and act on that illusion, you can get into a dangerous situation.

Another illusion is called the *leans*. The aircraft may be tipped quickly in rough air, and you get correct sensations of the attitude of the aircraft. Then, you may recover the plane so slowly that the angular motion is not perceptible and your senses retain the feeling that the aircraft is still tipped. The impression may be so strong that you will lean over to one side in an attempt to assume what you suppose to be the vertical. That's why it's called the leans. This sensation is one of the strongest and most frequently experienced in instrument flight. It gives false



impressions of both bank and pitch, particularly after entering a cloud in a turn.

Illusions Due to Postural Senses

Your postural or deep muscle sensations are caused by the stretching and contracting of muscles and tendons, by the shifting of abdominal muscles, and by pressure and touch. Over the years, your brain has established a relationship between these muscle sensations and your position with respect to ground and other objects. It combines these muscle sensations with those from your inner ear and automatically interprets them as position reports.

Such interpretations can be misleading and dangerous in flight because the brain translates the sensations as if they occurred on the ground and were connected with gravity. Thus, you mistakenly feel the effects of centrifugal force and acceleration during flight as rising, falling, slipping, or tilting from side to side. From these sensations alone, without vision or instruments, you can't distinguish between a slip turn to the left and a skid turn to the right. When the airplane enters an updraft, for example, you might think you were climbing because you are forced down in your seat and feel heavier than usual. Similarly, when the airplane enters a downdraft, you feel lighter than usual and may think that you are diving when you're actually in straight flight.

VERTIGO

Each of the illusions discussed up to now result from relying primarily on the limited reports of one sense. This is not often true in normal visual flight because, generally, you can compare the reports from *all* your senses and learn your true attitude. However, when visibility is not good and you can't test your sensations by what you see, the various sensations can mislead you completely and cause vertigo, the symptoms of which are dizziness and disorientation.

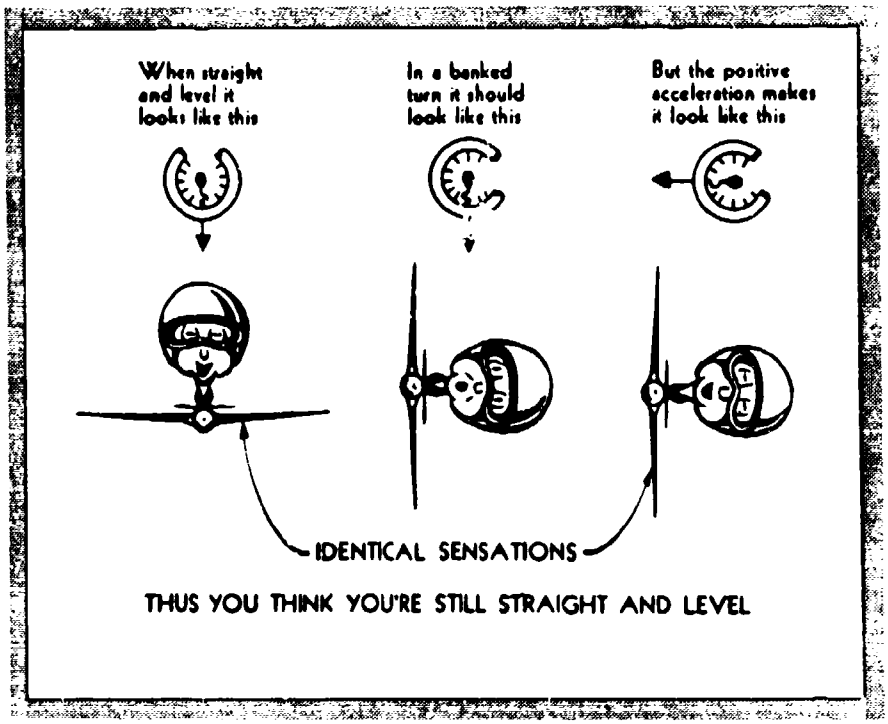


Figure 2-6. How you can be fooled in a banked turn

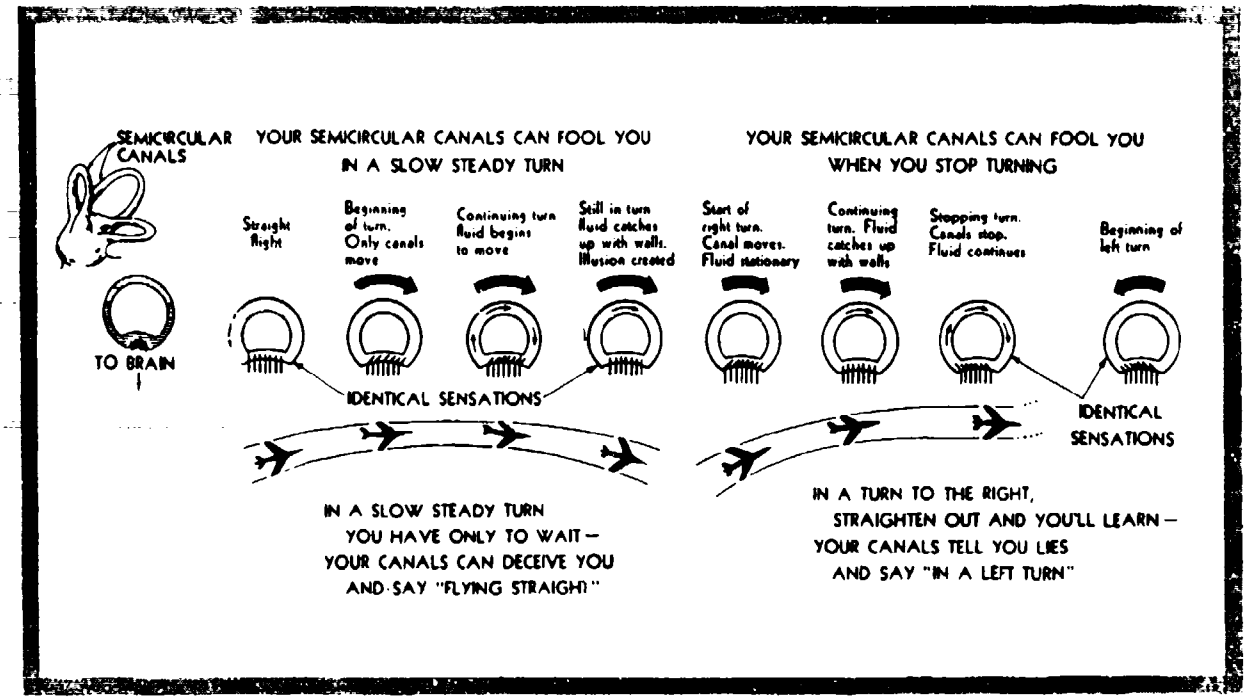
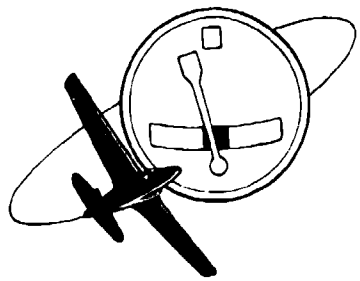


Figure 2–7. Semicircular canals give misleading sensations

As an example, consider the situation when you make a long turn to the right. As you begin your turn, your canals report correctly that you are turning to the right. However, because the turn is slow, the fluid in the semi-circular canals stops bending the sensory hairs, and you get the mistaken idea that you have stopped turning. Of course, if the visibility is good, you can readily see that you are still in the turn, and you ignore the report from your semi-circular canals. Suppose, though, it is night and only a few lights are visible. Since you cannot see much, you have little visual evidence to contradict the illusion that you have stopped turning. In fact, the brain may well interpret the message from the eyes as in agreement with the illusion. So you might go right ahead, swing right even more, and you could continue turning till you got in a most dangerous spiral. This type of illusion involving the eyes and the semi-circular canals is called an *oculogyral* illusion.

A similar type of illusion involving the static organ and the eyes is called an *oculogravic* illusion. It occurs whenever the sensations from the static organ are strong enough to override what the eyes see. In a violently banked turn, for example, you



could easily interpret the effect of the increased positive acceleration on your static organ as indicating that you were in a pull-out. With good visibility, you could see that was not so, and your brain would change its interpretation of the impulses from the static organ. However, where you could see little, the definite sensations from your static organ would influence your brain to make your visual clues agree. You would then be under an oculagravic illusion, believing that all your senses showed that you were in a pull-out when you were actually in a turn.

All this points to one thing—reliance on your instruments. They're the sure answer when you can't see well enough to orient yourself correctly by your senses. But you've got to make the decision to go instruments early. You can't wait till you start being disoriented. If you do so, you may become panicky, and your judgment may be impaired. So never try to fly half VFR and half IFR. If you have any doubts, go entirely on instruments.

YOUR SENSES IN INSTRUMENT FLIGHT

It is easier to say that you must rely on your instruments than it is to do so. All your life, your intuition and your training have conditioned you to orient and balance yourself by the combinded reports of your own senses. In flight, when you get the same kind of sensations, your brain interprets them and tends to react as if you were on the ground. This is all the more true in instrument flight when your best check—your vision—is not usable.

Of course, you can't prevent these sensations. You're bound to have them because that's the way

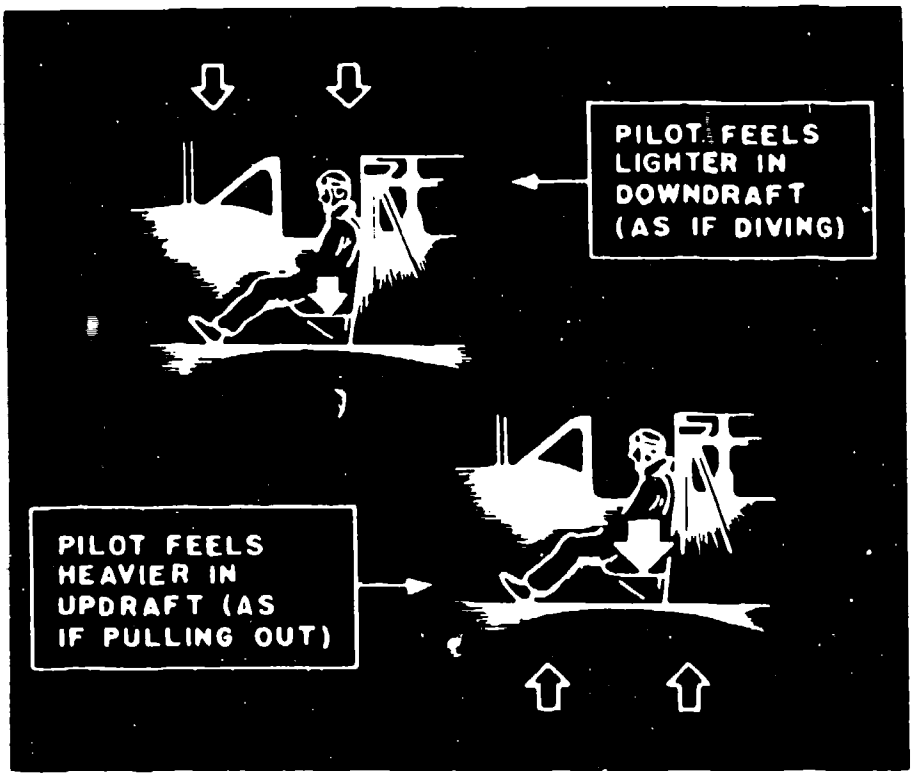


Figure 2–8. Updraft and downdraft sensations

your senses work. But you can avoid being misled my them. Overcoming your natural and long-practiced habit of depending on your senses requires understanding of the sensations, knowledge of the instruments, and practice to the point where reading the instruments becomes as much a part of your habits as using the senses you were born with. In fact, the instruments *are* your senses in instrument flight.

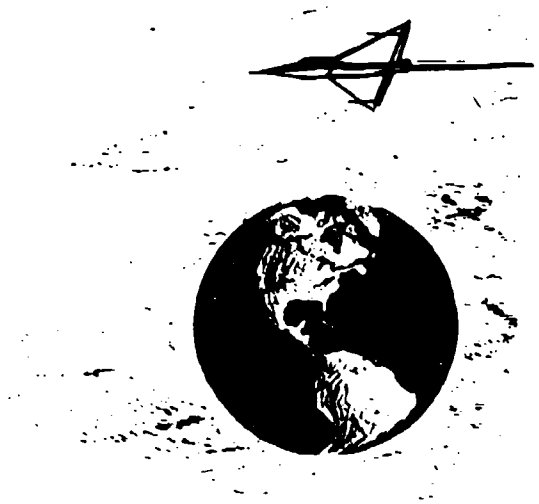
USING YOUR INSTRUMENTS AS SENSES

To use your instruments as effectively in flight as you use your senses on the ground, you must first know your instruments and develop confidence in them. You must understand how each of the instruments operates and the significance of the readings of each.

Secondly, you must learn to interpret the combined reports of your various instruments just as you interpret the combined reports of your own senses. Avoid fixing your attention on one instrument. Learn to scan the panel and gain an almost instantaneous picture of your situation. This takes hard study and consistent practice.

Thirdly, take into account that using your instruments is a little slower procedure than using your own senses. Tests show that you interpret the actual horizon about one fifth of a second faster than you interpret your instruments. You make a recovery from a dive about one and one half seconds faster in visual conditions than when you are on instruments.

Fourthly, remember that in instrument flight you are more susceptible than usual to the stresses of flight such as fatigue, boredom, and hypnosis. Long instrument flights often result in fatigue and boredom because you concentrate on your instruments and have no changes of scene to divert your attention. As a result, you may even be subject to some degree of hypnosis. The darkened cockpit, the roar of the engine, the sound of the slipstream, may lull you into a state of semi-hypnosis. To counteract this, occasionally move about in the seat, shake your head, and change cockpit lighting.



CHAPTER 3

PITOT-STATIC AND SUCTION INSTRUMENTS

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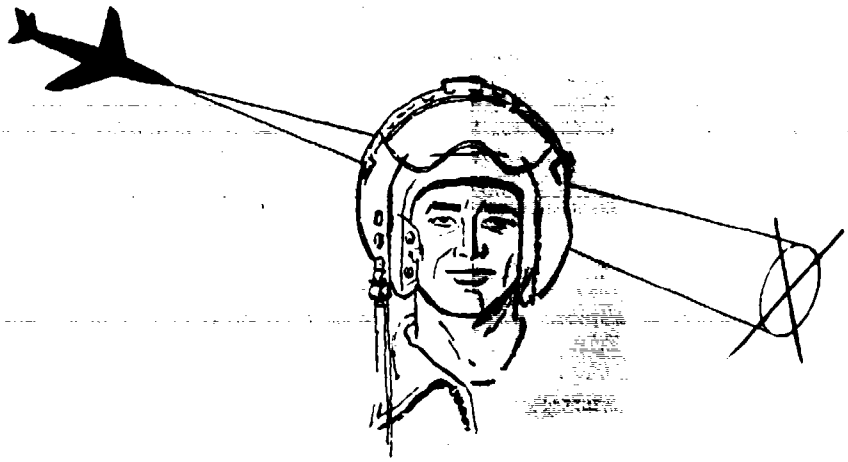


CHAPTER 3

PITOT-STATIC AND SUCTION INSTRUMENTS

THE pitot-static and suction instruments are grouped together here because both types are actuated by air. This chapter thus covers virtually all the non-electric attitude or speed-indicating instruments in common use today.

The pitot-static instruments measure pressure or pressure differentials. They include the airspeed indicator, Machmeter, altimeter, and vertical-speed indicator. The suction instruments depend on gyroscopes which run on suction from the engine-driven vacuum pump. This group includes the air-driven turn-and-bank indicator, the gyro-driven heading indicator, and the horizon indicator. These instruments are also manufactured in electrically operated versions which are discussed in the following chapter.

PITOT-STATIC INSTRUMENTS

Pitot-Static Tube

The source of the pressures for operating the airspeed indicator, the vertical-speed indicator, and the altimeter is the pitot-static system which provides two kinds of pressures to the instruments it serves. The pitot part of the system provides the impact air pressure—that is, the pressure of the airstream as the plane flies through the air. The static part of the system provides the still air pressure—that is, the pressure of the undisturbed air at the flight level.

There are three major parts to the pitot-static system: (1) the impact-pressure chamber and line, (2) the static-pressure chamber and lines, and (3)

the heating unit to prevent the icing of the pitot tube. Up to a short time ago, all three parts constituted a single unit—the pitot-static tube.

Recently, however, the pitot and static sources were separated in some aircraft in an effort to improve pitot-static performance. Where the sources are separted, the impact pressure is taken from the pitot tube (mounted on the leading edge of the wing, the nose section, or the vertical stabilizer), while the static pressure is taken from the static line attached flush with the side of the fuselage. On most aircraft using a flush-type static source, there are two vents, one on each side of the fuselage or nose. This is to compensate for any possible error in pressure that might occur on one of the vents when there are erratic changes in attitude, as in a steep turn, or roll. The vents are connected by a Y-type fitting. It is important to check the flush-type vents visually to see that they are not clogged.

Sometimes, in certain aircraft, an abrupt movement causes a momentary loss of impact or static pressure, and this causes temporarily wrong indications on the vertical-speed indicator and on the altimeter. Such erratic readings are particularly noticeable on the vertical-speed indicator, where they appear either as brief, excessive vertical motions or as motions in the direction opposite to the actual. If this effect appears to be greater than normal, have the flush-type vents checked for clogging.

Operation of the Pitot-Static System

The pitot chamber receives the impact pressure of the air on the open pitot tube as the aircraft moves along. The static chamber, if it is contained in the pitot head, is vented to the free undisturbed air through small holes on the top and bottom of the tube. For most accurate operation, the pitot-static tube should be parallel to the line of the relative wind. To achieve this condition, the tube is mounted parallel to the longitudinal axis of the aircraft.

In most conventional-type aircraft, there is an alternate source for static pressure in case of an emergency. This source usually taps its pressure from within the cockpit. Because of the venturi effect from the flow of air over openings in the aircraft, this alternate static pressure is usually lower than the pressure provided by the pitot-static tube. Therefore, when the static source switch is placed in the alternate position, the altimeter usually reads higher, the indicated airspeed is greater, and the vertical-speed indicator momentarily indicates a climb. When possible, check the alternate source in flight before going into instrument flight conditions.

Jet aircraft and aircraft with pressurized

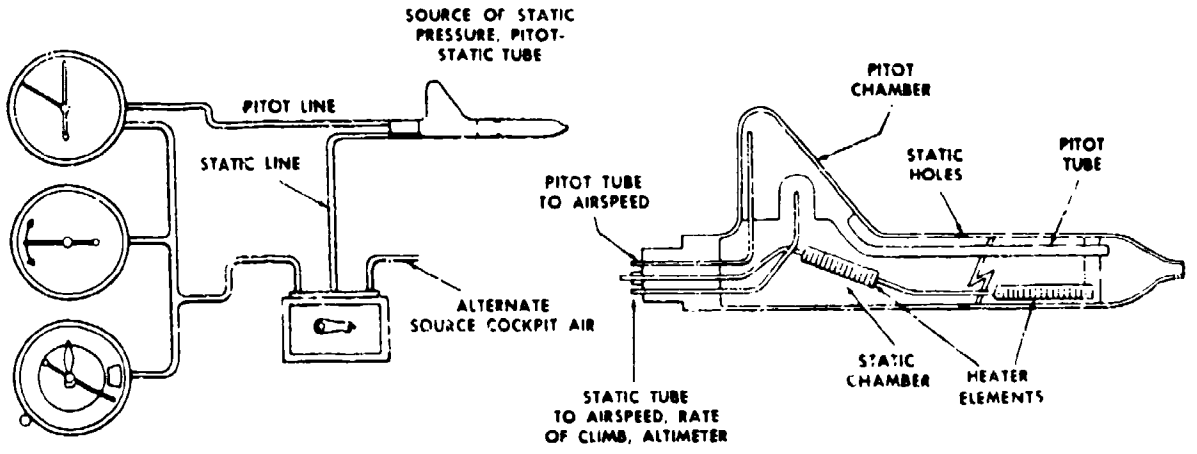


Figure 3-1. Conventional pitot-static tube, static pressure and alternate static source

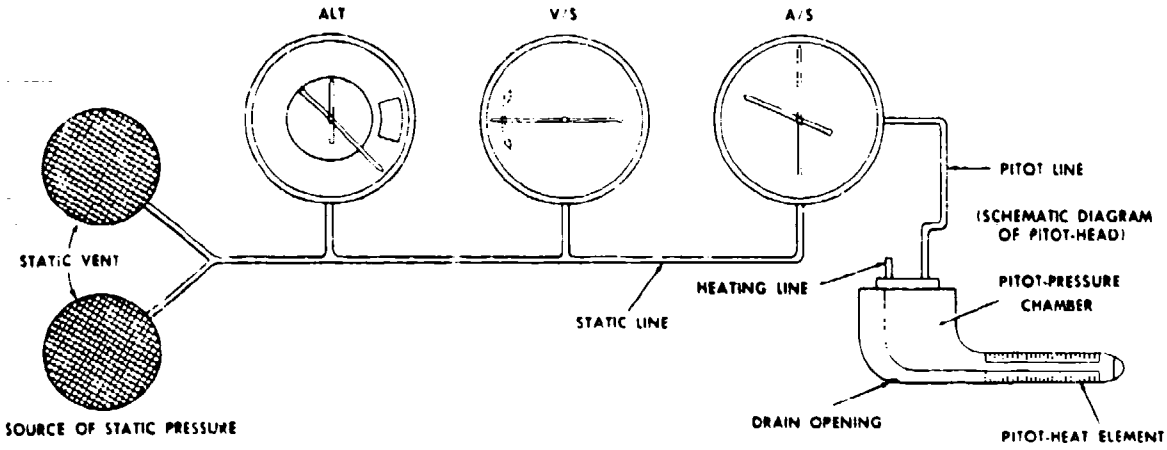


Figure 3–2. Flush-type static source

cockpits are usually equipped with the flush-type vent and no alternate source. On such aircraft, if the pitot-static system fails, first dump cabin pressure; *then* break the glass of either the airspeed indicator or the altimeter with a sharp instrument which will fracture the glass without damaging the instrument or bending the needle. The instruments will then read with approximate accuracy. If you must use a blunt object (such as your heel) to break the glass, smash the glass in the vertical-speed indicator because it is the least essential to safe flight. With this procedure, however, the instrument readings will not be correct. If the vertical-speed glass is broken, it will read in reverse, and the other pitot-static instruments will have a pronounced lag in their readings.

AIRSPEED INDICATOR

The airspeed indicator is a differential pressure instrument. It measures the difference between the impact pressure and static pressure, and converts it into an indication of speed. The case of the airspeed indicator (which is air-tight) is connected to the static line from the pitot-static tube. Inside the case is a small diaphragm made of phosphor bronze or beryllium copper. The diaphragm, which is very sensitive to changes in pressure, is connected to the impact pressure line.

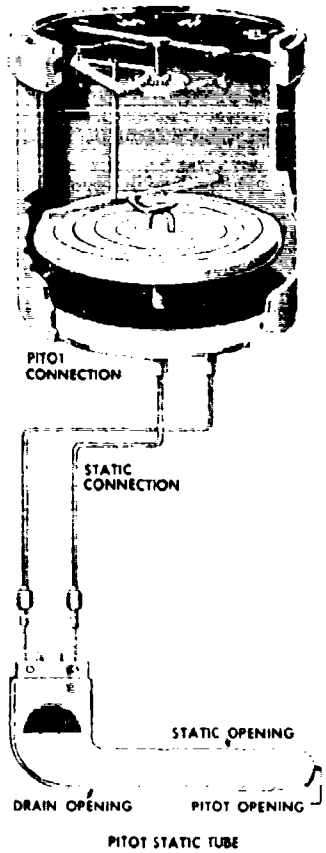


Figure 3–3. Airspeed indicator, with pitot and static connections

The needle or pointer is connected through a series of levers and gears with the free side of the diaphragm.

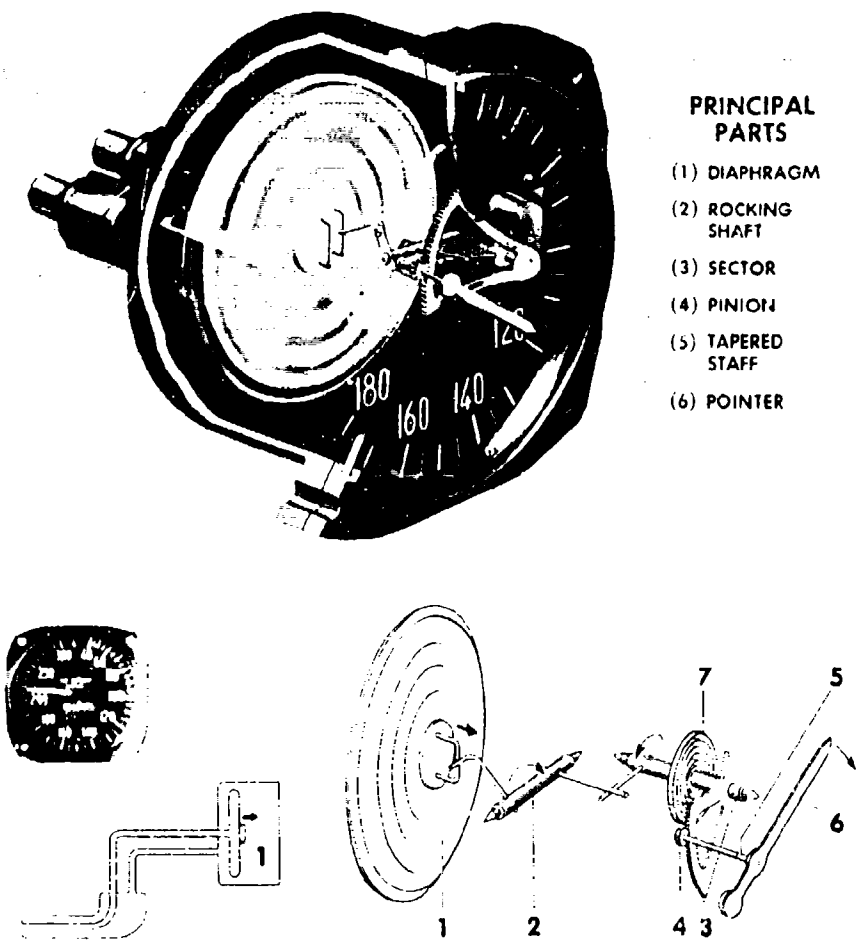
When the aircraft is stationary, there is no difference between the pitot and static pressures, and the pointer is at 0. (See Figure 3-3.) When the aircraft moves through the air, however, the pressure in the impact line becomes greater than the pressure in the static line. The faster the aircraft moves, the greater the pressure differential becomes. Since the diaphragm is connected directly to the impact pressure line, it is expanded by this increase in impact pressure. (See Figure 3-4.) The expansion or contraction of the diaphragm, in turn, controls the position of the needle by a series of levers and gears to the face of the instrument. The dial is so scaled that the needle indicates the pressure differential in knots.

Corrections to Indicated Airspeed

There are four kinds of airspeed figures: indicated, calibrated, equivalent, and true. Indicated airspeed is the airspeed read directly from the instrument. Calibrated airspeed is the indicated airspeed corrected for instrument installation error. Equivalent airspeed is calibrated airspeed corrected for compressibility error, and true airspeed is calibated airspeed corrected for altitude and temperature.

The indicated airspeed has to be corrected for

Figure 3-4. Diagram of airspeed indicator operation



● Operation.—The Airspeed Indicator measures the difference between impact air-pressure and static air-pressure. Impact pressure is supplied by the pitot side of the Pitot-Static Tube.

Static air pressure is led to the inside of the instrument case by the static side of the Pitot-Static Tube.

As the speed of the airplane increases, impact pressure becomes greater and greater, and this results in an increasingly wider differential between impact and static pressures. The diaphragm (1) expands more and more as the pressure inside it is built up; measurement of the amount of expansion gives the indicated airspeed of the aircraft. The linkage system must amplify as well as transmit this minute motion.

The linkage system operates very simply. When the diaphragm expands, the rocking-shaft (2) picks up the motion, transmits it to the sector (3); the latter turns the pinion (4) and the tapered staff (5). The pointer (6), which is attached to the tapered staff, moves around the calibrated dial, thus giving the indication of airspeed. The hairspring (7) keeps the linkage taut, and causes it to follow a contracting diaphragm movement as the airspeed decreases.

installation error because no pitot tube installation can be perfect. As a result, the differential actually established by the pitot tube is slightly different from the differential pressure it should establish theoretically. You can derive the calibrated airspeed (CAS) from the indicated airspeed (IAS) by using the calibration card in the aircraft. If there is no card, consider the calibrated airspeed to be the same as the indicated airspeed.

To convert calibrated airspeed into equivalent airspeed, you must take the compressibility error into account. This error is due to the fact that the angle of airflow across the head of the pitot tube decreases as the speed of the aircraft increases. As a result, the air molecules are compressed before entering the tube and they increase the pressure in the pitot line above what it should be. At speeds below 250 knots and at altitudes below 10,000 feet, the compressibility error is practically negligible; that's why it has not been considered important until recently. You can find a table of corrections for compressibility in the Operating Handbook for your aircraft or you can correct CAS for compressibility on the E6B computer as explained in Chapter 10.

The final correction—correcting for air-density error to get true airspeed (TAS)—is the most important of all. Usually the TAS exceeds the CAS by a considerable amount. The difference between TAS and CAS increases with altitude because the airspeed indicator is calibrated for an atmospheric pressure of 29.92 in. Hg and a temperature of 15° C. and it cannot adjust for changes in density. You make the correction for altitude and temperature (air density) on the navigational computer. (See Chapter 10.) The importance of this correction is shown by the fact that, at very high altitudes, the true airspeed may be double the indicated airspeed.

Use of the Airspeed Indicator

In climbs and descents, the airspeed indicator serves as a guide for controlling the attitude of the aircraft. Although in climbs and descents, the horizon indicator is the primary instrument, the airspeed indicator is important as a basic cross-check instrument in controlling the attitude of the aircraft. Predetermined power settings are

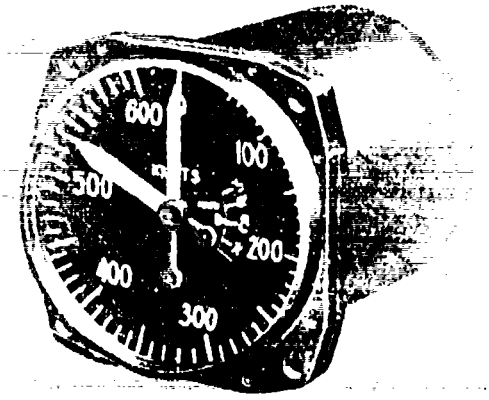


Figure 3–5. Maximum allowable type of airspeed indicator

used and aircraft attitude is controlled so as to obtain a predetermined airspeed.

The indicated airspeed at which an aircraft will stall is the same at any altitude or temperature. The airspeed indicator therefore provides a correct indication at all altitudes of safe flying speed. It indicates immediately, with very little lag, any change in aircraft speed. At times, there appears to be a lag in the airspeed indicator, after the aircraft has changed attitude. But that is not

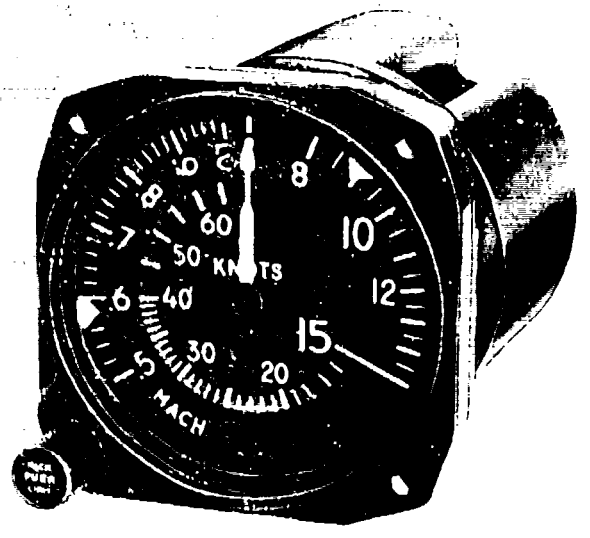


Figure 3–6. Airspeed and Mach-number indicator

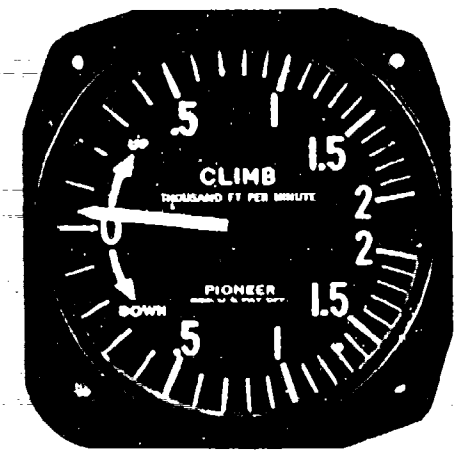


Figure 3-7. Vertical-speed indicator

a lag in the indicator. It is the aircraft itself that is not changing airspeed as rapidly as expected because time is required to change the momentum of the aircraft.

The airspeed indicator is also a most useful instrument when flying through turbulent air. Reference to it permits the pilot to hold his airspeed within safe limits and, by varying the power setting, to maintain altitude.

Airspeed and Mach Number Indicators

There are two types of instruments in naval aircraft which indicate both airspeed and Mach number. The first of these uses a needle to indicate the *limiting airspeed* for the operating altitude, while the other uses a movable scale to allow the airspeed needle to show the *actual Mach number*. You must distinguish clearly between these two types, as their use is different.

The first type properly described as a Maximum Allowable Type Airspeed Indicator, is shown in Figure 3-5. The needle which shows the maximum allowable airspeed is adjusted to a specific maximum allowable airspeed at sea level on a standard day. Then, after proper adjustment, it indicates the maximum allowable airspeed for any altitude. As the aircraft climbs, the indication of the needle goes lower. This needle is moved by an aneroid diaphragm, which operates on atmospheric pressure; so in effect it is an altimeter scaled to show maximum allowable airspeed for the pressure altitude encountered. *It does not show actual Mach number at all.* Like the "red line" on conventional aircraft airspeed indicators, it shows just the maximum allowable airspeed.

The other type of airspeed Mach combination (shown in Fig. 3-6) is mechanically similar. In this instrument, however, the aneroid unit rotates a movable dial so that at airspeeds in excess of 150 knots the single needle indicates both the airspeed on the fixed inner scale and the actual Mach number on the movable outer scale. As the altitude increases, the Mach scale moves so that the Mach indication reduces properly for the pressure altitude involved. The diaphragm which drives the needle and the aneroid diaphragm which drives the Mach scale are not connected to each other in any way. At low altitudes, the movable dial is masked by the stationary dial, which is graduated in knots.

The range of the instrument is 80 to 650 knots IAS and 0.5 to 2.0 Mach number, with a maximum operating limit of 50,000 feet. The instrument also incorporates a landing speed index and a Mach number setting index. You can set both indices manually through a knob at the lower left hand corner of the bezel. You can set the landing speed index from 80 to 145 knots by turning the knob in its normal out position. You can set the Mach limit anywhere in the entire Mach range by depressing the knob and turning it.

VERTICAL-SPEED INDICATOR

The vertical-speed indicator, often called the rate-of-climb indicator, is of extreme value during smooth, precision instrument flying, as it provides the pilot with the first indication that a change of altitude is taking place. This is the secondary pitch-control instrument, the primary instrument being the horizon indicator. The vertical-speed indicator indicates the rate of climb or descent by measuring the rate of change in the atmospheric pressure.

In effect, the vertical-speed indicator consists

of one air chamber inside another. The inside chamber is a diaphragm similar to the one used in the airspeed indicator. It expands when the inside air pressure becomes greater than the outside air pressure, and it contracts when the inside air pressure becomes less than the outside air pressure. The outer air chamber (the one around the diaphragm) is the airtight case of the instrument itself. The diaphragm is connected directly to the static line of the pitot-static system; therefore the air inside the diaphragm is at atmospheric pressure. The case is also connected to the static line but by a very small opening called a capillary tube.

When the atmospheric pressure is constant, the air pressure in the diaphragm and in the instrument case are equal. At this time the needle, which is connected to the flexible diaphragm, reads zero. As the atmospheric pressure changes, the pressure of the air in the diaphragm keeps up with the change, but the air in the case lags behind because it has to leak through the capillary tube to change toward the new pressure level. Thus, a differential pressure is established between the instantaneous static pressure in the diaphragm and the trapped static pressure in the case, and the diaphragm expands or contracts accordingly. A system of levers and gears transmits this expansion or contraction to the pointer to indicate the rate of pressure change as a descent or climb.

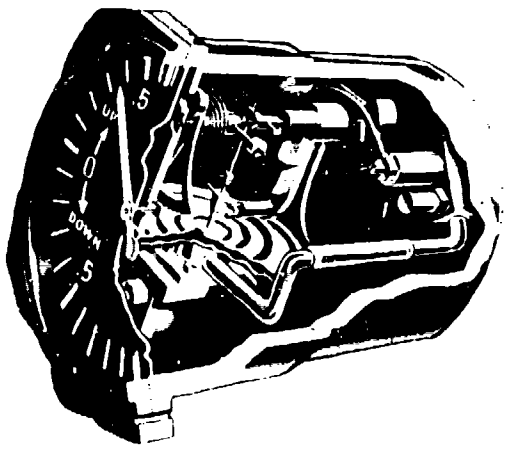


Figure 3–8. Cutaway view of vertical-speed indicator

As you know, atmospheric pressure decreases at higher altitude. During a climb, therefore, the trapped pressure inside the case is higher than that of the atmosphere and higher than that in the diaphragm. Thus during a climb, the diaphragm contracts; during a descent, it expands. If the climb or descent is more rapid, the degree of contraction or expansion is greater and the pointer shows comparably greater rate of climb or descent. As the diaphragm approaches the limits of its ability to contract or expand, each thousand feet of additional vertical speed causes a smaller amount of contraction or expansion. That's why the face of the instrument (see Figure 3–7) is calibrated to show each additional thousand feet of vertical speed as an ever-smaller unit on the dial.

The flow of air through the capillary tube is automatically controlled so that variations in air density due to changes in temperature and atmospheric pressure do not materially affect the indications of the instrument. (Note the interior view of a vertical speed indicator shown in Figure 3–8.)

The vertical-speed indicator is reliable whenever the rate of climb or descent is fairly constant. It usually reads correctly also when you have been flying level and start to climb or descent; in these cases, though, there is a small lag before it indicates the full rate. However, when you have been climbing or descending and then level off or change the rate of vertical speed, there is a noticeable time lag before the instrument reads correctly.

The leak in the case is so calibrated that it maintains a definite ratio between the pressure in the diaphragm and the pressure in the case so long as a constant rate of climb (or descent) is maintained. When the aircraft levels off, though, it takes the calibrated leak from 6 to 9 seconds to equalize the pressure in the case with the pressure in the diaphragm. This causes a lag of from 6 to 9 seconds in the indications of the instrument. When the aircraft is descending, the pressure inside the diaphragm is increasing. Again, the calibrated leak maintains a constant relation between the pressure in the diaphragm and the pressure in the case.

The indications of the vertical-speed indicator are not reliable in extremely rough air or when the attitude of the aircraft is constantly changing.

This is due in part to the lag in the instrument. Still, you can use the instrument to an advantage for indications of nose attitude if you have a thorough understanding of the instrument's lag and consider this lag in interpreting the indications.

Remember, though, that in a few aircraft equipped with the flush-type static air source, an abrupt movement of the aircraft or a change of power setting may cause momentary pressure changes at the point on the aircraft where the flush sources are located and momentary wrong indications on the vertical speed indicator and the altimeter. These erroneous readings are very brief. Do not "chase the needle." Wait for it to stabilize.

If the pointer does not read zero when the aircraft is on the ground, turn the zero adjustment screw or knob to correct the discrepancy.

THE ALTIMETER

The importance of the altimeter cannot be overrated. Particularly important is the proper setting and reading of this instrument. Many aircraft accidents have been caused by faulty settings of the altimeter by the pilot. Some midair collisions, for example, can be attributed to failure to maintain the proper assigned altitude, because of improper settings. More recently there have been an increasing number of accidents caused by improper reading of the instrument—often 10,000-foot errors.

This chapter discusses only the barometric type of altimeter—one which measures altitude on the basis of the relationship between pressure and height in a standard atmosphere. Radio-radar altimeters are discussed in Chapter 5. The type of altimeter discussed here is like a barometer because it measures the weight of the air above it and calibrates this data in terms of feet of altitude.

The altimeter case is airtight except for one opening which is connected to the outside air through the static side of the pitot-static tube. The pressure in the static tube and in the case is always the atmospheric pressure just outside the aircraft. Inside the case is the diaphragm—the part of the instrument which is affected by changes of atmospheric pressure. It consists of one or more aneroids, or airtight cells, from which 99 percent of the air has been evacuated. The more airtight the cells involved, the more sensitivity is obtainable. As the pressure around the diaphragm (the atmospheric pressure) decreases, the diaphragm expands. As the pressure around the diaphragm (the atmospheric pressure), increases, the diaphragm contracts. The contraction or expansion of the diaphragm is transmitted by a system of levers and gears to three indicating hands on the face of the instrument.

Reading the Altimeter

There are many types of altimeter dials in use. The same basic dial is found on all of them, but some recent changes may cause slight confusion at first.

The old type, which is shown in Figure 3-9, may still be found in a few aircraft. The largest pointer shows the hundreds of feet, each numeral indicating 100 feet; the broad short pointer shows the thousands of feet, each numeral indicating 1,000 feet; and the little, slender pointer shows the tens of thousands of feet, each numeral indicating 10,000 feet. Thus, the instrument dial shown in Figure 3-9 reads 13,455 feet altitude. The altimeter setting (30.3 in. Hg.) shows in the small window. This type of altimeter dial has been abandoned because it is too hard to determine rapidly the thousands and tens of thousands of feet, particulraly the ten thousands. In jet air-

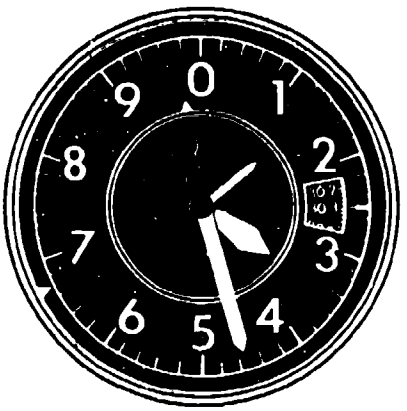


Figure 3-9. Old-type altimeter dial

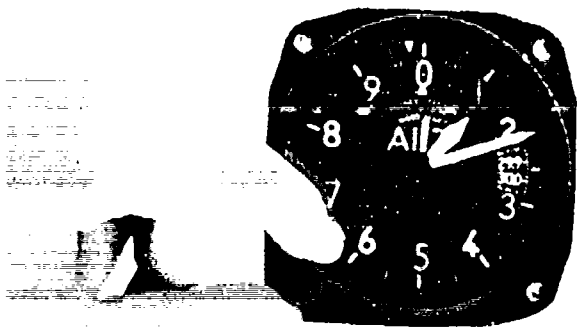


Figure 3-10. MB-1 altimeter

craft especially, the plane may change altitude by 10,000 feet very rapidly.

This problem has been attacked by two new altimeter dials. One uses a larger 10,000-foot pointer which reaches the edge of the dial, and it also has a cross-hatched "flag" which shows when the altitude is below 10,000 feet. The other has no pointers except the hundred-foot pointer and shows thousands of feet as numerals.

The MB-2 (see Figure 3-12) was developed both as a new altimeter and as a conversion for older models. It has a cross-hatched "flag" on the lower part of the dial and, instead of a 10,000-foot needle, it has a disk with a pointer extending out to the edge of the dial. There is a hole in the disk so located that at about 15,000 feet the edge of the flag just barely shows. At altitudes below 10,000 feet the whole flag shows.

The MC-1 (see Figure 3-11) is probably the easiest altimeter to read, though it looks rather different when you first see it. The single long pointer indicates hundreds of feet only. Thousands of feet show as numerals in the window on the left side of the dial. Below 10,000 feet, the first numeral box shows a cross-hatched area, thus warning the pilot that he is below 10,000 feet.

Determining Altitude

An altimeter reading of 9,000 feet does not necessarily mean that you are at 9,000 feet. You are merely at an indicated altitude of 9,000 feet above mean sea level if your altimeter is set to the local pressure corrected to sea level. This is not necessarily your true altitude, nor is it your altitude above the terrain.

By definition, altitude is the vertical distance from some reference point. The following types of altitudes and reference points are important to you.

True Altitude is the height above sea level.

Absolute Altitude is the height above terrain.

Pressure altitude is the height, or vertical distance, from the standard datum plane. This is a

Figure 3-11. MC-1 altimeter

Figure 3-12. MB-2 altimeter

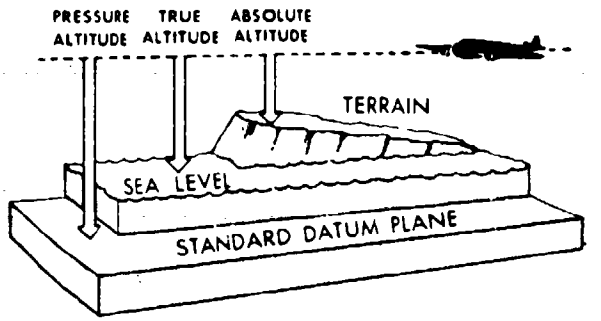


Figure 3–13. Types of altitude

theoretical plane where the air pressure (corrected to plus 15° C.) is equal to 29.92 inches of mercury.

Density altitude is pressure altitude corrected for temperature. When conditions are standard, the pressure altitude and the density altitude are the same; if the temperature is *above* standard, the density altitude is *higher* than the pressure altitude; if the temperature is *below* standard, the density altitude is *lower* than the pressure altitude.

The first step in determining your actual altitude, whether true, absolute, or pressure, is to determine your *calibrated altitude.* All pressure altimeters are subject to small errors due to the effect of the temperature on the various metals of the instrument. The corrections to be applied to the dial reading to compensate for these effects are shown on a calibration card which should be posted near the altimeter. By applying the appropriate correction to the indicated altitude you get the calibrated altitude. However, unless extreme accuracy is required, or if there is no calibration card, you may substitute indicated altitude for calibrated altitude when you correct for free-air temperature in determining the actual altitude by use of the E-6D computer.

Setting the Altimeter

The various factors of sea-level pressures and temperatures require frequent calculation to determine true altitude. If the pilots of two approaching aircraft had computed their true altitude on different pressure-temperature data because of the different areas through which they had flown, it would be very hazardous for them to attempt to pass. To achieve vertical clearance, therefore, all aircraft in an area are given an arbitrary pressure level known as an altimeter setting. The weather officer computes the altimeter setting by use of the barographs and scale, every 30 minutes for sequence reports and on request. The altimeter setting may be generally defined as the pressure in inches of mercury of the reporting station corrected to sea-level pressure.

Setting the pressure scale to the altimeter setting causes the altimeter to read indicated altitude. Flying indicated altitude ensures traffic separation, since in passing, the different altimeters are equally affected by whatever pressure and temperature conditions may exist. You need not make allowance for nonstandard atmospheric conditions but must keep your altimeter adjusted to the latest altimeter setting.

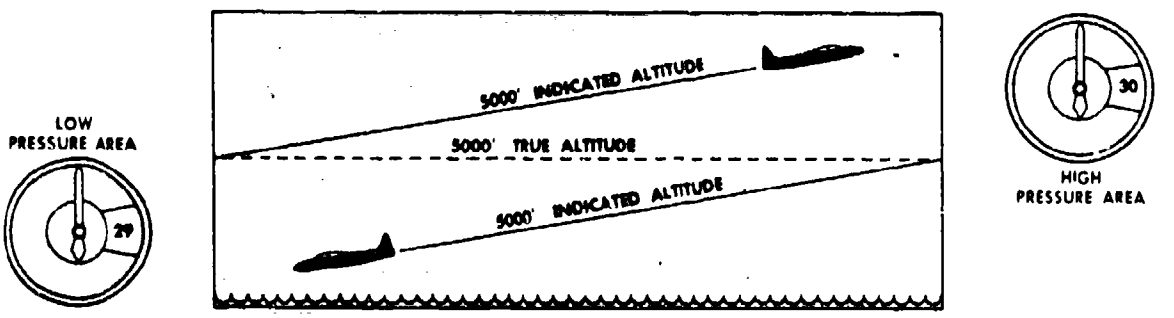


Figure 3–14. The effect of pressure on altitude

The danger of this system is that safe terrain clearance is not guaranteed; the indicated reading is generally the correct altitude only when the aircraft is about to land at the airport from which the setting was furnished. To determine adequate terrain clearance, you must allow for possible errors in your indicated altitude, such as mechanical errors, temperature errors, change of pressure from the time the altimeter setting was computed to the time it is used, and the difference in pressure between the position of the aircraft and the station which reports the altimeter setting. During instrument flight and under conditions of poor visibility, it is very important that you frequently reset your altimeter to the latest altimeter setting which you can obtain from a range station or control tower. Look at Figure 3-14 and you can see the need for doing this, particularly when flying from a high-pressure area into an area of lower pressure.

In flying between shore stations, using the corrected local pressure as the altimeter setting provides the greatest accuracy and safety. The altitude always represents an indicated altitude value for the approximate local pressure, provided you obtain current settings as you travel. Over oceans, however, a different system is used because there are no terrain obstructions and it is not important to maintain the indicated altitude as near to actual altitude. Prevention of mid-air collisions is the only serious problem. Therefore, trans-oceanic flights are conducted on pressure altitude. As soon as the plane is clear of land, the altimeter is set to 29.92. By proper assignment of pressure altitude flight levels, collisions are avoided.

Sometimes local instructions direct use of field pressure instead of the altimeter setting for local training or tactical flights. The altimeter is adjusted to read zero before take-off, regardless of field elevation. The setting window will then show uncorrected local pressure (uncorrected for field elevation.) Do not use such settings in flight from one field to another.

Temperature Correction

Since pressure altimeters are pressure gages calibrated in feet on the basis of a standard pressure-altitude relationship, nonstandard atmospheric conditions will make their readings inherently wrong. On a warm day, the air expands and weighs less per unit volume than on a standard or colder day; so it is necessary to climb an additional 550 feet to reach the pressure level that will indicate 10,000 feet on a standard day. Much more dangerous to the pilot is the cold day. On a cold day, when you reach a pressure level that indicates 10,000 feet, you are actually flying several hundred feet lower. Use the E-6D computer to correct the indicated altitude for the temperature aloft. The resulting correction will be accurate only when the standard lapse rate exists; however, this method is always more nearly accurate than assuming that the indicated reading is the actual altitude. An even better method of getting the correct true altitude is to use the pressure altitude. Set the altimeter to 29.92 and correct for temperature on the E-6D.

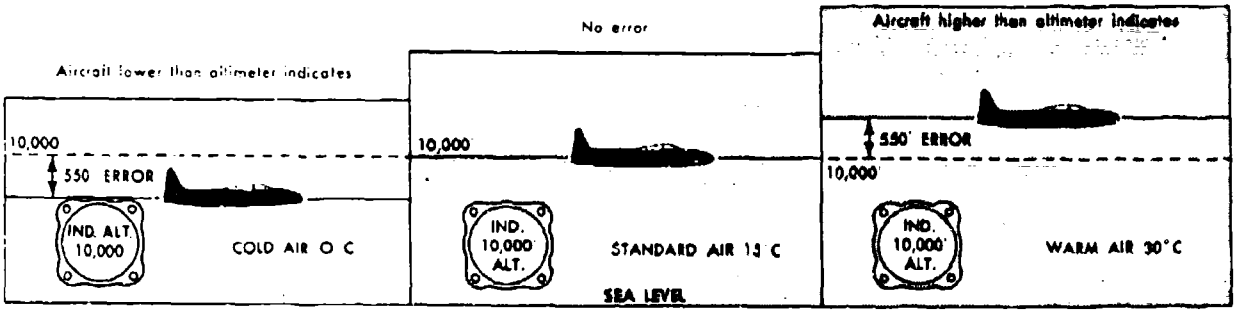


Figure 3-15. Inherent altimeter error due to temperature changes

At 2,000 feet, the temperature error is 70 feet when the mean temperature varies 10° C. from the standard temperature; this error decreases to zero as altitude decreases. Do not assume, therefore, that the altimeter will indicate the correct altitude in the air simply because it reads correctly upon landing.

Altimeter Errors

A particularly important source of error may be the altimeter itself. The scale may not be correctly oriented to standard pressure conditions. Altimeters should be checked periodically for scale errors in altitude test chambers where standard conditions exist. Large errors should be removed mechanically; small errors should be recorded on the calibration card.

Another type of error is due to lag. The altimeter may tend to lag, particularly when large changes of altitude are made. This type of error, which is called "hysteresis" or "after effect," varies with the climb and descent. When an altimeter is taken aloft, to 19,000 feet for example the indicated reading will be slightly low, gradually increasing as time passes. This increase, called "drift," is due to the elastic characteristics of the diaphragm. On the ground, it is loaded in a state of equilibrium by the heavier pressures of ground level, and it requires time to reach a state of equilibrium under the lighter pressures at 19,000 feet. Likewise, if it remains at altitude for several hours, the instrument reads slightly high on descending and gradually decreases, or "recovers" over a period of time.

Friction is also a possible source of error. Regardless of construction, all mechanical devices are subject to friction error, and the altimeter is no exception. Still another cause of error is the effect of varying temperatures on different metals of the altimeter, mentioned before in connection with calibrated altitude. The calibration card should provide for these errors. It cannot provide, however, for errors due to improper installation, damage, icing, or clogging of the pitot-static tube. The different positions, or attitudes, that the altimeter assumes in flight may also be a possible cause for error; however, the use of counterweights in construction has largely eliminated incorrect readings due to the position of the instrument or any of its parts.

Using the Altimeter

During instrument flight along airways, you maintain flight altitude by flying indicated altitude. To be sure of terrain clearance, though, you must correct the indicated altitude for instrument and temperature errors. When you fly from an area of high pressure to an area of low pressure, the actual altitude becomes lower than the indicated altitude, creating a dangerous situation; so keep the barometric scale of the altimeter set to the latest altimeter setting. When you fly through air colder than standard, the actual altitude becomes lower than the indicated altitude; calculate your true altitude by using the E-6D computer.

At higher altitudes, different altimeters do not read alike because of differences in construction and scale errors. Different aircraft models show variations caused by different static air sources, and individual altimeters may vary by as much as 800 feet. Pilots flying formation, therefore, should cross check between themselves and adjust their altimeters to an average of the various instruments. For the same reason, ATC assigns flight altitudes over 29,000 feet at 2,000-foot intervals instead of 1,000-foot intervals.

Don't ignore density altitude. It determines the power output of your engine and becomes especially important in take-off. The Operating Handbook tells you how many feet of runway are needed for take-off at different altitudes, but these are density altitudes. Density altitude is the altitude for which a given air density exists in the standard atmosphere. If the barometric pressure is lower or the temperature is higher than standard, then the density altitude of the field is higher than its actual elevation. Every pilot knows this through observation of its effect; on hot days your plane requires more take-off runway and doesn't climb so well as usual. The effect is greater, however, than you may realize. Take Denver, for example, with an elevation of 5,500 feet. At a temperature of 110° F. and a barometer reading (corrected to MSL) of 29.55 in. its density altitude is about 10,000 feet. Now one typical jet fighter requires 5,300 feet take-off ground roll at 5,500 feet density altitude, but 8,100 feet take-off ground roll

at 10,000 feet density altitude. Obviously, failure to calculate density altitude before take-off from an 8,000-foot runway at Denver on that day could have fatal results. Get density altitude from the tower or compute it on the E-6B computer, using runway temperatures (often 5° C. above station temperature). Check your handbook before hot weather or high elevation take-offs.

GYRO-SUCTION INSTRUMENTS

The gyroscope of a gyro-suction instrument is driven by air sucked in by an engine-driven vacuum pump. Multi-engine aircraft usually have more than one pump. In any event, operation of this set of instruments depends on the proper operation of the vacuum system. Pump failure shows in the form of reduced pressure on the vacuum gage, usually regulated to 4 in. Hg. Since the air must be filtered before entering the delicate gyro mechanism, a clogged filter also shows as a pressure drop on the vacuum gage if there is a master filter. If the aircraft has individual filters on each instrument, as in older aircraft, the individual instrument with a clogged filter will operate improperly but the vacuum gage will provide no clue.

The key to the construction of this group of instruments is the gyro motor, which may be suction-operated or electrically operated. Therefore each of these instruments is also made in an electrically operated version, which is discussed in the next chapter.

Although the electric-type gyros are more likely to fail, they do operate under conditions which the suction-type cannot master. Aircraft vacuum pumps cannot maintain an adequate pressure differential between the atmospheric pressure and the vacuum line at altitudes above about 30,000 feet; the temperatures below −35° F. also make vacuum-driven gyroscopes unreliable. Therefore, jet and other high-altitude aircraft are usually equipped with electric gyro-instruments. To understand either type of gyro instruments, you must first understand the principle of the gyroscope.

THE GYROSCOPE

Any spinning object exhibits gyroscopic properties, but only a wheel designed and mounted

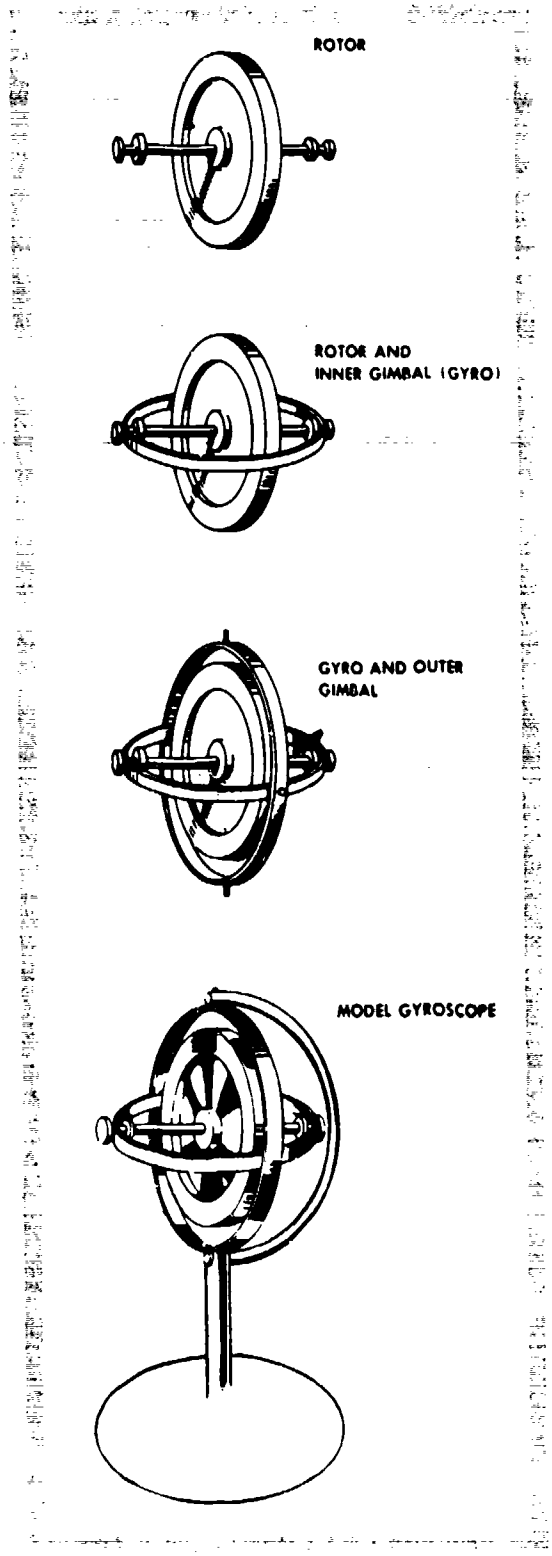


Figure 3-16. Primary elements of a standard gyroscope

to utilize these properties is called a gyroscope. A gyroscope is a spinning wheel, or rotor, which is universally mounted—that is, mounted so that the spin axis can assume any direction in space. The mountings of the gyro wheels, called "gimbals," may be circular rings, rectangular frames, or, in flight instruments, a part of the instrument case itself. Note, in Figure 3-18, that the rotor is free to spin about axis x-x on bearings in the inner ring or gimbal; the inner gimbal is free to turn about axis y-y on pivots in the outer gimbal; and the outer gimbal is free to turn about axis z-z on pivots in the support. Such a rotor is said to have three planes of freedom. It is free to rotate in any plane in relation to the base and is so balanced, that with the gyro wheel at rest, it will remain in any position in which it is placed. Restricted or semi-rigidly mounted gyros are those so mounted that one of the planes of freedom is held fixed in relation to the base.

Of course, the gyroscope illustrated in Figure 3-16 is only a model. Two important design characteristics of a regular instrument gyro are great weight, or high density, for its size and rotation at high speeds with low-friction bearings.

Properties of Gyroscopic Action

All practical applications of the gyro are based on two fundamental properties of gyroscopic action—rigidity in space, and precession.

Rigidity in Space. When the rotor of a gyro is spinning, it has the ability to remain in its original plane of rotation regardless of how the base is moved. However, since it is impossible to have bearings without some friction, there is some deflective force upon the wheel.

Precession. An operating gyro resists a force which attempts to change the direction of its spin axis, but it moves in response to such a force or pressure. The movement is not a direct one in response to the force; it is a resultant movement. The gyro axis is displaced, not in the direction of the applied force, but at right angles to the applied force, and in such a way as to tend to cause the direction of the rotation of the rotor to assume the direction of the torque resulting from the applied force. This property of an operating gyro is called gyroscopic precession.

For example, when a force is applied upward

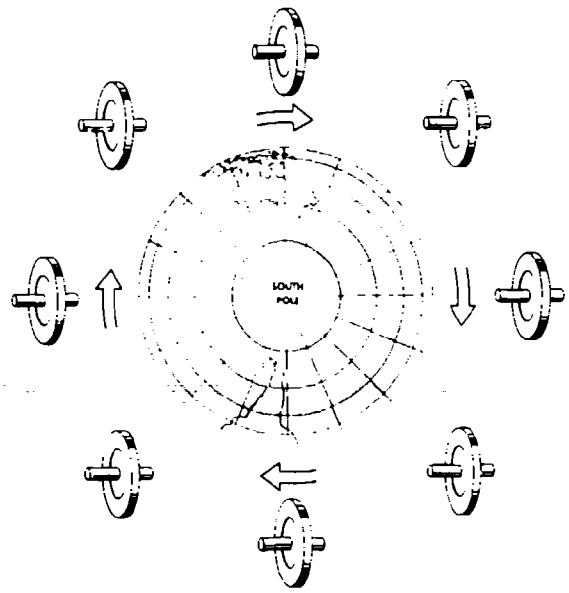


Figure 3-17. Action of a freely mounted gyroscope

on the inner gimbal, as shown in Figure 3-18, it is as if the same force were applied to the rim of the rotor at F. (See Figure 3-19.) The force at F is opposed by the resistance of the gyroscopic inertia, preventing the rotor from being displaced about the axis y-y. However, with the rotor spinning clockwise, the precession takes place 90° ahead in the direction of rotation at P. (See Figure 3-20.) The rotor turns about axis z-z in the direction of the arrow at P. (See Figure 3-21.) The rate at which the wheel precesses is proportional to the deflective force applied (minus the friction in the gimbal ring, pivots and bearings.) If too great a deflective force is applied for the amount of rigidity in the wheel, the wheel precesses and topples over at the same time.

It is this property of gyroscopic precession as well as the property of rigidity, or gyroscopic inertia, that are utilized in gyroscopic instruments. Gyroscopic inertia establishes a reference in space unaffected by any movement of the supporting body. Precession is utilized to control the effects of drift, whether it is apparent drift or mechanical drift; it maintains the reference in the required position.

Drift. A free gyro (one not provided with an erection system) maintains its axis fixed in relation to space, and not in relation to the surface

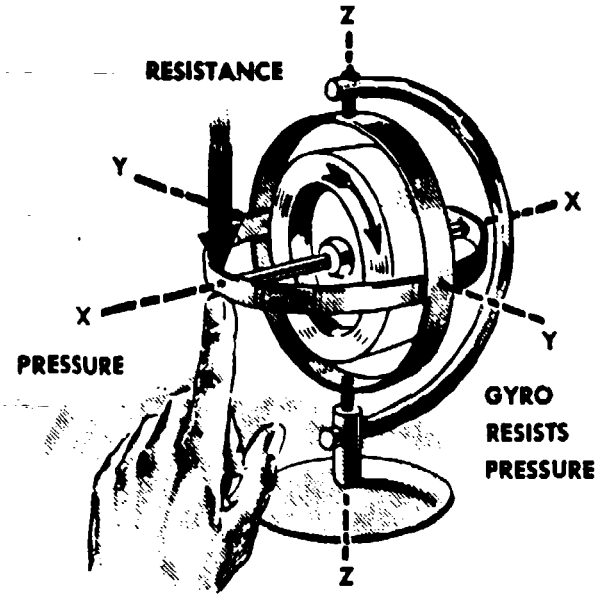


Figure 3–18. Force applied to a gyro

of the earth. For example, imagine such a gyro at the equator, starting with the spin axis horizontal and pointed in an east-west direction. The earth turns in a west-to-east direction with an angular velocity of one revolution every 24 hours. To an observer out in space, the spin axis of the gyro would appear to maintain its direction pointing east.

However, to an observer on the earth, stationed where the gyro is, the spin axis would appear gradually to tilt or drift. At the end of three hours the spin axis would have tilted 45°; at the end of six hours, the spin axis would have tilted 90° and would be in a vertical position. At the end of 12 hours the spin axis would be horizontal again but pointing west; at the end of 24 hours it would be back where it started. (See Figure 3-22.) This action of a free gyro is known as apparent drift. To overcome apparent drift as well as mechanical drift caused by bearing friction or slight unbalance, a gyroscopic instrument must be provided with an erecting device which maintains the spin axis in the required position. This erecting device applies a force to the gyro whenever drift occurs. Precession returns the spin axis to its normal position, maintaining an accurate reference. (See Figure 3-23.)

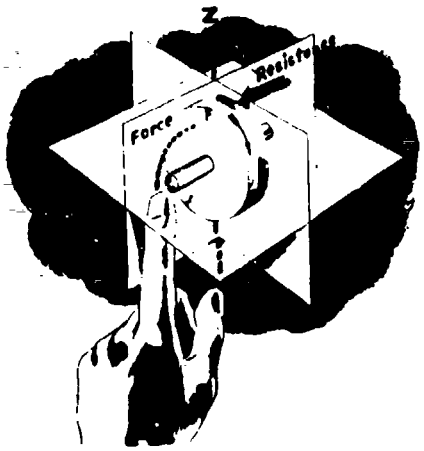


Figure 3–19. Transmission of force

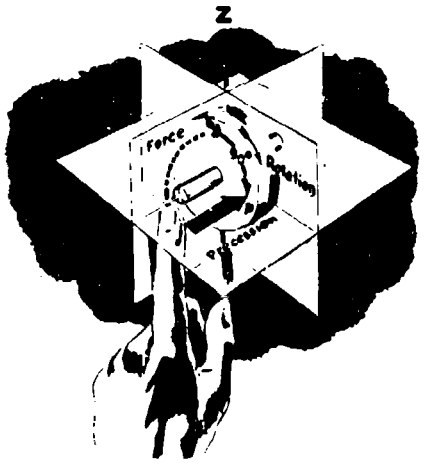


Figure 3–20. Direction of precession

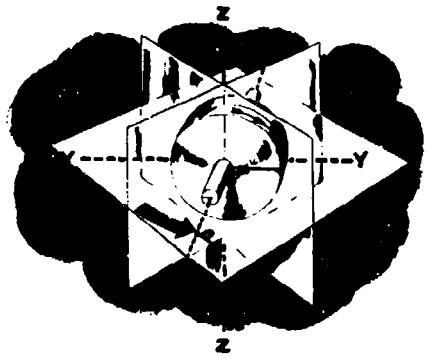


Figure 3–21. Precessional movement

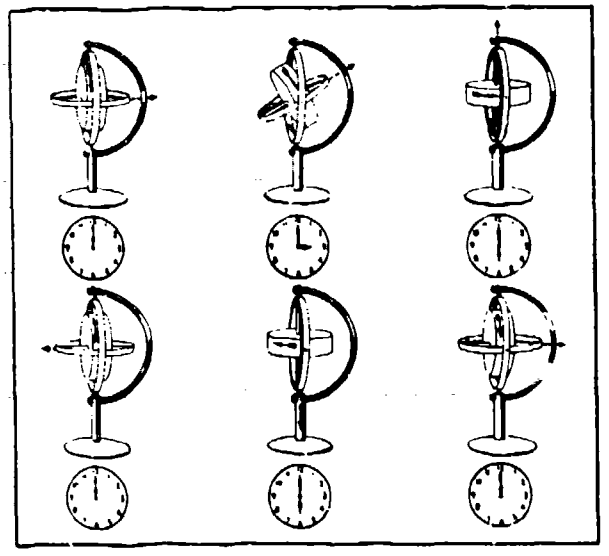


Figure 3-22. Apparent drift

Gyro Instruments

The three basic gyro instruments are the turn-and-bank indicator, the heading indicator, and the horizon indicator. The turn-and-bank indicator utilizes the gyroscopic property of precession and is a semi-rigidly mounted instrument. The heading indicator is freely mounted; it utilizes the gyroscopic property of rigidity in space to establish a reference plane and the gyroscopic property of precession to maintain the vertical axis of the rotor perpendicular to the earth's surface.

TURN-AND-BANK INDICATOR

The only suction-operated instrument still maintained on most new naval aircraft is the turn-and-bank indicator. This is not because the electric turn-and-bank indicator is no good but, rather, because it is necessary to provide a means for emergency instrument flight in case of electrical failure. However, this instrument now plays a secondary role. It is used primarily for cross-checking other instruments or for flight on partial panel. Therefore, many new aircraft have a two-inch instead of three-inch dial on the turn-and-bank indicator, and the instrument is placed in a less central position on the panel.

The turn-and-bank indicator was one of the first modern instruments to be used for controlling an aircraft without visual reference to the ground or horizon. It is a combination of two instruments, a ball and a turn needle. The ball part of the instrument is directly actuated, while the turn indicator depends on the gyroscopic property of precession for its indications.

The Ball

The ball part of the turn-and-bank indicator consits of a sealed, curved glass tube containing water-white kerosene and a black agate or common steel ball-bearing which is free to move inside the tube. The fluid provides a dampening action and insures smooth and easy movement of the ball. The tube is curved so that when it is held in a horizontal position the ball has a natural tendency to seek the lowest point, which is the center. A small projection on the left end of the tube contains a bubble of air which compensates for expansion of the fluid during changes in temperature. Two strands of safety wire are wound around the glass tube as reference markers to indicate the correct position of the ball in the tube. The plate to which the tube is fastened and the reference wires are usually painted with a luminous paint.

The natural forces acting on the ball in straight-and-level flight are: (1) gravity, which acts toward the center of the earth, and (2) the force exerted by the bottom of the tube which is

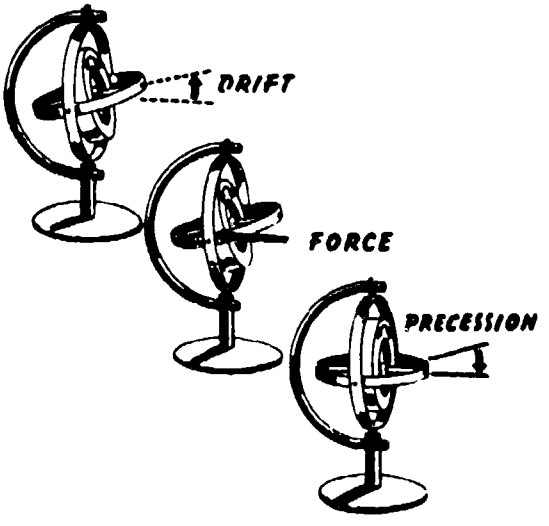


Figure 3-23. Precession controlling drift

Figure 3–24. Turn-and-bank indicator

always perpendicular to the tangent at the point of contact. It acts from the point where the ball makes contact with the tube through the center of the ball.

In a coordinated turn, the natural forces acting on the ball are: (1) gravity which pulls toward the center of the earth, (2) the force exerted by the bottom of the tube, and (3) centrifugal force which acts in the horizontal plane and outward from the center of turn.

The ball assumes a position between the reference markers when the resultant of centrifugal force and gravity acts midway between the reference markers. When the forces acting on the ball become unbalanced, the ball moves away from the center of the tube.

In a skid, the rate of turn is too great for the angle of bank. The centrifugal force is excessive, and the resultant of centrifugal force and gravity is not opposite the mid-point between the reference markers, but toward the outside of the turn. Consequently, the ball moves in that direction. Correcting to coordinated flight calls for increasing the bank or decreasing the rate of turn, or a combination of both.

In a slip, the rate of turn is too slow for the angle of bank. There is not enough centrifugal force, and the resultant of centrifugal force and gravity causes the ball to move toward the inside of the turn. Correcting to coordinated flight requires decreasing the bank or increasing the rate of turn, or a combination of both.

The ball instrument serves to check your coordination. It is actually a "balance" indicator, because it indicates the relationship between the angle of bank and the rate of turn. It tells you the "quality" of the turn; whether the aircraft has the correct angle of bank for its rate of turn.

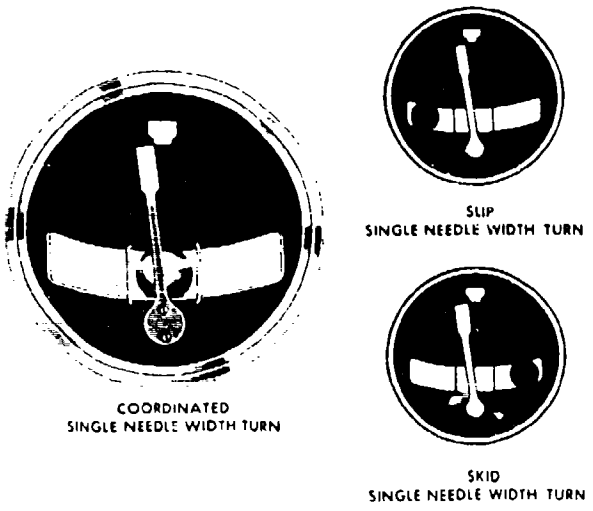


Figure 3–25. Indications of the turn-and-bank indicator

The Turn Needle

The turn needle is actuated by a gyro. A restrictor valve to control the suction on the turn needle gyro is installed between the main suction line and the instrument. On the older systems, the restrictor valve control is behind the instrument panel and is not accessible to the pilot. Newer-model aircraft have a valve control on the instrument panel, which enables you to adjust the suction on the turn needle while in flight. On some models, the suction gage may also be switched to the turn needle, enabling you to know the actual suction on the instrument.

The desired vacuum on the turn-and-bank indicator is 1.9 to 2.0 inches of mercury (Hg); it should be set between the limits of 1.8 in. Hg and 2.1 in. Hg. Low vacuum causes a lower rotor rpm and reduces the indication from what it would be if the rotor rpm were within limits. High vacuum causes the deflection to be greater than normal.

The turn needle indicates the rate (number of degrees per second) at which the aircraft is turning about its vertical axis. By using the turn-

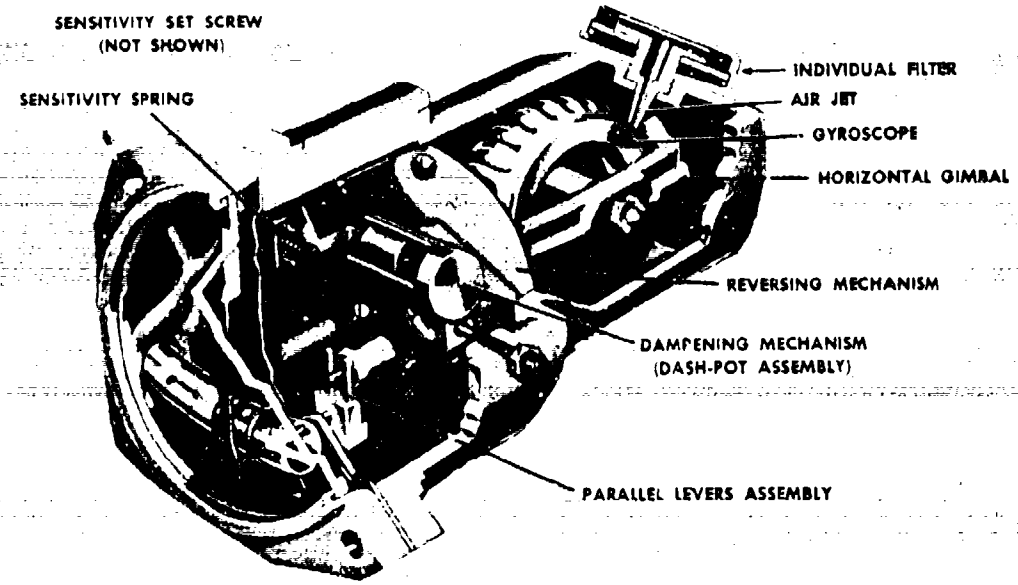


Figure 3-26. Cutaway view of turn-and-bank indicator

and-bank indicator, you can check for coordination and balance in straight flight and in turns. If you cross-check this instrument against the airspeed indicator, you can determine the relation between the lateral axis of the aircraft and the horizon (angle of bank). For any given airspeed there is a definite angle of bank necessary to maintain a coordinated turn at a given rate.

GYRO HEADING INDICATOR

The gyro heading indicator is a suction-operated directional gyro. It is fundamentally an instrument designed to facilitate the use of the magnetic compass. Any pilot can imagine the difficulties he would have to contend with in instrument flying if he had to depend for directional information solely on the magnetic compass. The gyro-driven heading indicator overcomes these difficulties. It is not affected by the centrifugal force of turns, by rough air, by magnetic disturbances, or, within certain limits, by the orientation of the aircraft.

The instrument operates on the principle of the rigidity in space of a universally mounted gyroscope. The rotor turns in the vertical plane, and a circular compass fixed at right angles to the plane of the rotor (to the vertical gimbal). Since the rotor remains rigid in space, the points on the card hold the same position in space relative to the vertical plane. The case simply revolves about the card. During turns, of course, the rotor may deviate from the vertical plane of rotation, but the erecting mechanism quickly returns the rotor to its normal plane of rotation.

The heading indicator can operate properly with a suction gage reading as low as 3.5 in. Hg or as high as 5.0 in. Hg, but the limits used for adjustment should be between 3.75 in. Hg and 4.25 in. Hg, with 4.0 in. Hg the desired reading.

Of course, the instrument cannot operate in all attitudes of flight because of the way it is constructed and the way it operates. The stop or limiting factor in the instrument is the caging arm. In the uncaged position, the caging arm rests on the bottom of the vertical gimbal ring and in that position restricts the movement of the vertical gimbal ring about the rotor or the horizontal gimbal.

The limits of operation of the instrument, for all practical purposes, are 55° of pitch and 55° of bank. *On some headings*, though, the gyro does not spill or tumble even though 55° of bank or

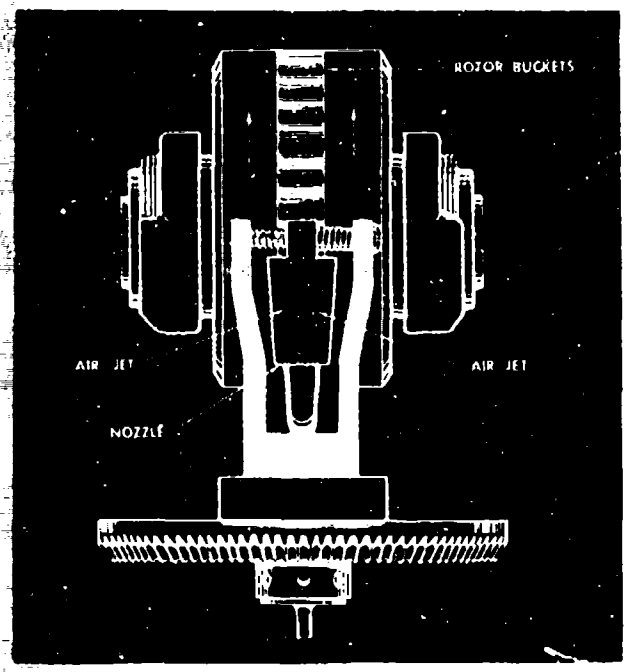


Figure 3-27. Heading indicator gyro rotor and nozzle assembly

pitch have been exceeded. If the rotor is aligned with the longitudinal axis of the aircraft, it will not tumble even though the pitch attitude of the aircraft exceeds 55°.

When the horizontal gimbal touches the stop, the precessional force causes the card to spin rapidly. You can correct this by caging and uncaging the instrument.

No gyroscope yet designed has eliminated precession from the original plane of rotation. In the gyro heading indicator, this precession causes the card to drift, or creep, away from the true reading. The chief cause of creep or drift is friction. An unbalanced condition of the gimbal rings also causes errors. If the gyro unit is out of balance, there is a force applied to the rotor which causes precession.

Another cause of error is the effect of the rotation of the earth, which causes a universally mounted gyroscope to precess, the amount depending on the position of the aircraft. At the equator there is no effect. Above and below the equator, the precession increases according to the distance from the equator in opposite directions in the Northern and Southern Hemispheres. The effect of the earth's rotation is counteracted by balancing the gimbal rings. Then, so long as the plane flies somewhere near the same latitude, there is no problem. However, in a flight entailing great changes of latitude the error would become apparent, particularly if the equator were crossed. If the instrument were corrected for error in the Northern Hemisphere and flown in the Southern Hemisphere, the error and correction would act in the same direction, and cause a noticeable amount of creep.

When considering the errors in this instrument, it is well to remember that error in the heading indicator is frequently the result of an improper setting from the magnetic compass. Incidentally, you adjust the card of the heading indicator by means of the caging mechanism. This rotates the vertical gimbal by gears or a clutch, depending on the design of the particular model.

Before take-off, ground check the heading indicator to determine whether it is operating properly. To do this, first see that there is sufficient vacuum. While the engine is warming up, check whether the rotor is turning by first caging and then uncaging the instrument with a gentle twisting motion. If the rotor is turning, the card will stop as soon as the instrument is uncaged. To assure the proper speed of operation, allow the gyroscope to run up for five minutes before take-off. During taxiing, you can check the gyro head-

ings if the limits are exceeded and the gyro is determine large amounts of creep. The gyro heading indicator is extremely useful during take-off under instrument conditions since it is not affected by the acceleration of the aircraft.

During flight, the gyro heading indicator is used to maintain straight flight and make turns to headings. Whether you set the card with the compass or use the heading of zero, you use the magnetic compass as the reference. Be careful in reading the compass. Unless you check the compass deviation card, the indicator may appear to drift several degrees during a turn. *Check the gyro heading indicator at least every 15 minutes against the magnetic compass.* After setting the instrument, uncage it by pulling the caging knob straight out. If there is an error of more than 3° in a period of 15 minutes, turn in a "squawk."

During maneuvers which exceed the limits of the instrument, it should be caged. At all other times the instrument may be left uncaged. It is obvious that frequent aerobatic flight with the instrument uncaged shortens the life of the gyro unit. A great deal of force is applied to the bearings if the limits are exceeded and the gyro is "spilled."

SUCTION-OPERATED HORIZON INDICATOR

The suction-operated horizon indicator is virtually obsolete. It is generally found only in aircraft manufactured before 1950. This manual will therefore not discuss the theory and construction of this instrument in any detail. Like all horizon indicators, it has a horizon bar which moves in such a way that the position of the miniature airplane in relation to the horizon bar corresponds to the position of the aircraft in relation to the actual horizon.

The miniature airplane is supported from the base on the front of the case and is approximately in the center of the instrument face. The horizon bar is supported by an arm which extends back on the right side of the instrument to a pivot at the back of the horizontal frame. The pivot allows the horizon bar to move up and down but

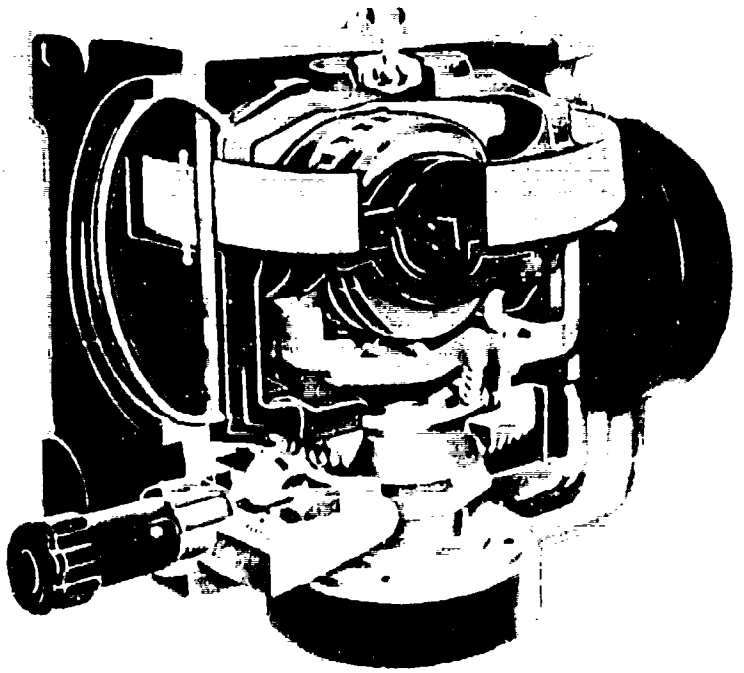


Figure 3-28. Cutaway view of suction-driven heading indicator

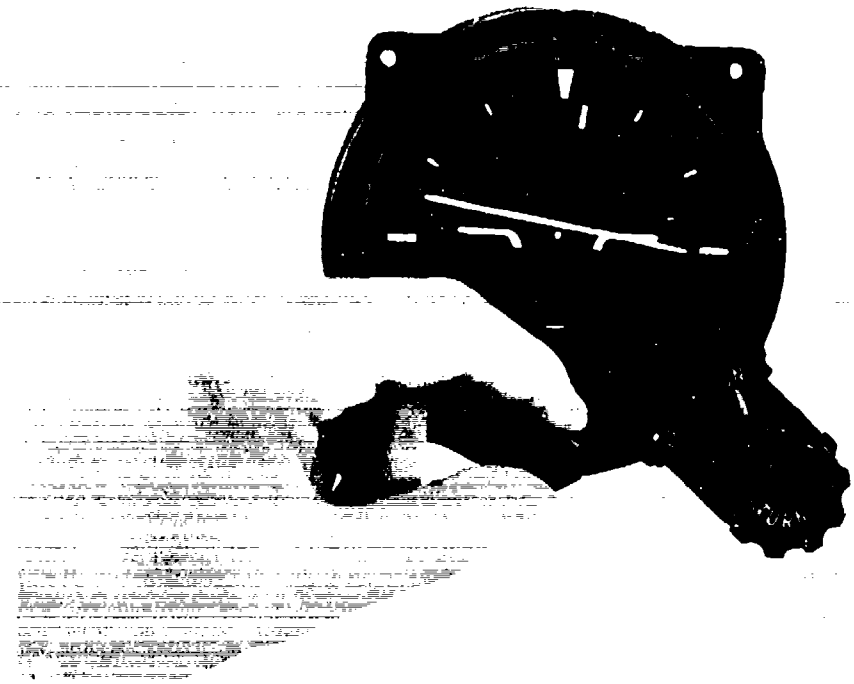


Figure 3-29. Suction-operated horizon indicator

allows it no lateral motion. The horizon bar is held constantly horizontal since the frame on which it is mounted is held horizontal laterally by the gyro. In other words, the miniature airplane moves with the case and with the actual airplane around the horizon bar which is held level by the gyro. The bank of the aircraft is thus accurately reflected by the bank of the miniature airplane in relation to the horizon bar. The pitch of the airplane is indicated by the vertical position of the minature airplane in relation to the horizontal bar.

The basic mechanism of the instrument is a freely mounted gyroscope which always remains in a constant plane relative to the earth when the instrument is operating. This gyro is driven by suction which should be within 0.25 in. Hg. of the desired vacuum of 4.0 in. Hg.

The gyro rotor and gyro housing can be held rigidly in a horizontal plane with respect to the instrument case by use of the caging mechanism. To cage the gyro, pull the caging knob on the face of the instrument and turn it clockwise as far as it will go; then push in. To uncage, pull the knob and then turn it counter-clockwise as far as it will go; then push the knob in.

The limits of the horizon indicator are determined by its construction—100° of bank, and 70° of pitch. Maneuvers in excess of these limitations cause the gyro to precess violently, upset, and become useless. It remains useless until it erects itself or is caged and then uncaged in level flight.

Errors

The horizon indicator is subject to slight errors in both bank and pitch due to the effect of the erecting mechanism in a turn. The bank and pitch errors are greatest in a slow turn and after 180° of turn. The indications should return to normal after 360° turn.

The bank error causes the instrument to indicate slightly less than the actual amount of bank

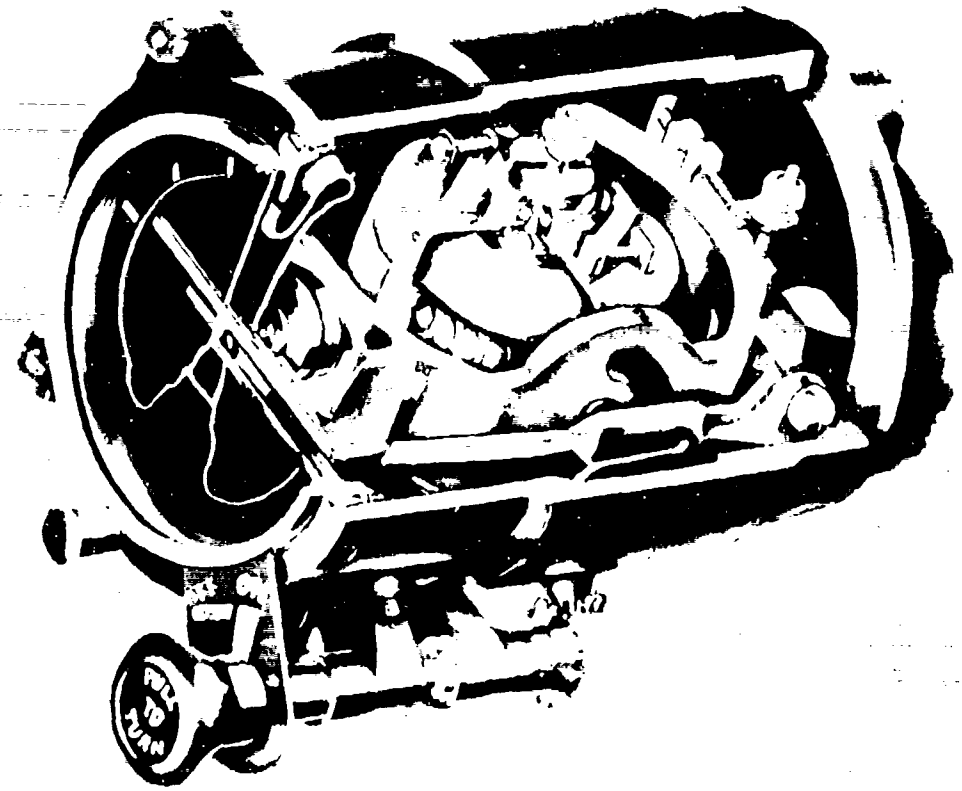


Figure 3-30. Cutaway view of horizon indicator

during a turn, or a slight bank in the opposite direction after level flight has been resumed. The pitch error causes the horizon bar to dip slightly below its correct position for level flight. This error is small; however, if you follow the indications of the horizon indicator in slow turns without reference to other instruments, you may enter a gradual descent and, in time, lose considerable altitude. The action of the erecting mechanism corrects these bank and pitch errors in a short time after level flight has been resumed.

Acceleration can also give wrong indications by causing the erection mechanism to react in such a way as to make the horizon bar move downward. This results in a tendency to dive the aircraft while accelerating. Deceleration has the opposite effect—causing the horizon bar to move upward. Both these errors are proportional to the amount of acceleration or deceleration and to the elapsed time involved.

Other errors in the indications of the instrument may be caused by precession of the gyro as a result of worn or dirty gimbal bearings or an out-of-balance condition in any of the moving parts. A loss of vacuum due to dirty filters or other causes will also keep the instrument from operating properly.

Using the Horizon Indicator

Because of frequent errors of indication, it is necessary to coordinate the suction-driven horizon indicator with the other flight instruments. In straight-and-level flight, the pilot who relies too

much on the suction-driven horizon indicator will most likely find his flight erratic. You must therefore cross-check it with the turn-and-bank indicator, heading indicator, and altimeter. In turns, the pitch error causes an improper attitude to be shown by the instrument. Constant cross-checking with the other instruments is again necessary. In climbs and descents, the acceleration and deceleration of the aircraft causes pitch error. You must take this into consideration in order to have a proper attitude for the maneuver.

In addition, remember that the indications of the horizon indicator are only approximations of the exact pitch attitude, because of the small changes of attitude caused by variation in the airspeed, load, and air density. To help you take these changes into account, the instrument has an adjustment knob with which the miniature aircraft may be moved upward or downward inside the case.

Caging the Instrument

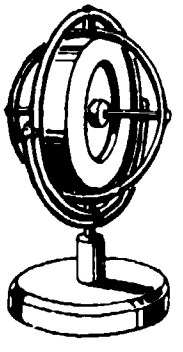
When the limits of the instrument are exceeded, it will spill or tumble. You must avoid this because it brings a force to bear against the rotor which produces very violent precession until the opposite limit is reached and there is an abrupt stop in the precession. This may result in cracked, flattened, or loosened bearings, any one of which causes excessive friction and precession.

If you expect to exceed the limits, therefore, you should cage the instrument, although flying with the instrument in the caged position does cause considerably more than normal wear. Exceeding the limits of the horizon indicator may be compared to driving an automobile into a stone wall; flying with the instrument caged can be compared to stopping the same automobile by slamming on the brakes before hitting the stone wall. You avoid immediate damage but you do cause excessive wear.

The suction-driven horizon indicator should be uncaged only in level flight. The indications of the instrument depend on the position of its universally mounted gyro, and if you uncage it in an unlevel attitude, it tends to remain in an unlevel plane, except for the action of the erecting mechanism. When uncaging the instrument, be sure that it is fully uncaged. If you're not careful to see that this is done, the clamps in the caging mechanism will decrease the maneuvering limits, and the instrument will spill even in a normally safe maneuver.

Be particularly careful in caging the horizon indicator. Rough, forceful caging causes the instrument to be spilled many times. The damaging results are similar to those caused by exceeding the limits of the instrument caged wears it excessively; therefore, it should be caged only when the limits are to be exceeded.

In summary, remember that the horizon indicator is the most realistic attitude instrument on the panel and its indications are close approximations of the actual attitude of the aircraft itself. Don't be too concerned with its errors. Just remember what they are and take them into account in interpreting its indications. Finally, remember that the instrument should always be left uncaged unless its limits are to be exceeded.



CHAPTER 4

ELECTRIC INSTRUMENTS

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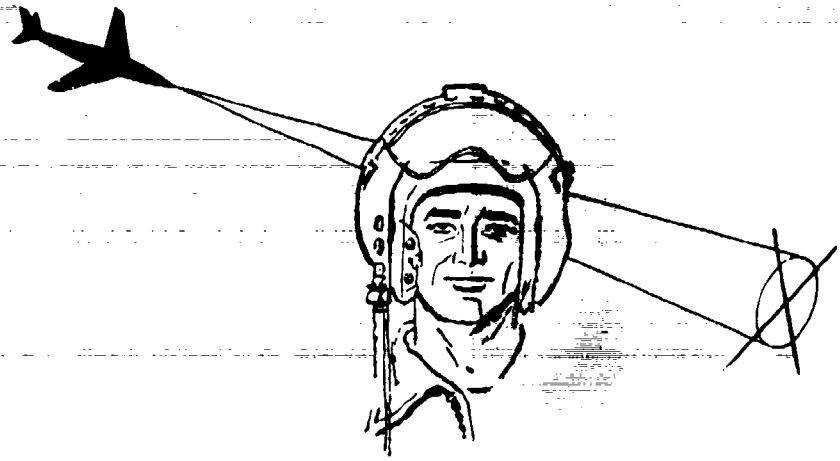


CHAPTER 4

ELECTRIC INSTRUMENTS

THIS chapter covers the various instruments which utilize the aircraft electrical system for their operation. These include the electric versions of the turn-and-bank indicator, electric horizon indicators, and electric heading indicators. (Some of the electric heading indicators are merely directional gyros with electric gyro motors; some are types of remote-indicating compasses; and some are combination directional gyros and compasses). This chapter deals first with the instruments which are electric versions of the suction-operated gyro instruments previously discussed.

ELECTRIC TURN-AND-BANK INDICATOR

The electric turn-and-bank indicator is now widely used, but the policy is to maintain the suction-operated turn-and-bank indicator as a standby in case of electric failure. Remember, though, that the suction type of turn-and-bank indicator may oscillate or give readings of insufficient needle deflection above 30,000 feet because it does not get adequate vacuum from the engine-driven pump. In the electric version this problem is not present. Of course, the ball element of

all turn-and-bank indicators is the same; only the turn needle mechanism is different.

The electric turn-and-bank indicator is operated on current supplied directly from the aircraft batteries—DC current. It is housed in a hermetically sealed case to eliminate the danger of moisture condensation due to extreme temperature and pressure changes and to keep out sand, dust, salt air, fungus and other environmental nuisances. The gyro turns at a nearly constant rate of 4,500 rpm regardless of flight altitude or temperatures. The gyro, or rotor, is in effect a small electric motor. Soon after power is applied, before takeoff, enough heat is generated to keep the motor's lubricant solvent even at altitudes where the outside temperature is extremely low.

For its indications, the electric turn-and-bank indicator relies on precession, just as the suction-operated turn and bank indicator does. The instrument can be calibrated to indicate a single-needle-width turn at the rate of either 3° per second or 1½° per second. The 4-minute turn needle, calibrated for a rate of turn of 1½° per second, was developed for use in high-speed aircraft to decrease the angle of bank for a single-needle-width turn. The 4-minute-turn needle measures motion about the vertical axis of the aircraft at only half the magnitude of the 2-minute-turn needle. Two-minute-turn needles are still installed in conventional aircraft. One change in presentation of the 4-minute turn needles is the fact that some of these needles are hinged above the ball, whereas the 2-minute needle is hinged below the ball. (See Figures 4-1 and 4-2.)

ELECTRIC GYRO HEADING INDICATOR

Occasionally, you may encounter the C-1 electric gyro heading indicator. Note that the dial or presentation of this instrument resembles certain remote-reading compasses—the type which combine a magnetic compass unit with a gyro heading indicator slaved to it (as described later in this chapter).

The electric heading indicator, like the suction-driven heading indicator, utilizes the property of rigidity in space to establish a reference plane. The aircraft turns about this gyro, causing an indication of heading change on the instrument. Since this gyro is not sensitive to the earth's magnetic field, it indicates correct headings only when set after reference to a North-seeking instrument such as a magnetic compass.

The C-1 heading indicator has a round flat card visible only in the top half of the instrument. This card turns as the aircraft turns, and you read the heading indication under the lubber line. The card can also be turned by the LOCK SET knob at the lower right corner of the instrument. When

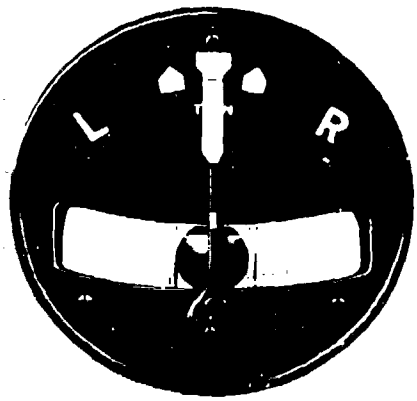


Figure 4-1. Turn-and-bank indicator with two-minute needle

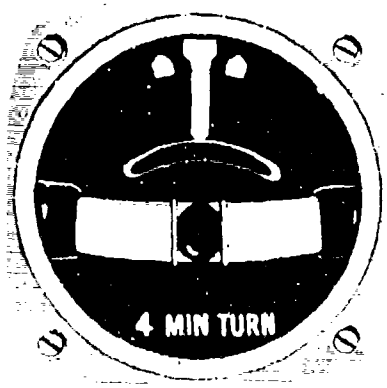


Figure 4-2. Turn-and-bank indicator with four-minute needle

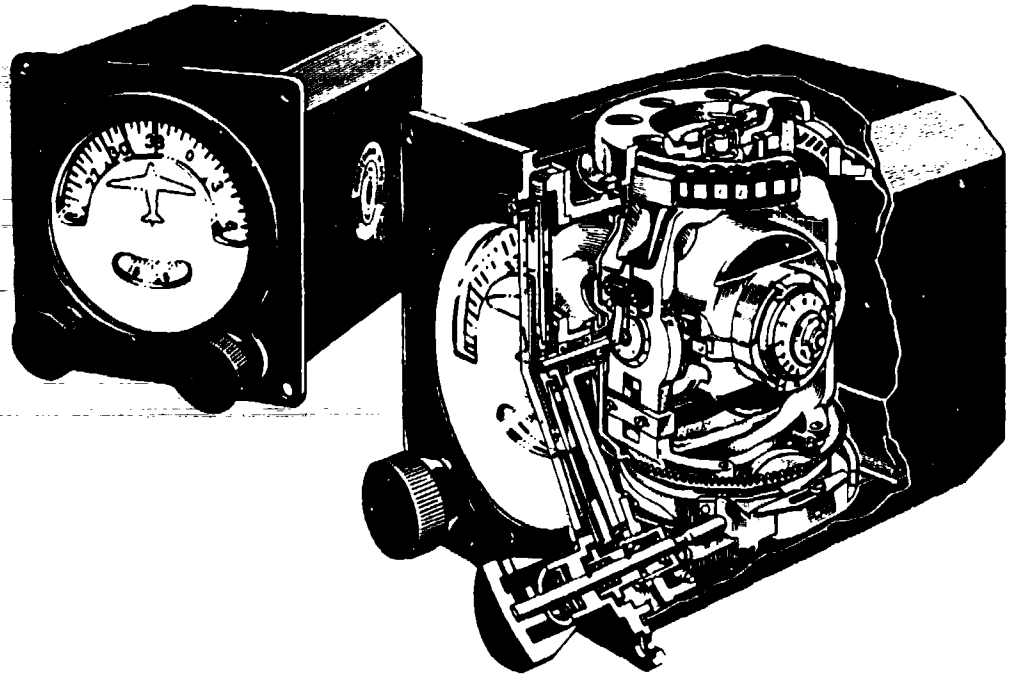


Figure 4–3. C–1 electric directional gyro heading indicator

this knob is pushed all the way in it cages the gyro and renders it non-indicating. With the knob all the way in, the card will turn as the knob is turned, and you can place any heading under the lubber line. The card seen through the lower window shows the reciprocal of the heading being flown.

A SET COURSE knob on the lower left of the instrument is used to set the arrowhead of the course indicator dial to the heading flown. Releasing the SET COURSE knob releases the arrowhead and lets it move with the card. It thus becomes an easily readable reference to keep aligned with the lubber line and eliminates the need for remembering a numerical value to keep the aircraft on course.

Approximately two minutes after power and inverter have been turned on, the instrument is ready for use. It must be set to a correct magnetic heading to be accurate. The operating limits of the C–1 Indicator are 60° right or left bank.

When entering a maneuver that may exceed the limitations, cage the gyro. Otherwise always leave it uncaged. If the operating limits should be accidentally exceeded while the gyro is uncaged, the indications of the instrument will be unreliable. To restore the instrument to normal operation, bring the aircraft to straight-and-level flight, cage the gyro, and set it to the correct magnetic heading.

ELECTRIC HORIZON INDICATORS

The suction-operated type of horizon indicator, still found in older aircraft, has now given way to the electric type, which is free of many of the drawbacks of the older type. The suction-operated indicator was erratic at high altitudes, tumbled during violent maneuvers, and possessed other inherent limitations.

The new instrument, among the most useful of all found on an aircraft's instrument panel, has become the primary instrument for the control of modern aircraft. Pilots who have learned to rely on the horizon indicator, and who understand the few limitations it possesses, can perform acro-

batics on instruments with complete confidence.

This chapter considers the H-6 and H-6A horizon indicators. Other electric types are the A-1, the A-2, the H-5, the J-3, and the J-8. An early electric type, the H-3, was widely used in aircraft built prior to 1950, but it proved unsuited to jets because of its slow erection characteristics and its lack of a caging mechanism. In the remote type of horizon indicator, the gyroscope and its associated components which control the action of the indicator are located together in a place remote from the location of the indicator itself. The two basic components of the instrument are manufactured as separate units. The Navy uses the K-4A and K-4B control unit and the MM-1 and MM-2 indicators.

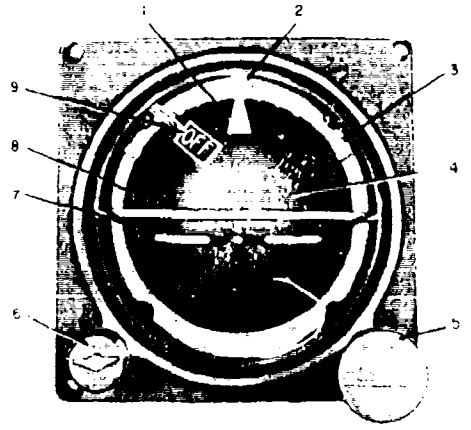
HORIZON INDICATORS H-6 AND H-6A

Horizon indicators, Model H-6 and Model H-6A, provide the pilot with a flight reference which he can use naturally without any interpretation, just as he refers to the natural horizon in clear-weather flying. Both models have a number of outstanding design features: low "turn error" at high speeds and at steep angles of bank, good erection rate, mechanical caging, electric flag alarm, increased pitch trim travel, heated bezel glass to eliminate condensation, and primarily stainless steel construction. The H-6A has a numerical pitch scale in addition to the horizon bar operation, and it has a wider angle of visibility.

Both models have been designed for high-speed aircraft and for aircraft with a fast engine warm-up. As soon as the power to the instrument is turned on, the gyro can be erected by a mechanical caging device to the true attitude of the aircraft. After this, the erection is completed by the ball erector mechanism.

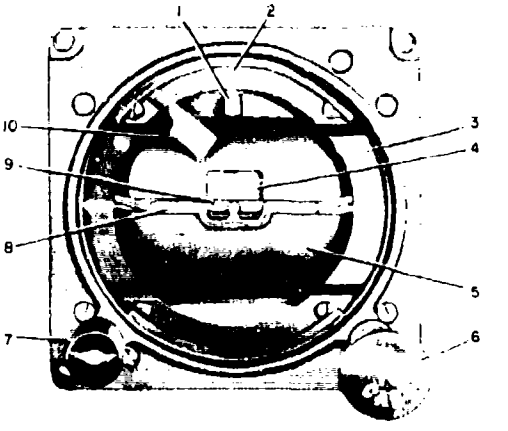
Principles of Operation

The operating principles of the Model H-6 and Model H-6A horizon indicators are similar to those of other models in that the gyro remains substantially fixed in relation to the earth while the instrument case with its associated parts moves about the gyro to provide accurate bank and pitch indications. By observing the indications relative to the bezel indices, you can move the airplane to any chosen flight attitude. You don't have to manipulate the instrument itself except to



1 Bank Index
2 Vertical Index
3 Bezel Mask
4 Sphere
5 Caging Knob
6 Trim Indicator Adjusting Knob
7 Trim Indicator (Miniature Airplane)
8 Horizon Bar
9 Power-Failure Warning Flag

Figure 4-4. Model H-6 horizon indicator



1 Bank Index Spoon
2 Vertical Index
3 Bezel Mask
4 Pitch Scale
5 Spoon
6 Caging Knob
7 Trim Indicator Adjusting Knob
8 Trim Indicator (Miniature Airplane)
9 Horizon Bar
10 Power Failure Warning Flag

Figure 4-5. Model H-6A horizon indicator

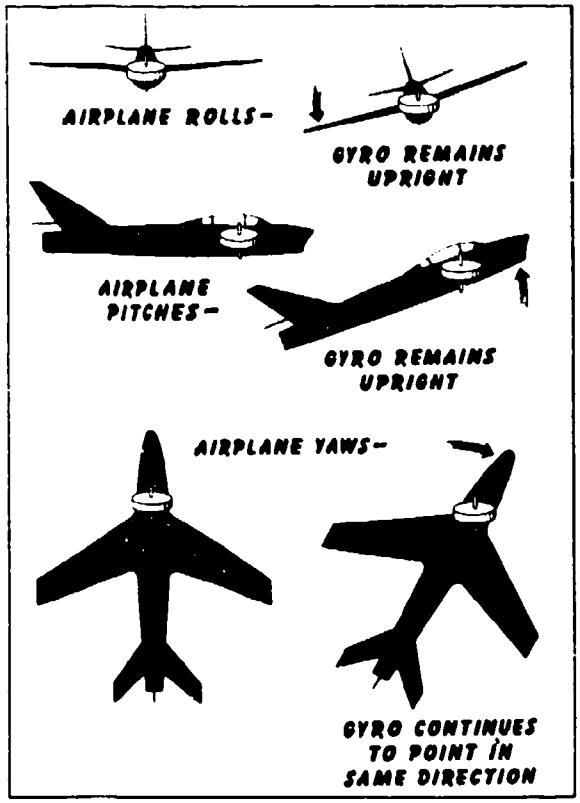


Figure 4-6. Gyro stability

adjust the trim indicator to correspond with varying load conditions and operate the mechanical caging device.

The horizon bar, which you see through the front of the instrument, is your substitute—within the airplane—for the horizon. During flight, the horizon bar is laterally stabilized, or fixed, in relation to the surface of the earth. Because of its mounting, it is independent of the instrument case and the motion of the airplane. By comparing the position of the horizon bar and the bank indicator with the indices on the bezel mask, you know immediately the attitude of the airplane.

The stabilized reference is provided by use of a gyroscope with an erecting mechanism. As the airplane rolls or pitches, the spin axis remains upright. (See Figure 4-6.) These deviations from the normal attitude are shown on the indicator and you can control the airplane by referring to the indicator.

The rotor and stator of the electric motor driving the H-6 and H-6A are enclosed in a gyro housing, and the combined assembly is referred to as the gyro. The gyro is free to pivot in its gimbal, and the gimbal is free to rotate in the bearings of the bearing support.

The pitch indication of the horizon indicator is the result of the relative movement between the gimbal and the stabilized gyro housing. As the airplane (and the case) move around the lateral axis of the gyro, the horizon bar is similarly moved up or down with relation to the miniature airplane (trim indicator). This vertical displacement shows the pitch position of the aircraft with reference to the natural horizon.

The roll indication of the instrument is the result of the lateral rotation of the airplane (and the case) around the gimbal which is stabilized by the operating gyro. This motion about the longitudinal axis is shown on the face of the instrument by a tilt of the miniature airplane (trim indicator) relative to the horizon bar and rotation of bezel mask indices with reference to the bank index. This angular displacement indicates the roll of the aircraft as compared to the natural horizon.

The mechanical caging system used cages the gyro to the true attitude of the aircraft, and not to the true vertical. Thus, if the true attitude of the airplane coincides with the true vertical, no further erection of the gyro is necessary. If the true attitude of the airplane does not coincide with the true vertical, the ball erector mechanism erects the gyro to the true vertical at a rate of approximately two degrees per minute. Therefore, cage the gyro when visual horizon reference is available.

Use of the Horizon Indicator

Closing the main power supply switch causes the gyro to start rotating, the power-failure warning assembly to operate, and the bezel glass to warm up. If the equipment is operating properly, the warning flag will now disappear. Failure of the warning flag to disappear indicates either improper phase rotation or an open or short circuit. Check with the maintenance people.

In starting up the gyro, do not cage it unless you have a visual horizon reference, because the

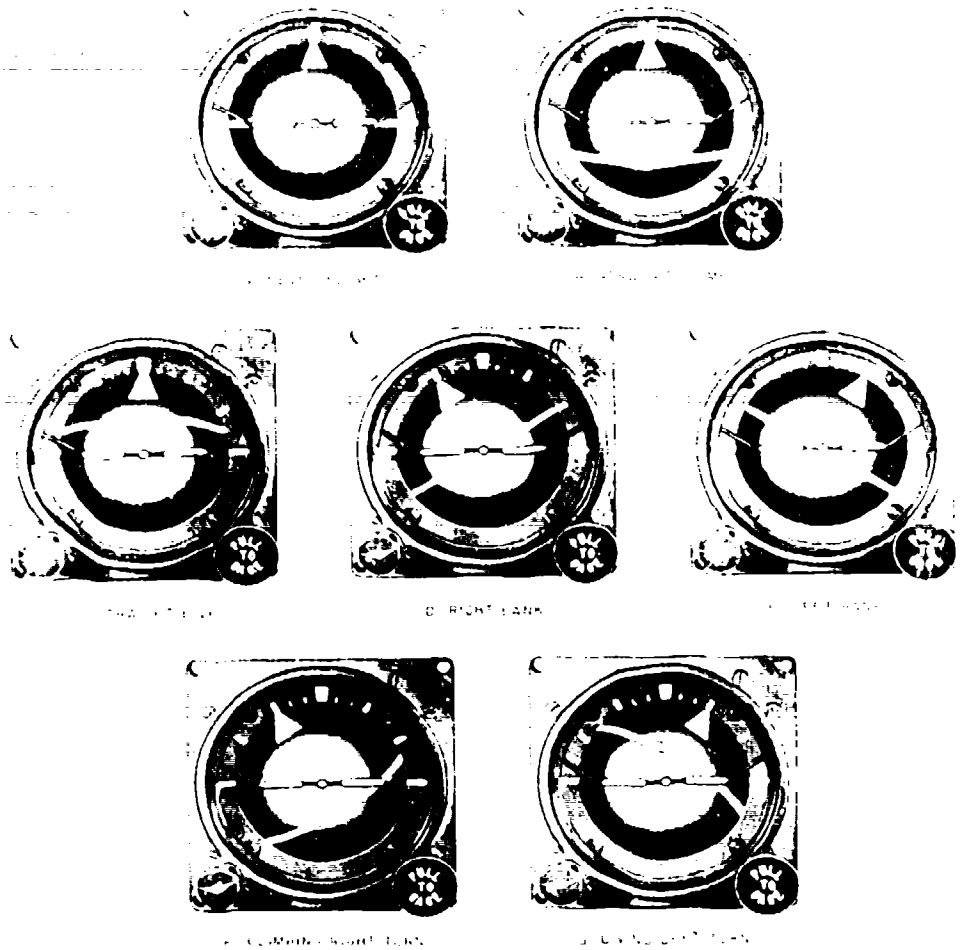


Figure 4–7. Model H–6 indications during normal flight

gyro cages to the true attitude of the aircraft and not to the true vertical.

During instrument flight, you see the horizon on your horizon indicator just as you see the natural horizon during contact flight. Visualize the miniature airplane as representing the aircraft in flight, flying toward the horizon represented by the horizon bar. In other words, the position of the miniature airplane relative to the horizon bar represents the attitude of the aircraft relative to the natural horizon.

In flight, just before using the indications of the instrument, adjust the height of the miniature airplane (trim indicator) to the desired flight condition. This height may vary slightly as loading and other conditions change, and it is good practice to check it from time to time during flight.

When the miniature airplane is aligned with the horizon bar, the aircraft is in level flight, both laterally and longitudinally; the aircraft is neither banking, diving, nor climbing. When the miniature airplane is above the horizon bar, the aircraft is climbing, and when it is below the bar, the aircraft is diving. In inverted flight, when using the non-tumbling horizon indicator, the airplane-horizon components of this instrument still give a true picture of the aircraft's position with reference to the horizon—except that climbing and diving are reversed. For example, in inverted flight, when the miniature airplane is above the horizon, the actual aircraft is diving. When the miniature airplane appears to be tilted relative

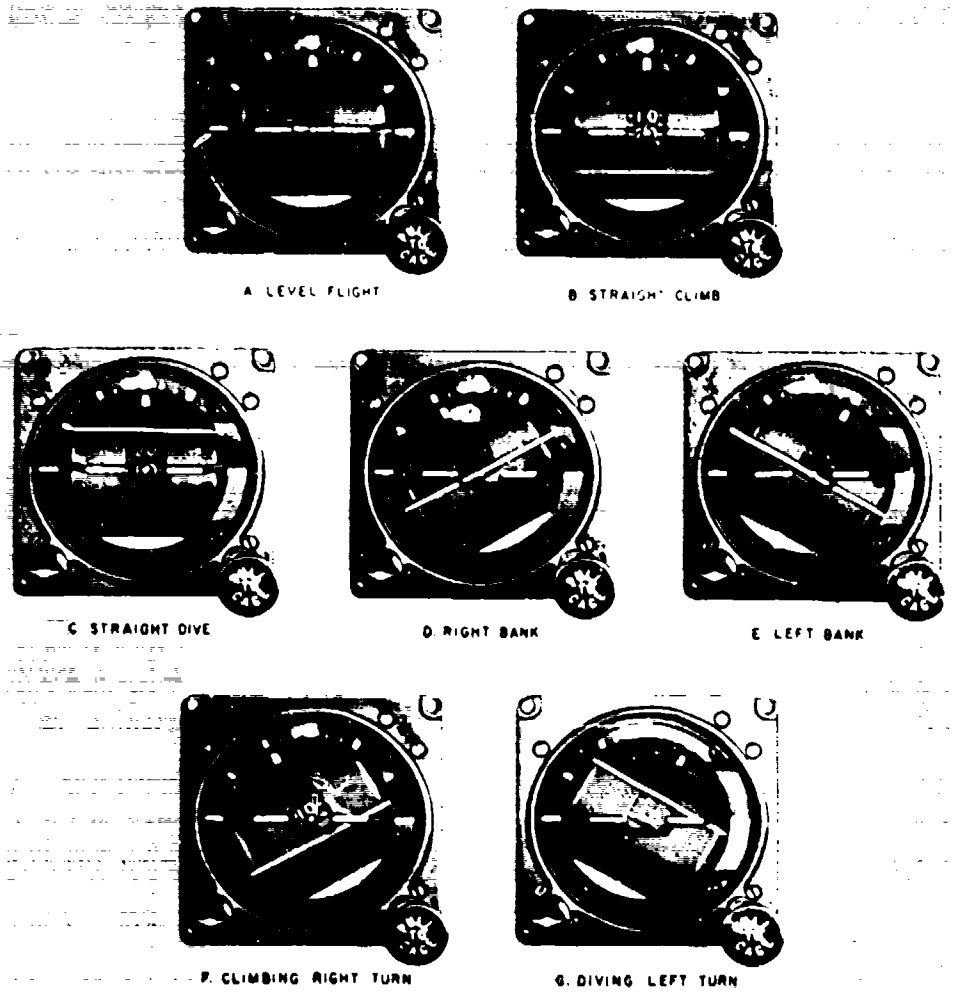


Figure 4-8. Model H-6A indications during normal flight

to the horizon bar, the aircraft is banking. (In actuality, the horizon bar tilts, making the miniature airplane *appear* to tilt. The little airplane is adjustable in flight to give a true picture but it is fixed and immobile.) The miniature airplane appears to tilt to the right for a right bank and to the left for a left bank, giving the pilot a true picture of aircraft attitude. In addition, the bank index at the the top of the bank indicator dial indicates the amount of bank on the bank scale.

Performance During Acrobatics

The horizon indicator is designed to portray the pitch attitude of the aircraft to 27° in both dive and climb, and aircraft roll to 90° in right and left bank. At the pitch limits, the horizon bar reaches the extremes of visibility through the face glass, but the numerical pitch scale on the H-6A, which is visible through a window in the face, reads up to 80°. In addition, roll can be computed beyond the 90° limits.

All these limitations, however, apply only to the indices and not to the gyro itself, which is never upset during acrobatics, loops, or inverted flight. Roll may be computed through 360°, and in inverted flight the pitch and roll indications of the horizon bar are as accurate as they are in normal flight.

Whenever the airplane approaches a vertical climb or dive attitude as it does during a loop, a small stop on the gyro assembly comes in contact with an adjustable slot secured to the gimbal.

The effect of this is to precess or rotate the gyro and gimbal assembly a controlled extent of 180° in roll. This action is momentary and is nothing like the "tumbling" or upsetting of the gyro. After the completion of this precession, the gyro is completely operative. Any displacement that may have occurred is corrected almost immediately by the erection mechanism.

The pitch indications of the instrument are identical for erect and for inverted flight, except that in the inverted attitude the bank index is 180° opposite the vertical index. *If the bank index is 180° opposite the vertical index, you know that you are in inverted flight and you must act accordingly.*

Performance During Turns

A temporary displacement of the gyro from its normal position during turns is commonly referred to as "turn error". The amount of displacement depends on the rate of turn, airspeed, erection rate, gyro inclination, and gyro pendulosity. In the H-6 and H-6A horizon indicators, the erection rate, gyro inclination, and gyro pendulosity are so low that the turn error is either negligible or very slight through a wide range of airspeeds and bank angles on either side of the design airspeed of 550 mph and bank angle of 50°. (At the design airspeed and bank angle, the turn error is zero.) After the airplane has returned to level flight, the gyro is automatically returned to its normal position by the erection mechanism.

Operating Limits

The following are the operating limits for the Model H-6 and Model H-6A horizon indicators as measured from level flight conditions:

Trim Adjustment (miniature airplane):
- Trim indicator adjustable from horizontal indices from +6 −20°.

Indicating Limits:
- Horizon bar travel ..... ±27°
- Pitch scale travel (H-6A only) ..... 5 to 80°

Operating Range:
- Full maneuverability in both roll and pitch:
  - Roll freedom ..... 360°
  - Pitch freedom—stops at ..... ± 84°

Mechanical Caging Time:
- Within 3° in roll and pitch—approximately 10 seconds.

Settling Time After Mechanical Caging:
- Normal ground or flying attitude (maximum):
  - Model H-6 ..... 3 Minutes
  - Model H-6A ..... 2 Minutes

Settling Accuracy:
- Pitch ..... ±1°
- Roll ..... ±1°

COMPASS-CONTROLLED HEADING INDICATORS

This section deals with some of the prinicpal types of remotely controlled magnetic heading indicators. The simple panel-type magnetic compass and the principles of magnetism are covered in the next chapter.

Before going into specific systems, you will find it helpful to look over the following rundown of the typical components of such a system.

The *compass transmitter* contains a compass, compensator, and a synchro. As the compass turns, the synchro follows its motion by induction. The compass float is in fluid and is free to tilt within certain limits. There is a flux valve arrangement directly below the direction-seeking unit, and the magnetic lines of flux cutting through a conductor induce an electric voltage in it. This voltage is transmitted through an amplifier to the indicator. Generally this unit is not gyro-stabilize except in the Flux Gate type (a

Figure 4-9. Moving-pointer, settable-pointer compass indicator

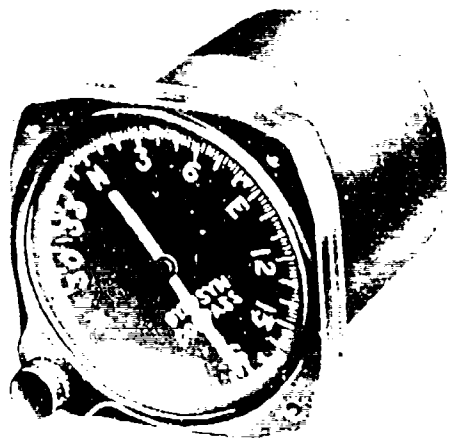


Figure 4–10. Moving-dial compass indicator

Figure 4–11. Moving-pointer, settable-dial compass indicator

Pioneer trade-name). The transmitter unit also includes a compensation device similar to that found in the panel compass.

The *amplifier* increases and interprets the signals from the transmitter and sends them on to the indicator. This unit also serves as a power supply and electric junction box for the system.

The *indicators* in remote compass installations may be master direction indicators (MDI) or repeater indicators. The master indicator sometimes may provide a control, compensation, or adjustment, but usually is designated as master only if it has a gyro or other mechanism within its case. The repeater dial may look exactly like the master dial, but it merely repeats the indications on the master indicator by use of a synchro drive. There are four common types of indicators. Sometimes the same compass model may be used with various different indicator dials in different aircraft.

1. Moving pointer, settable-pointer type (Fig. 4–9). This type, not now in common use, indicates direction on the long, single needle; the double needle is manually adjusted to a desired heading. Thus it is easy to make sure that you are flying on the desired heading. This type is commonly used in transport aircraft, for which heading is usually important.

2. Moving-dial type (Fig. 4-10). This type is easy to read because the heading you are flying is always at the top; however, with this type, it is more difficult to visualize your flight direction relative to the compass points. The reciprocal of your heading shows in the window.

3. Moving-pointer, settable-dial type (Fig. 4-11). This is a type now in wide use which tries to meet all the requirements—heading indicated at top (if desired), easy determination of 90° and 180° headings, and visual orientation as to north. You may either set north at the top index and read your heading from the needle, or you may set the desired heading at the top index and fly to hold the needle vertical. In this latter situation, you can also read off the 90° and 180° positions relative to the heading set on the top index.

4. Radio-magnetic type (Fig. 4-12). This is the latest indicator, the RMI or ID-250, which has resulted from the need to reduce the number of dials on the panel. In this instrument, the needles are not for indicating magnetic heading but for direction finding or magnetic bearing indicating systems. (See Chapter 7.) The magnetic heading is shown under the top index pip, and smaller pips mark the 90° and 180° points. In other words, so far as the compass heading indicator is concerned, this type is used in the same way as the moving dial type (Fig. 4-10). The big difference is the addition of radio bearing data. In this connection, it is important for you to know that the RMI needles may be connected to different equipment in different aircraft, and there is no real uniformity as to whether the

Figure 4–12. Radio-magnetic indicator

single or double needle is used for any particular system. Either needle may be connected to the ARN-7, ARN-6 (MF/DF), ARN-25 (UHF/DF), ARN-14 (VOR), ARN-21 (Tacan), and others.

The point is that the indicator does not identify the compass. Even the words on the dial are not conclusive. For example, though one dial may say "Slaved Gyro Magnetic Compass" and another, "Gyrosyn Compass," the term "Gyrosyn" is merely a trade-name for the Sperry brand of slaved gyro magnetic compass. As a matter of fact, the two dials thus labelled might be part of the same or different systems, though both would be used in slaved gyro systems, as discussed later.

The *flux valve* is a sensing device which determines direction from the horizontal component of the earth's magnetic field; that is, from the earth's magnetic lines of flux. This type of compass is less affected by dip than the ordinary magnetic compass. Incidentally, the term "gyro flux gate" is a trade-name for a gyro-stabilized induction coil magnetic compass system in which magnetic induction rather than electrical induction is used to transmit the direction sensed by the compass unit.

The terms *slaved gyro magnetic compass*, *slaved heading indicator*, *compass controlled direction gyro*, and other such titles describe a general type of compass system used as the basis for most remote-indicating compass systems today. Briefly and simply, the system centers about an electric gyro heading indicator which is mechanically set and precessed on the basis of magnetic heading signals from a remotely located compass transmitter. A "free gyro" switch permits disconnecting the gyro from the magnetic control in areas of magnetic disturbance, such as polar regions and carrier decks.

Compass errors are still present, though to a limited extent, in the new systems. All the compass systems discussed here eliminate deviation or reduce it to a constant. None of the present systems, however, eliminate variation. Dip, or the vertical element of the earth's magnetic force, continues to cause trouble, but only in the higher latitudes; in the case of the gyro flux gate compass, the problem of dip is eliminated even there. Turning errors and temporary inaccuracies caused by tilting in any direction over about 30° still occur in most of these compass systems. Here, again, the gyro flux gate system is the exception; it allows 65° limits of pitch and bank, but if the limits are exceeded it is damaged unless caged. Some early models of gyro flux gate compass permitted manual adjustment for variation so that they read true heading if desired, but this feature is no longer incorporated in compasses now in use.

With this information in mind, you can now consider the main compass systems which are in general use in naval aircraft. The early gyromagnetic (slaved gyro) compass systems such as the G-2, P-2, J-1, J-2, or C-2 or -3 (commercial designations) are not considered here because they are going out of use. The discussion will center, rather, on the gyro flux gate type (briefly), the S-2 slaved gyro magnetic compass system, and the MA-1 compass-controlled directional-gyro system (with mention of the N-1 magnetic slaved directional gyro stabilized compass system).

GYRO FLUX GATE COMPASS SYSTEM

The gyro flux gate system is bulky and is generally found only in large aircraft. It eliminates turning error, dip at higher latitudes, acceleration errors (including pitching and rolling errors), and

Figure 4–13. Gyro flux gate transmitter, usually installed in the wing of the airplane

deviation; it will operate properly through maneuvers up to 65° of pitch or bank. Because it eliminates dip, it has become a necessity for polar flights, though there is no magnetic compass which operates properly near the magnetic poles themselves.

The gyro flux gate compass system is composed of these main parts—transmitter, master indicator, amplifier, repeater indicator, inverter, and caging switch.

The transmitter (Fig. 4–13) contains the compass element, or flux gate, and is placed in the aircraft where it will be least affected by outside magnetic fields, usually in the wing or tail. The flux gage is the compas element. It is an electrical device in which certain voltages are induced by the earth's magnetic field; the particular voltage induced depends on the position of the flux gate in respect to that field.

The transmitter also contains an electric, universally mounted gyro with a normal operating speed of around 10,500 rpm. The flux gate is attached to the bottom of the gyro housing and consequently is always horizontal to the earth's surface, regardless of the attitude of the aircraft

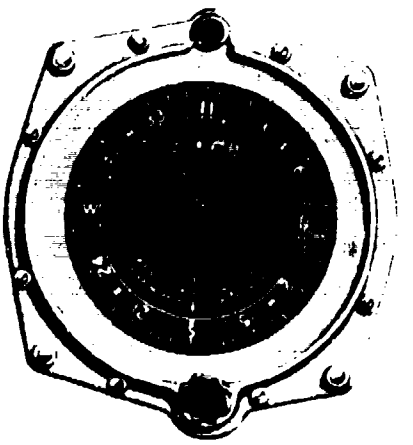


Figure 4–14. Gyro flux gate compass master indicator

or change of airspeed. Thus, magnetic dip error never occurs in a gyro flux gate compass. The limits of operation of the gyro are 65° of pitch and bank.

An erection mechanism incorporated on the gyro housing always keeps the axis of rotation of the gyro in the vertical plane. The caging mechanism is used for the same purpose as the caging mechanism on the horizon indicator—to erect the gyro quickly or to prevent damage when the limits of operation are being exceeded. It is remotely controlled by a caging switch located near the master indicator.

The master indicator (Fig. 4–14) has a large azimuth dial. It is generally located in the navigator's compartment and presents the indications which are received from the transmitter. At the bottom of the indicator face, there is a VARIATION knob by which the variation for any particular area can be set into the indicator so that the indicator will read true headings at all times. Corrections for as much as 56° E or W variation can be applied. With the variation dial set on 0°, the indicator shows the normal magnetic headings. Deviation can also be compensated for at the master indicator. This compensation can be made at 24 points on the indicator face (every 15°) and eliminates the need for a compass correction card.

The amplifier is used to step up the signal received by the flux gate so that it may be sent to the indicator. A gain-control is provided to increase compass sensitivity in extreme latitudes. There are five settings available; No. 3 is the position for normal use.

The repeater indicators duplicate the readings on the master indicator at places other than the navigator's compartment. As many as six repeaters may be connected to one master indicator, and the readings on each of the repeaters incorporate the corrections for deviation and variations made at the master indicator. A course-setting pointer is provided on the repeater dial. The power for the compass system comes from the inverter which supplies 400-cycle alternating current at 115 volts.

The fact that the gyro assembly is inaccessible to the operator makes it necessary to have a remote caging switch to operate the caging mechanism. This switch may be any one of three types: push-button, toggle, or manual crank. The first two types actuate an electric motor which turns the caging arm by means of a flexible drive shaft. The third type, which is found only on older installations, rotates the caging arm mechanically. With the push-button switch, the gyro cannot be left in the caged position. On the toggle-switch type, the gyro can be left caged; in that position, however, the compass indications are subject to dip error.

S-2 SLAVED GYRO MAGNETIC COMPASS SYSTEM

The slaved gyro magnetic compass provides a visual indication of the magnetic heading of an aircraft on an indicator whose operation is governed by a gyro. The spin axis of the gyro is stabilized in a horizontal plane by means of a leveling device, and its orientation in azimuth is slaved to the earth's magnetic meridian by a "direction-sensing" component. It is, in effect, a gyro stabilized compass.

The flux value (Fig. 4–15) is the "direction sensing" component of the system. Because it is suspended in a damping fluid, the "direction-sensing" component, or fundamental unit, is maintained on the average in the horizontal plane, and therefore detects the direction of the horizontal component of the earth's magnetic field. This horizontal component of the earth's magnetic field which is sensed by the flux valve is the basic heading reference. The sensing unit remains pen-

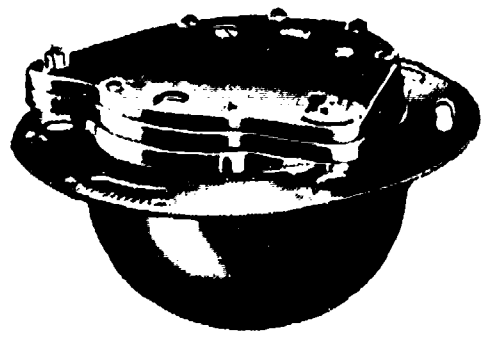


Figure 4–15. Flux valve, S–2 system

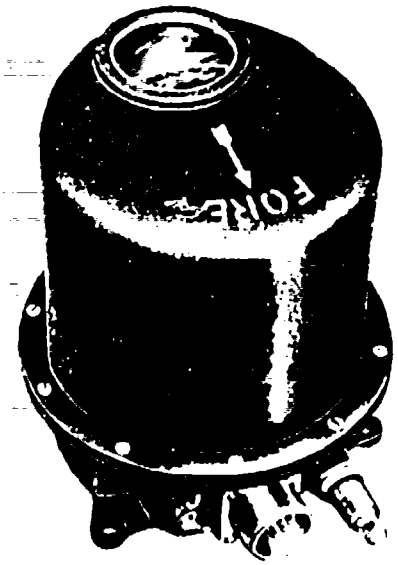


Figure 4–16. Directional gyro control, S–2 system

dulous through approximately 30°. When this limit is exceeded, the sensitive element also picks up part of the vertical component of the earth's magnetic field, which gives a false alarm.

The sensing unit transmits the direction information electrically to the flux valve synchro stator in the directional gyro control. If the gyro spin axis is misaligned with the axis of the flux valve, it is precessed by means of a torque motor until it is aligned with the direction that the flux valve detects, thus slaving the gyro to the earth's magnetic meridian. A compensator eliminates errors caused by the parts of the aircraft and its electrical apparatus.

The directional gyro control (Fig. 4–16) houses the gyro which is controlled in azimuth by the flux valve. In addition, the gyro spin axis is controlled in a horizontal plane by a liquid level switch which operates a second torque motor to precess the gyro if it tilts. Thus, the gyro is slaved to the earth's magnetic meridian by the flux valve, and its spin axis is maintained parallel to the earth's surface by the liquid leveling device. As the aircraft turns, the case of the directional gyro control rotates in azimuth around the directionally stabilized gyro. This rotation angularly displaces the stator of the heading synchro (within the directional gyro control) relative to its rotor. In this way, the sensed indication is transmitted and made visible on a remotely located indicator.

The repeater indicator or other heading indicating instrument shows the heading sensed by the flux valve. It includes a synchro which responds to the electrical influence of the heading synchro in the directional gyro control and has a pointer or card attached to its rotor. Thus, as the synchro rotor in the repeater indicator electrically follows the rotor of the heading synchro, the pointer or card moves to indicate the turn angle and the magnetic heading of the aircraft in degrees.

The slaved gyro magnetic compass amplifier (Fig. 4–17) performs a dual function. First, it controls a torque motor which precesses the gyro to align it with the sensed direction, or the earth's magnetic meridian. Secondly, to accelerate the gyro erection and its orientation in azimuth, the amplifier supplies above-normal operating power

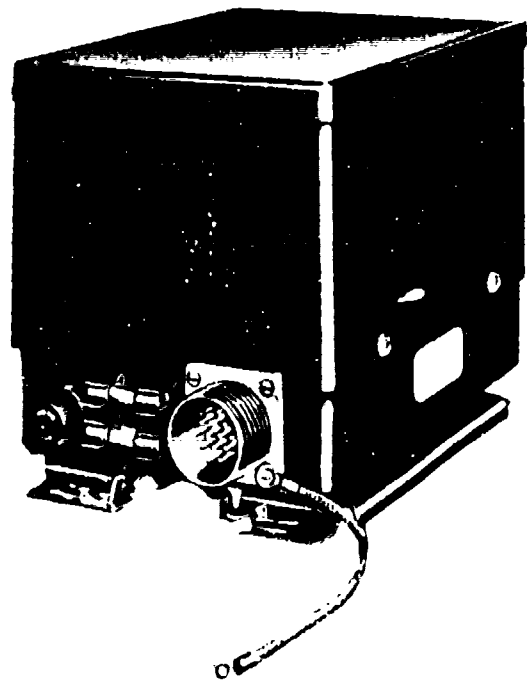


Figure 4–17. Slaved gyro magnetic compass amplifier, S–2 system

for approximately three minutes to the two torque motors in the directional gyro control. It is advisable, therefore, not to take off until about three minutes after the aircraft power is turned on. Since the system will not go through its fast slaving cycle until the DC power is supplied, it is necessary for AC and DC power to be supplied simultaneously for proper sequence of operation. Interruption of the aircraft's power supply in excess of one minute causes the fast slaving cycle to be repeated.

By using a low precession rate, northerly turning error and turn error are minimized. The gyro has a low random drift, which is corrected when it is slaved to the magnetic meridian. However, when the gyro is used as a free gyro, occasional corrections are necessary to correct for this drift.

The system is tested for accuracy under magnetic conditions which simulate those of the earth's surface and it gives correct headings under slaved gyro magnetic operation over all portions of the earth except where the magnetic lines of force dip at an angle of 84° or more. For navigation in these areas—the polar areas—the system is used as a free gyro by placing the SLAVED GYRO-FREE GYRO switch on the compass controller in the FREE GYRO position. This prevents it from being slaved to an unreliable reference—the vertical magnetic lines of force.

The compass controller (Fig. 4–18) is used to select free or slaved gyro operation, to set in a selected heading manually on the heading indicating instrument, and to monitor synchronization with the flux valve by means of a sync meter. The sync meter pointer usually oscillates in flight because the pendulous element in the flux valve swings back and forth. The compass controller is designed for operation by the pilot's right hand.

When more than three repeater indicators are used in this system, a compass repeater amplifier is required. This amplifier can serve as many as six repeater indicators. Thus, it is possible to use a total of nine repeaters in a single installation, three without and six with the amplifier.

A transmission error compensator is used where accuracies greater than one-half of one degree are required. It is used to compensate electrically for the double-cycle transmission error introduced into the system.

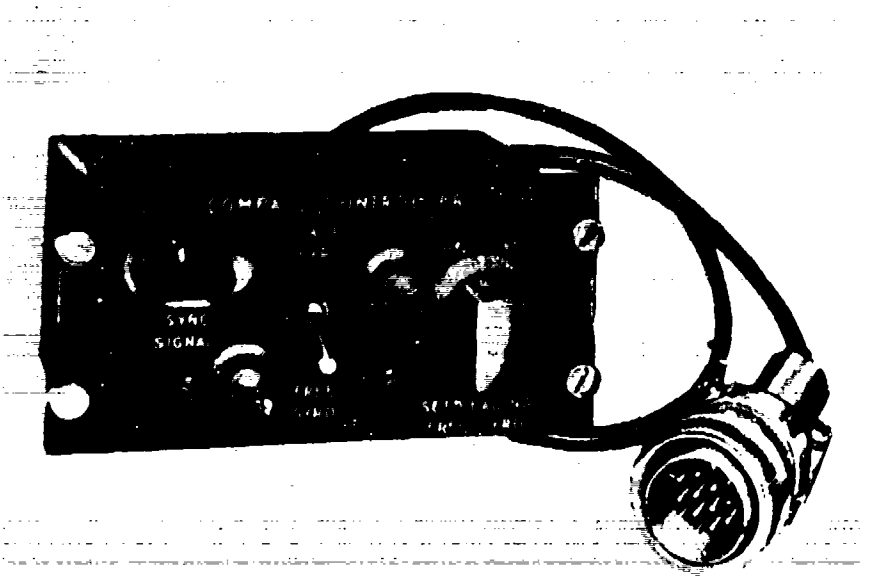


Figure 4–18. Compass controller, S–2 system

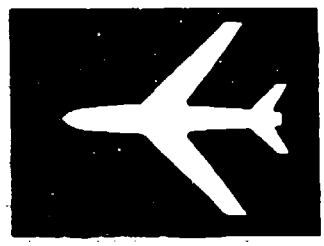
Operating the S-2 System

For proper sequence of operation, both the AC and DC power supply must be turned ON simultaneously on the S-2 system. Auxiliary switches, if used, should also be turned ON to start the operation.

For automatic setting of the instrument, put the SLAVED GYRO-FREE GYRO switch on the controller in the SLAVED GYRO position. In this position, the system indicator is that of a stable magnetic compass. To orient the gyro quickly when the power supply is first turned on, the amplifier supplies high leveling and slaving voltages for two to three minutes. When the gyro and the flux valve are misaligned by approximately seven degrees, the slaving rate is approximately 90° per minute. The normal slaving rate which follows this fast cycle is from three to six degrees per minute. This slaving rate for both fast and normal conditions decreases as the amount of misalignment decreases until a synchronized null is reached. The sync meter should be regularly monitored to insure proper synchronization.

When the SLAVED GYRO-FREE GYRO switch is in the SLAVED GYRO position, rotating the SET HEADING-FREE GYRO switch has no effect on the system. Therefore, if you want to set the instrument manually, put the SLAVED GYRO-FREE GYRO switch on the controller in the FREE GYRO position. If the sync meter pointer indicates to the right of the index line, turn the SET HEADING-FREE GYRO switch to the DEC (Decrease) position. The dial of the directional-gyro-control and the repeater pointer or card will rotate in a numerically decreasing direction at approximately 90° per minute, and the meter pointer will eventually move to the left. If the meter pointer indicates to the left of the index line, turn the SET HEADING-FREE GYRO switch to the INC (Increase) position. The dial of the directional gyro control and the repeater pointer or card will rotate in a numerically increasing direction at approximately 90° per minute, and the meter pointer will eventually move to the right. When the meter pointer is centered on the index line, the system is then synchronized within ±1 degree. If you now want to return to automatic operation put the SLAVED GYRO-FREE GYRO switch in SLAVED GYRO position.

With the SLAVED GYRO-FREE GYRO switch in FREE GYRO position, the system operates as a directional gyro. You can set the heading indicating instrument to the desired reference heading by means of the SET HEADING-FREE GYRO switch. In directional gyro operation, the system is subject to the same drift limitations as other directional gyro indicators. At periodic intervals make drift corrections by means of the SET HEADING-FREE GYRO switch. The sync meter is not reliable in areas near the magnetic poles, but when you return to slaved gyro operation in areas of sufficient magnetic intensity, you can synchronize the system explained before.



Operating Limits of S-2 System

Flux Valve. The fundamental unit of the flux valve remains pendulous through 30° in both path and roll. When these limits are exceeded or a turn is being executed, the instrument picks up the vertical component of the earth's field which distorts its sensing and causes false signals. In temperate latitudes and for turns not exceeding three minutes' duration, this error will not exceed ten degrees. Restoring the aircraft to an attitude within these limits again renders the fundamental unit pendulous, and it automatically resumes correct sensing.

Directional Gyro Control. The gyro in the directional gyro control is free to operate within 80° from level flight in dive and climb and in right and left bank. At the limits, it strikes mechanical stops which render the indications on the directional gyro control and the repeater indicators inaccurate. After return to level flight, reset the instrument as indicated above.

Drift Rate in Free Gyro. The gyro is calibrated for zero drift at a latitude of approximately 42° N. Therefore, when this compass system is being used as a directional gyro at any other latitude, corrections should be made for earth's drift rate. The random drift of the gyro, after it has been operating for at least two hours, will not exceed ±8° for a one-hour period at approximately 24° C.

MA-1 COMPASS SYSTEM

The MA-1 compass-controlled directional-gyro system is now installed in most new naval aircraft. It is a slaved gyro type of system, also known as the J-4. Various manufacturers who make this type of compass system call it by their own names, too. Sperry calls this a "Gyrosyn" (the same name Sperry used for earlier slaved gyro compass systems). Eclipse-Pioneer calls its version the "Polar" compass system; Lear names it "Precise"; and Kearfott calls it the "S4A." All are basically the same, though not identical.

The principal new feature of this system is the latitude compensation, which reduces free gyro precession from the normal 15° every hour to less than 4° per hour. Kearfott, using some units made by other companies, makes a similar system called the "N-1" which reduces this actual free gyro drift to only one degree per hour. Both the MA-1 and the N-1 feed into the RMI type of indicator in the usual installation. (See Figure 4-12.)

The compass-controlled directional-gyro system provides an accurate stabilized indication of aircraft heading through 360° in azimuth. It has electrical outputs for operating a radio-magnetic indicator (RMI), omnirange, and autopilot. The system may be operated either as a compass-controlled directional-gyro system or as a low-drift free-gyro system.

The components of the system include a directional gyro, a controller, an amplifier, and a compass transmitter. (See Figure 4-19.) The indication of heading is displayed on a radio-magnetic indicator, omnirange, or whatever other indicator is linked to the system. The directional gyro (Type KD-3) is a remote, hermetically sealed gyro that supplies azimuth information to the system in the form of a synchro output. The controller (Type KE-7) contains all operating controls for the system. These controls include a knob for setting the heading, a mode-of-operation switch for free-gyro or compass-slaved operation, and a knob for setting latitude correction during free-gyro operation. The controller also provides indications of system synchronization or power failure. The amplifier (Type KE-8) receives signals from the compass transmitter and the directional gyro. It provides electrical outputs for gyro leveling and compass slaving as well as an output of directional information. The amplifier also serves as a junction box and power supply for the system. The transmitter is the same type as used in earlier systems, such as the S-2.

Compass-Controlled Gyro Operation

A gyro is inherently very stable for short periods of time, but is subject to long-time drift. A magnetic compass, on the other hand, wanders continuously about the correct heading because of acceleration of the aircraft and the like, but its average indication (except over the magnetic polar areas) is very accurate. The compass-controlled directional-gyro system combines a magnetic-compass transmitter and a directional gyro to secure the advantages of both. The long-period accuracy of the average compass heading is retained as is the short-period accuracy of the gyro, while the short-period oscillation of the compass and the long-time drift of the gyro are eliminated.

Here is how it is done. An error signal corresponding to the difference between the compass heading and the gyro heading is amplified and applied to a torque motor on the gyro. The torque motor precesses the gyro in the direction that reduces the difference between gyro and compass headings. Since the precession rate of the gyro is only 1½ degrees per minute, the gyro responds to the average heading of the compass transmitter and is insensitive to short-period oscillations of the compass. Because the heading of the gyro is constantly being controlled by a signal from the compass transmitter, drift of the gyro is eliminated, and an accurate, stabilized indication of the heading of the aircraft is obtained.

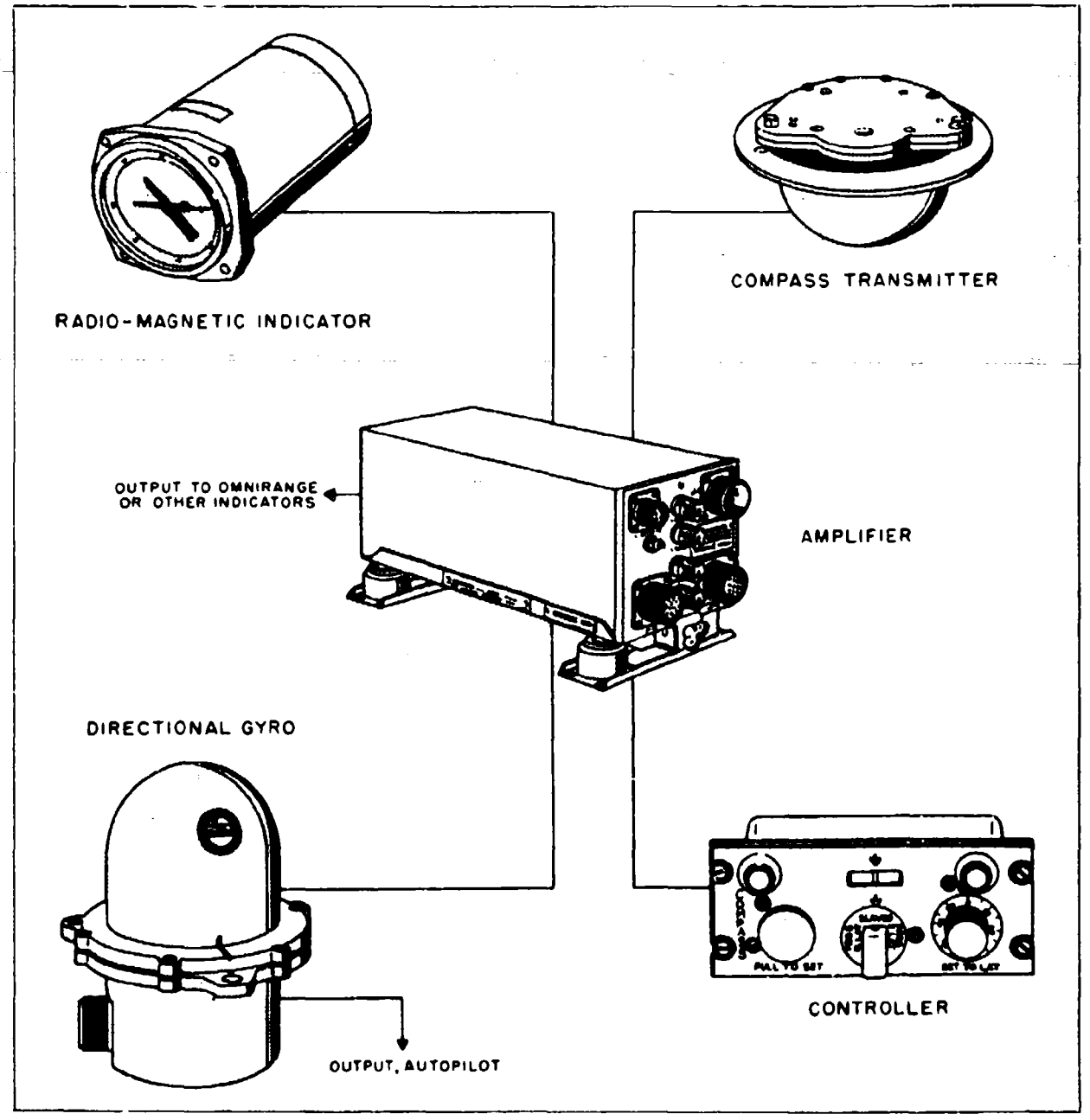


Figure 4–19. Compass-controlled directional-gyro system, type MA–1

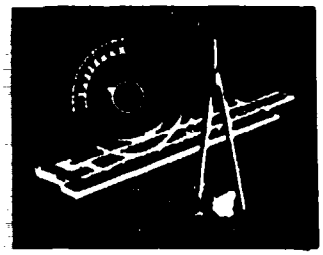
Free-Gyro Operation With Latitude Compensation

When the system is operated as a free gyro, the compass transmitter is disconnected, and the gyro is subject to apparent drift due to the rotation of the earth. To overcome this apparent drift, an adjustable direct current is used to precess the gyro. The magnitude of this current is such that the precession rate is equal and opposite to the apparent drift rate of the gyro at the latitude in which the aircraft is flying. Thus,

system operation is subject only to an actual gyro drift rate of less than four degrees per hour.

Autopilot Operation

The compass-controlled directional-gyro system can be used to provide stabilized heading information for autopilot operation. The autopilot signal, which is in the form of a synchro output, can be taken from either the servoed output synchro of the system or directly from the optional autopilot output of the gyro.



Type KE-7 Controller

The controller contains all the controls necessary for the operation of the system and the indicators which show system synchronization and power failure.

The heading-set knob, labeled PULL TO SET, is used to set the heading of the system. It rotates a synchro differential which is electrically connected between the output synchro of the gyro and a synchro control transformer in the amplifier. This arrangement makes it possible to change the heading of the servoed output synchro of the system without actually moving the gyro. An autopilot switch connected to the heading-set knob operates when the knob is pulled out. This switch can be used to cut out the autopilot when the system heading is being changed.

The mode-of-operation selector switch, labeled N. LAT-SLAVED-S. LAT, selects either compass-controlled or free-gyro operation. There are two switch positions for free-gyro operation: one for northern latitudes, and one for southern latitudes.

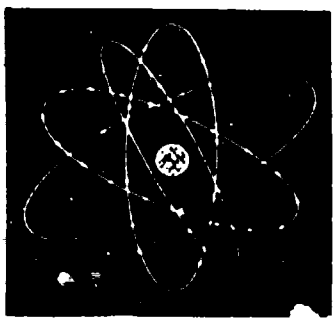
The latitude compensation control, labeled SET TO LAT, controls compensation for apparent drift due to the earth's rotation. This control, which is effective only when the system is set for free-gyro operation, allows a direct current to flow in the coils of the slaving torque motor of the gyro. This current precesses the gyro at a rate equal and opposite to the apparent drift due to the earth's rotation.

The synchronization indicator shows when the system is synchronized. This indicator incorporates a white pointer that is visible through the window in the front panel of the controller. When the pointer is in line with the white arrow on the panel, the system is in synchronization—that is, the angular position of the servoed shaft in the amplifier corresponds to the direction indicated by the compass. The indicator is actually a zero-center milliammeter that measures the direct current in the coils of the slaving torque motor of the gyro. It is inoperative when the system is set for free-gyro operation.

The power failure indicator shows when power to the system is turned off or has failed. This indicator incorporates a red flag that is visible through the window in the front panel of the controller whenever either the AC or DC power supply is switched off or fails.

Operating the MA-1 Compass System

The Type MA-1 compass-controlled directional-gyro system is designed for either compass-controlled or free-gyro operation. There is no ON-OFF switch in the system. Power is applied when the aircraft electrical system is turned on. After it is turned on, wait three minutes to allow time for the gyro to come up to speed before setting the heading. A red flag is visible through the glass window at the front of the controller until both the AC and DC power have been applied to the system.



For compass-controlled operation, set the mode-of-operation switch, labeled N. LAT-SLAVED-S. LAT, to the SLAVED position. Then pull out the heading-set knob (labeled PULL TO SET) and turn it until the pointer of the synchronization indicator is in line with, or close to, the white arrow on the panel. This indicates that the system is in synchronization. Remember, though, that there are two different settings of the heading-set knob which will result in an indication of synchronization. One of these indications is erroneous. You can recognize the proper setting by the fact that, when you turn the heading-set knob clockwise, the pointer of the synchronization indicator approaches the white arrow from left to right; when you turn the knob counterclockwise, the pointer approaches the arrow from right to left. In short, on the correct setting, the pointer should approach the white arrow by motion in the same direction as that in which the knob is being turned.

The latitude compensation knob marked SET TO LAT is inoperative when the system is set for compass-controlled operation. In normal operation, the pointer of the synchronization indicator wanders about the correct indication but does not remain off to one side for any appreciable period of time. The corrected heading of the aircraft is indicated on the radio magnetic indicator or omnirange, whichever is used as indicator for the system.

For free-gyro operation, turn the mode-of-operation selector switch, labelled N. LAT-SLAVED-S. LAT. to either the N. LAT or S. LAT position, depending on whether the aircraft is flying in northern or southern latitudes. Turn the latitude compensation control, labelled SET TO LAT, to the latitude in which the aircraft is flying. Then pull out the heading-set knob and set the system to the desired heading as read on the system indicator. As the latitude of flight changes, periodically set the latitude-compensation knob to the new latitude. When you have set the system for free-gyro operation, the synchronization indicator becomes no longer operative, so that the pointer remains at, or very close to, the white arrow.

CHAPTER 5

MISCELLANEOUS INSTRUMENTS

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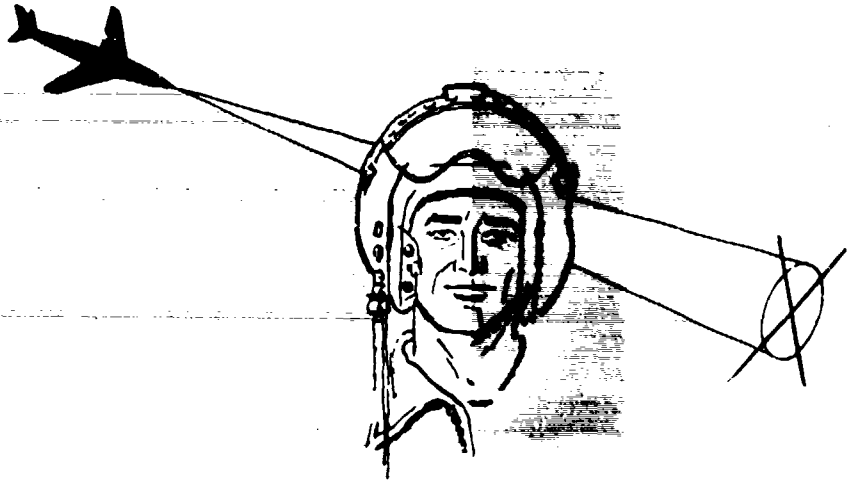


CHAPTER 5

MISCELLANEOUS INSTRUMENTS

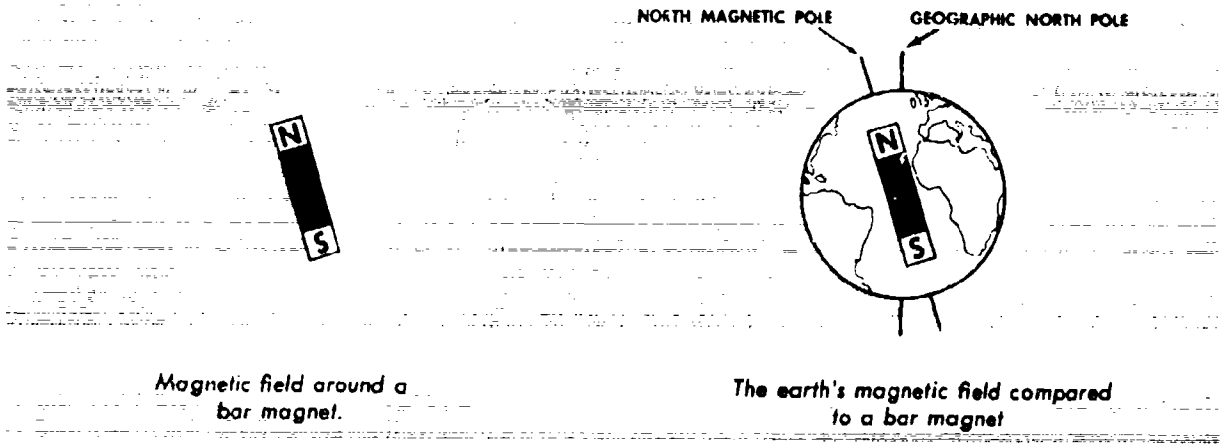
THIS chapter discusses two instruments which have a more-or-less auxiliary role in instrument flight, but which are nevertheless important. These are the ordinary panel magnetic compass and the radar altimeter.

MAGNETISM AND MAGNETIC FIELDS

A simple bar magnet has two centers of magnetism which are called poles. Lines of force flow out from each pole in all directions, eventually bending around and returning to the other pole. The area through which these lines of force flow is called the field of the magnet. The poles usually are designated *north* and *south*. If you place two bar magnets near each other, the north pole of one will attract the south pole of the other.

There is a magnetic field surrounding the earth, too. It acts very much as though there were a huge bar magnet running along the axis of the earth with its ends several hundred miles below the surface. However, the magnetic and geographic poles of the earth do not coincide. The north magnetic pole is located in Baffinland at 73° N., 96° W., and the south magnetic pole at 72° S., 155° E.

The lines of force in the earth's magnetic field are parallel to the earth's surface at the magnetic equator but point increasingly downward when moving toward the magnetic poles themselves. Speaking technically, the lines of force have a



Magnetic field around a bar magnet.

The earth's magnetic field compared to a bar magnet

Figure 5–1. Magnetic fields

vertical component which is zero at the equator but builds up to 100 percent of the total force at the poles. If a magnetic needle is held along these lines of force, this vertical component causes a dip of the needle, a deflection downward. It is this deflection which causes some of the larger compass errors.

PANEL-TYPE MAGNETIC COMPASS

The panel-type magnetic compass is simple in construction. It contains two steel magnetized needles mounted on a float around which is mounted the compass card. The needles are parallel, with their north-seeking ends pointed in the same direction. The compass card has letters for cardinal headings, and number every 30° in between. The last zero of the degree indication is omitted. Between these numbers the card is graduated for each 5°.

The float assembly, which consists of the magnetized needles, compass card, and float is housed in a bowl filled with acid-free white kerosene. This liquid dampens out excessive oscillations of the compass card, and its buoyancy relieves part of the weight of the float from the bearings. The liquid also provides lubrication and prevents rust within the instrument case.

On the bottom of the bowl is a pedestal on which the float rests. Jewel bearings are used to mount the float assembly on top of the pedestal. At the rear of the compass bowl there is a diaphragm to allow for any expansion or contraction of the liquid and prevent the formation of bubbles or possible bursting of the case.

The glass face of the compass is an integral part of the bowl and has mounted behind it a lubber line, or reference line, by which compass indicators are read. If the face is broken, the fluid is lost and the compass becomes inoperative. On top of the compass is a compensating device consisting of several small bar magnets which are adjustable by two set-screws labeled N-S for north-south and E-W for east-west.

Compass Errors

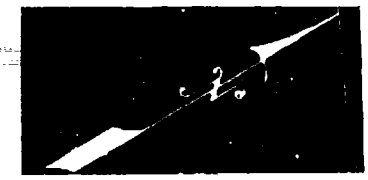
Variation. In navigation, course computations on aeronautical charts are based on the relation of the course to the true geographic North Pole. The magnetic compass, however, points to magnetic north—not to the true North Pole. The angular difference between true and magnetic north is known as variation. It is different for different spots on the earth. Lines of equal magnetic variation are called isogonic lines and are plotted on aeronautical charts with the amounts shown in degrees of variation east or west. A line connecting the 0° points of variation is termed the agonic line. These lines are replotted periodically

to take care of any change which may occur as a result of the shifting of the poles or any changes in local magnetic deposits.

Deviation. Electrical equipment mounted in the aircraft and accessories made of iron or steel, such as guns and armor plate, may affect the reading of the magnetic compass. The difference between the indications of a compass on a particular aircraft and the indications of an unaffected compass at the same point on the earth's surface is called deviation. To counteract the magnetic effect of the aircraft equipment and reduce this deviation, compensating magnets on the compass are adjusted as follows:

On a surveyed compass rose, the aircraft is pointed toward magnetic north and compensated with the N-S screw until the compass reads correctly. This is repeated on a heading of east, and the error is adjusted by use of the E-W screw. On headings of south and west, half the error is taken out by adjusting the compensating screws. Then the compass is swung through 360°, and the errors at each 30° mark are noted. These remaining errors are entered on the compass deviation card in the cockpit.

Deviation may change for each piece of electrical equipment turned on. In addition, the magnetism of the aircraft itself may change as a result of severe jolts. Therefore, it is necessary to swing the compass periodically and prepare a new



correction card. Deviation also changes with latitude, so the compass should be swung on arrival at a new base of materially different latitude from the old base.

Magnetic Dip. The tendency of the magnetic compass to point down as well as north in certain latitudes is known as magnetic dip. This is responsible for the northerly and southerly turning error as well as the acceleration and deceleration error on headings of east and west.

At the magnetic equator, the vertical component of the earth's magnetic field is zero and the magnetic compass is not disturbed by this factor. As you fly from the magnetic equator to the higher latitudes, the effect of the vertical component of the earth's magnetic field becomes pronounced.

This tendency is not noticed in straight-and-level, unaccelerated flight because the compass card is mounted in such a way that its center of gravity is below the pivot point and the card is well balanced in the fluid.

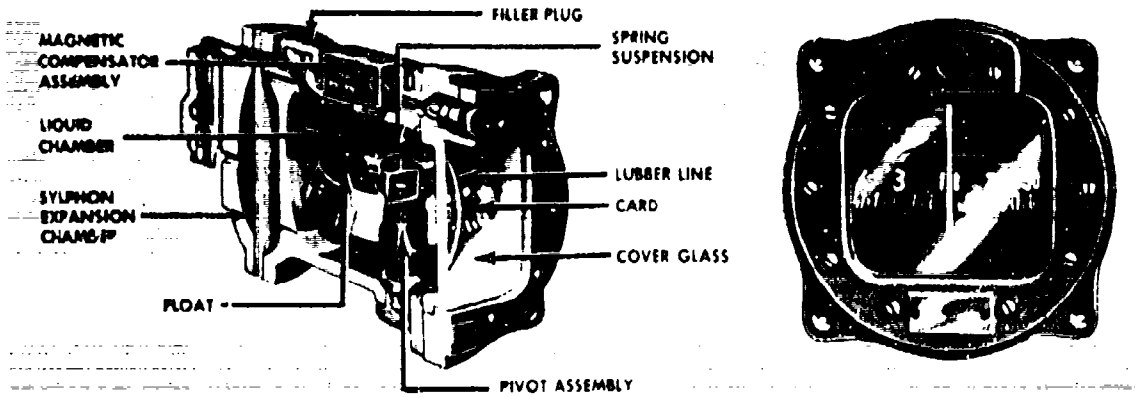
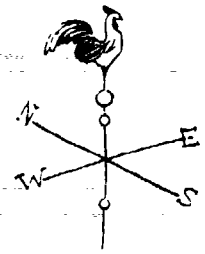


Figure 5–2. Cutaway and front view of panel-type magnetic compass

When the aircraft is banked, however, the compass card banks, too, as a result of the centrifugal force acting on it. While the compass card is in this banked attitude in northern latitudes, the vertical component of the earth's magnetic field causes the north-seeking ends of the compass to dip to the low side of the turn, giving the pilot an erroneous turn indication. This error called northerly turning error, is most apparent on headings of north and south. In a turn from a heading of north, the compass briefly gives an indication of a turn in the opposite direction; in a turn from a heading of south, it gives an indication of a turn in the proper direction but at a more rapid rate than is actually the case. In southern latitudes, all these errors are reversed. They are called southerly turning error.

Acceleration Error. Acceleration error is also due to the action of the vertical component of the earth's magnetic field. Because of its pendulous-type mounting, the compass card is tilted during changes of speed. This deflection of the



card from the horizontal results in an error which is most apparent on headings of east and west. When the aircraft is accelerating or climbing on either of these heading, the error is in the form of an indication of a turn to the north; when the aircraft is decelerating or descending the error is in the form of an indication of a turn to the south. Acceleration error is constantly present during climb and descent.

Oscillation Error. Oscillation error is due to the erratic swinging of the compass card, probably the result of rough air or rough pilot tech-

Figure 5-3. Adjusting the E-W screw

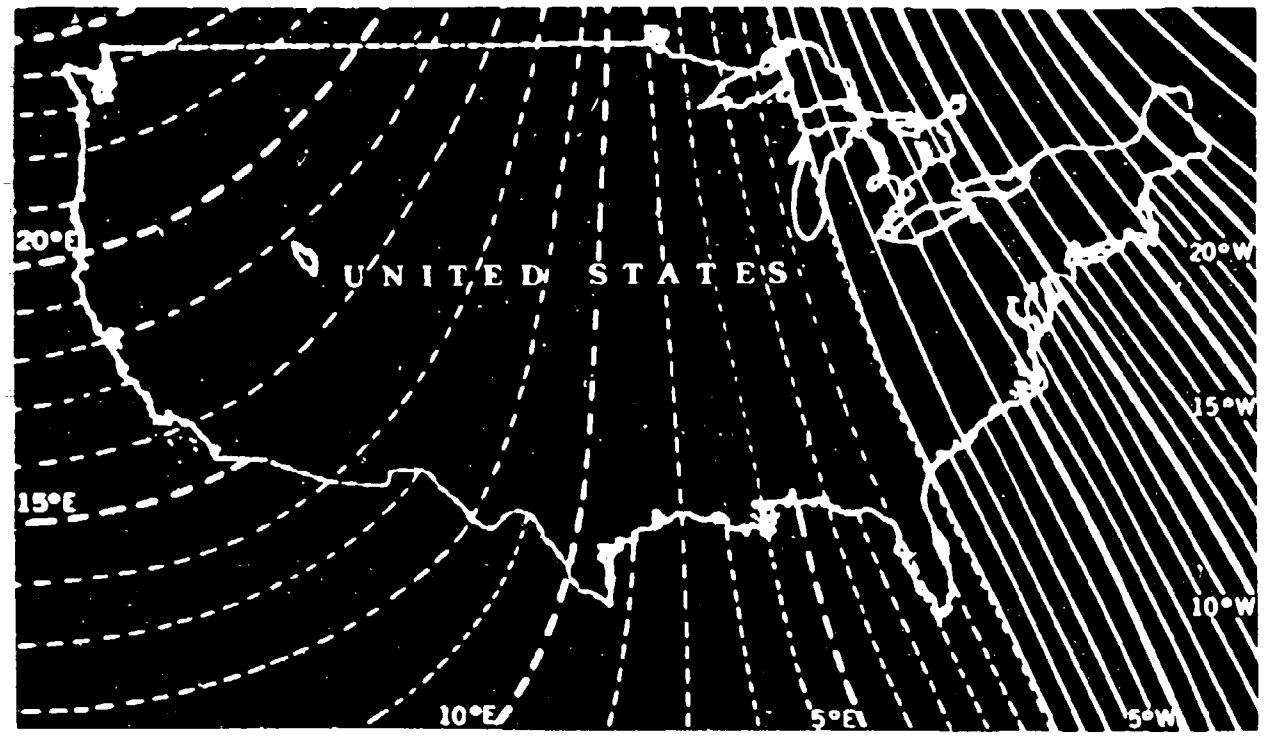


Figure 5–4. Magnetic variation in the United States

nique. The fluid serves to reduce this oscillation.

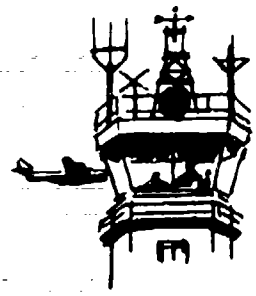
The magnetic compass, if you understand its errors and characteristics thoroughly, offers you a reliable means of determining the direction in which your aircraft is headed. When reading the compass to determine direction, be sure that the aircraft is as steady as possible, is not in a turn, and is flying at a constant airspeed.

Uses of the Panel Compass

In modern aircraft, the panel compass is principally a standby instrument. It is used for training or cross-check purposes and when an electrical or other failure renders the remote-indicating compass or slaved gyro heading indicator useless.

One of the principal reasons for its reduced importance is the large and variable amount of deviation present, especially near the pedestal. Electrical and electronic gear, armament, and nose landing gear create deviation errors which vary as that equipment is used, and the compass correction card cannot allow for all possible variations in the amount of deviation. The other compasses, discussed in Chapter 4, largely eliminate this problem.

The panel-type compass is so mounted that when the aircraft is in straight-and-level, unaccelerated flight, the vertical component of the earth's magnetic field has no effect on the compass indication. When the aircraft is banked, however, on or near a heading of north or south, or when it is accelerated or decelerated on or near east or west headings, the compass indications are erroneous. Because of this dip error, precision flying without the use of a suction driven or electrically driven heading indicator is difficult, especially in rough air. Another disadvantage is that the fluid in which the panel compass is immersed to dampen oscillations is subject to swirl which may



create noticeable error. Additionally, the comparatively small size of the compass bowl restricts the use of efficient dampening vanes.

In the extreme latitudes (near the North and South Poles) the panel-type magnetic compass is practically useless. The horizontal component of the earth's magnetic field is very weak, and the lines of flux cannot make the needles line up with them. Therefore compasses may spin erratically or indicate incorrectly in the Arctic and Antarctic regions.

RADAR ALTIMETERS

Basically, radar is an electronic means for measuring distance by determining how long it takes for a transmitted radio signal to be reflected back from an object to a receiver antenna. A radar set can thus be used as an altimeter to measure distance from the aircraft to the ground or water. Such an instrument provides absolute altitude.

There are two types of radar altimeters, each with a different purpose. These are the FM/CW (frequency-measuring, constant-wave) type and the pulse type.

FM/CW-Type Radar Altimeter

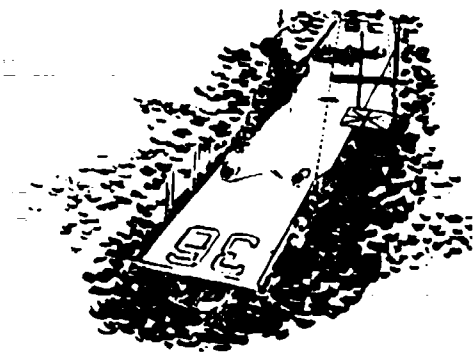
The transmitter of the FM/CW-type transmits a signal which varies in frequency at an extremely rapid and constant rate. The receiver picks up the reflected signal. A frequency-measuring device measures the difference in frequency between the transmitted signal and the reflected signal at any instant. This difference in frequency is used to actuate an electric meter calibrated in feet. The two FM/CW instruments now in use are the AN/APN-1 and the AN/APN-22 radar altimeters.

Accuracy of the APN-1 Radar Altimeter. All FM/CW radar altimeters work better over water than land because the water reflects radio signals better. (Arid soil is an especially poor reflector.) Over land, you have two problems. First, most terrain is not level and the needle fluctuates as the ground level and terrain reflectivity change. Secondly, no present model of radar altimeter can anticipate changes in terrain

ahead. They only show the altitude at the instant.

APN-1 Altimeter

The AN/APN-1 altimeter is limited to 4,000 feet absolute altitude above the terrain. It takes about two minutes for warm-up and may be set in high range or low range. In high range, the dial reads 400 to 4,000 feet, and in low range it reads 0 to 400 feet. When set to high range, readings in the range between 400 and 500 feet over water or 400 and 600 feet over land may be inaccurate, particularly on the high side. Therefore, when flying with the APN-1 within 600 feet of the terrain or water under conditions of poor visibility, keep the instrument set in low range. In this way, as soon as you get within 400 feet, it will begin to read accurately. It does no harm to fly with the radar altimeter running even at an altitude in excess of its limits. In fact, this may be advisable because the instrument is thus warmed-up and ready for use.



In low range, the altimeter reads 0 to 400 feet and is accurate to ±6 feet +5 percent of the absolute altitude above the terrain. This accuracy is based on extreme conditions of temperature, humidity, and battery voltage. During normal operating conditions, the probable error is ±6 feet +3 percent of the absolute altitude above water and ±6 feet +5 percent of absolute altitude above the *terrain*. At absolute altitudes below 20 feet the accuracy of the APN-1 varies with the antenna installation.

In high range, the altimeter reads 400 to 4,000 feet and is accurate to ±60 feet +5 percent of the absolute altitude above *water*. Over varying terrain, sand, fields, hills, and trees, the probable error may be ±60 feet +10 percent of the absolute altitude above the terrain; between altitudes of 400 to 1,000 feet this error may be as great as ±60 feet +20 percent of the absolute altitude above the terrain.

The APN-1 Altitude Limit Indicator. The altitude limit indicator is a red light mounted on the instrument panel; it is used in conjunction with the altitude limit switch. By means of the limit switch, you may preset the equipment to any one of 12 different altitudes between 50 and 300 feet on the low range, and to any one of 11 different altitudes between 750 and 3,000 feet on the high range. When setting the altitude limit switch on the high range, add a zero to the altitude limit switch readings. When you fly at or below the preset altitude, the red light on the instrument panel will be on. The light is equipped with an adjustable dimming cap by means of which the intensity of the light may be changed.

You can safely exceed the limiting altitude on the APN-1 without damage. The needle will read up to at least 400 feet in low range and 4,000 feet in high range. When these altitudes are exceeded, the needle continues to indicate the altitude until a point is reached where the altitude greatly exceeds the maximum dial range. At this point, a "drop-out" level is reached and the needle drops to some low value. This is normal and must not be interpreted as a malfunction.

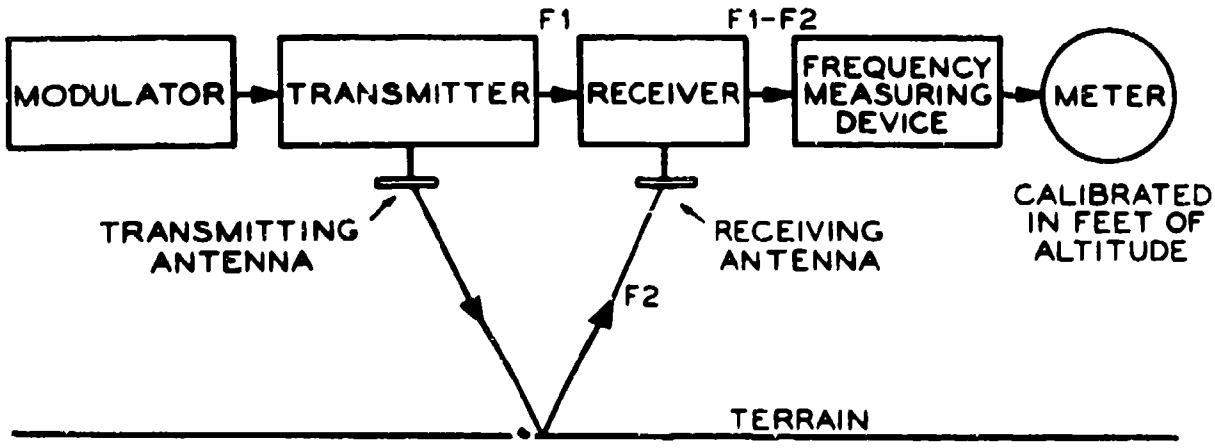


Figure 5-5. APN-1 radar altimeter sequence

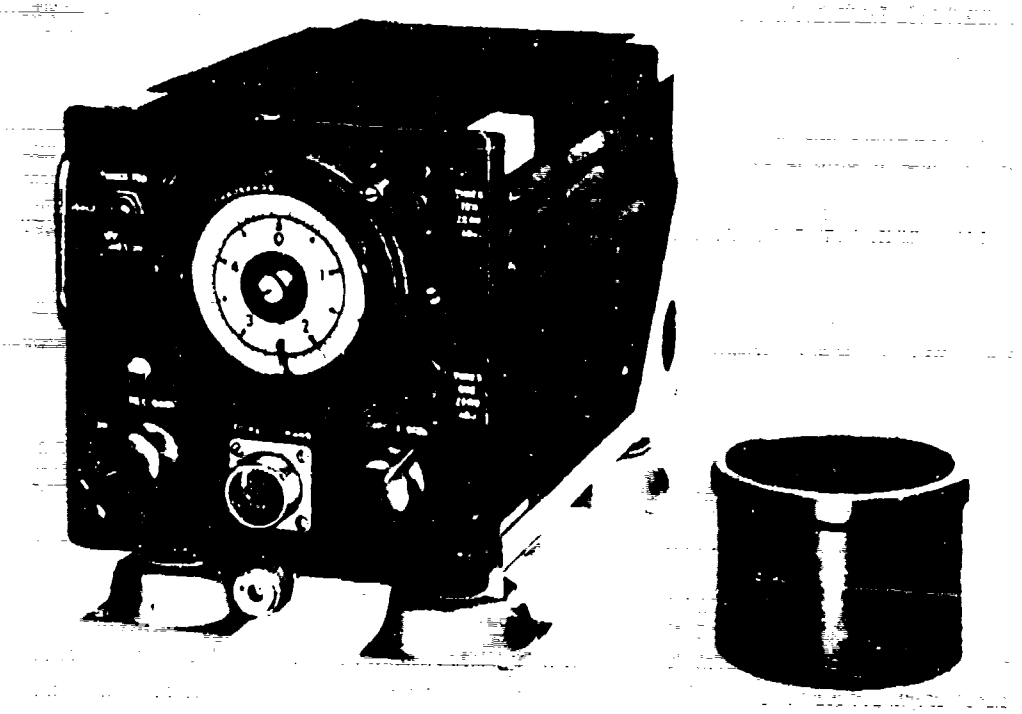


Figure 5–6. Indicator I–152–C for SCR–718 radar altimeter

APN–22 Radar Altimeter

The AN/APN–22 is also an FM/CW type, but it has a higher range. Like any FM/CW type, its error is figured as a percentage of the absolute altitude or a fixed installation equipment type of error, whichever is larger. This instrument has a top limit of 10,000 feet altitude above the ground and 20,000 feet above water. Its error is ±5 percent (that is, $\frac{1}{20}$) of the indicated absolute altitude, or ±2 feet between 0 and 40 feet; for example:

Indicated Abs. Alt.	*Plus Minus Error*	*Actual Abs. Alt*
20 ft	2 ft	18 to 22 ft.
500 ft.	25 ft	475 to 525 ft.
5,000 ft	250 ft	4,750 to 5,250 ft.
15,000 ft	750 ft	14,250 to 15,750 ft.

The APN–22 has a reliability indicator, in that the needle drops behind a mask if an unreliable signal is received.

Uses of FM/CW Radar Altimeters

FM/CW radar altimeters are used to determine clearance from the surface. As such they are very helpful in avoiding collision with the terrain. They are also useful under all instrument conditions. They are widely used for seaplane landings and to a lesser extent for landplane landings. They are essential for hurricane penetration to determine pressure levels and altimeter settings for the aneroid altimeter. They are not usually useful for pressure-pattern or jet-stream flight because they do not operate at the altitudes employed by most jet and long-range transport aircraft.

PULSE-TYPE RADAR ALTIMETER

The pulse type of radar altimeter operates like a conventional radar set in that it transmits ultra-high or super-high frequency pulses. These pulses are reflected back to the receiver where they appear on a cathode-ray tube. The only pulse-type radar altimeter in use by the Navy is the SCR-718. Most of the errors of the pulse type are fixed, regardless of altitude.

The SCR-718 is still found in some VR aircraft and in high-altitude bomber types such as the AJ. It has an accuracy of ±50 feet plus a small percentage error which is insignificant to the pilot. Its range limits are 200 to 50,000 feet. Notice that it is not suitable for use on landings because of its minimum-range limit. The indications are read from a cathode-ray tube, shown in Figure 5-6. For information on how to use this instrument, see the Operating Instructions, AN 16-40SCR718-3.

The pulse-type radar altimeter is generally used for pressure-pattern flying, jet-stream flying, and for bombing. While its fixed error leads to some inaccuracy in pressure-pattern flying, this altimeter is the best instrument available for the purpose. It reads absolute altitude, of course, and for pressure-pattern work is usable only on over-water flights to determine altitude above actual sea level.

CHAPTER 6

ANALYSIS OF MANEUVERS

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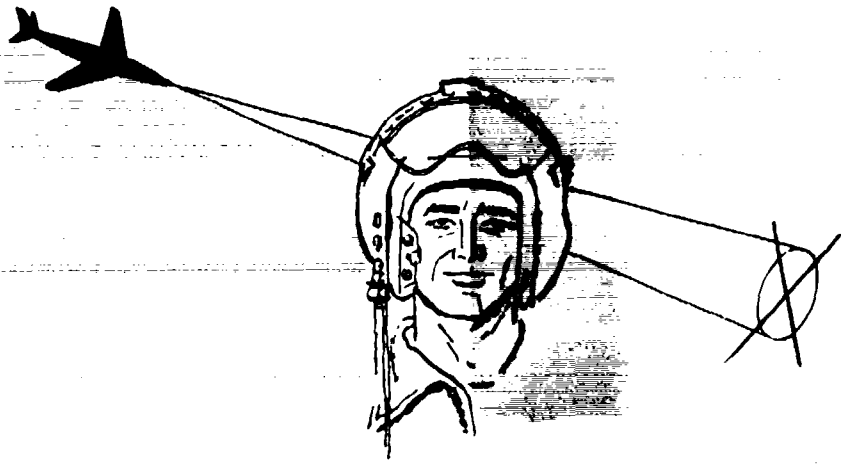


CHAPTER 6

ANALYSIS OF MANEUVERS

INSTRUMENT flight, like visual flight, depends on complete and accurate control of the aircraft. This, in turn, is based on the principles of aerodynamics and the way they affect the attitude of the aircraft under various conditions. A full understanding of these factors will help you do a better job of controlling the attitude of your airplane in both visual and instrument flight.

ATTITUDE INSTRUMENT FLYING

The attitude of an aircraft is the relationship of its longitudinal axis (or fuselage), its lateral axis (or wings), and the earth's surface or any plane parallel to the earth's surface. Attitude instrument flying is controlling the attitude of an aircraft through reference to flight instruments.

Attitude instrument flying is like visual flying in that both use reference points to determine the attitude of the aircraft. While flying by visual reference to the earth's surface, you determine the attitude of the aircraft by observing the relation between the nose and wings of the aircraft and the natural horizon. While flying by reference to flight instrument, you determine the attitude of the aircraft by observing indications on the instruments which give you essentially the same information as you get by visual reference to the earth's surface.

Another similarity between attitude instrument flying and visual flying is the way in which the aircraft is controlled. You use exactly the

same control techniques while flying by reference to instruments as you do in visual flying. The largest single learning factor in attitude instrument flying is that of interpreting the flight instruments to determine the attitude of the aircraft.

Attitude Instrument Flying Skills

Attitude instrument flying consists of three major types of skills—instrument coverage (scanning); instrument interpretation; and aircraft control.

Instrument Coverage. Instrument coverage is commonly termed *scanning*. Experiments in scanning have shown that a pilot whose instrument flying proficiency is at a high level cross-checks his instruments much more often than a pilot whose proficiency is at a lower level. In fact, the lack of precision in instrument flying can often be traced back to slow and inaccurate cross-checking. The best way to improve proficiency is through practice.

The most common faults in instrument scanning are:

1. Omitting an instrument entirely from the scan.
2. Placing too much emphasis on a single instrument.
3. Gazing too long at the wrong instrument.

As an example of how improper scanning occurs, consider the case of a pilot attempting to reduce the airspeed and hold straight-and-level flight. As the power is reduced, he observes the manifold pressure gauge so closely in order to make the proper adjustments that he neglects to observe the instruments which would indicate a deviation from straight-and-level flight. This failure to observe the proper instruments sufficiently could very well be the underlying cause for a poorly executed maneuver.

There is no one set order to follow while scanning the instruments; it depends on the type of maneuver to be executed. During certain maneuvers, one instrument or group of instruments may be of prime importance; during other maneuvers, other instruments may be of prime importance.

Instrument Interpretation. The second major type of attitude instrument flying skill is instrument interpretation; experience has shown that this is difficult to learn. However, since

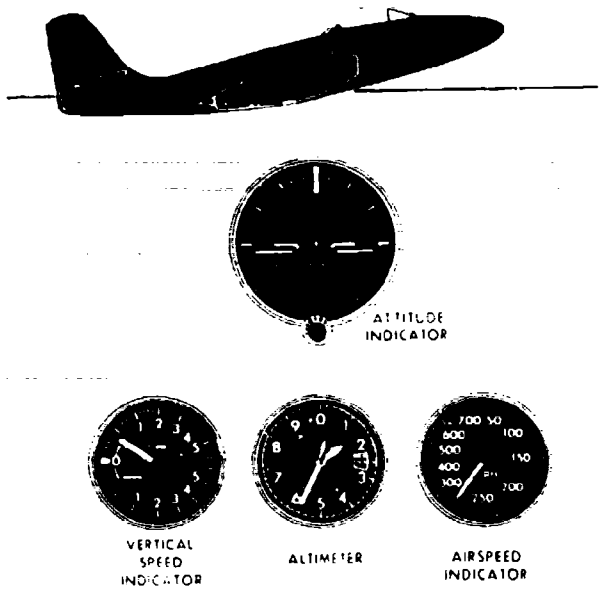


Figure 6–1. Attitude instruments as they might appear in a climb

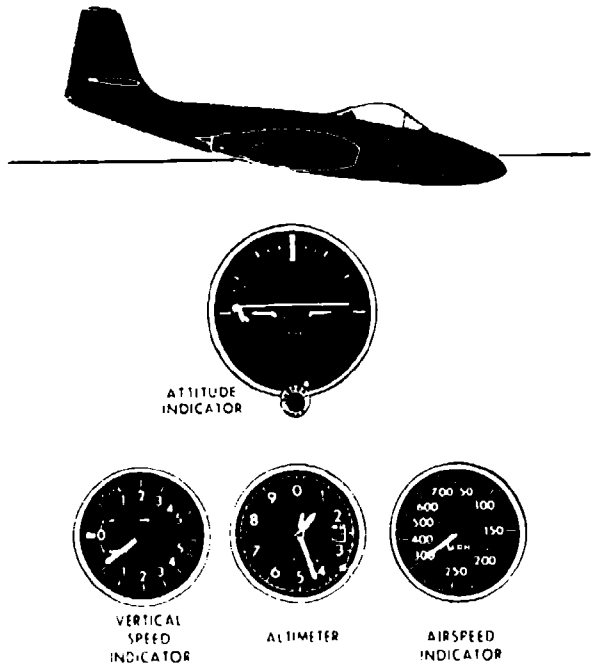


Figure 6–2. Attitude instruments as they might appear in a descent

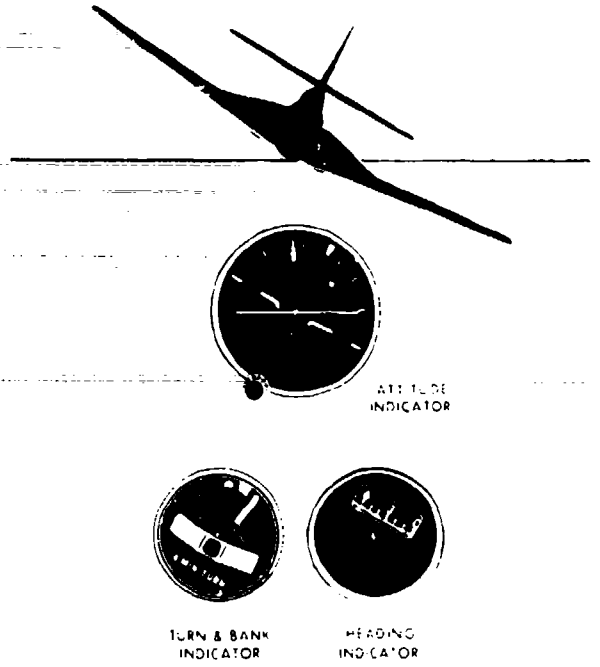


Figure 6–3. Attitude instruments in a right turn

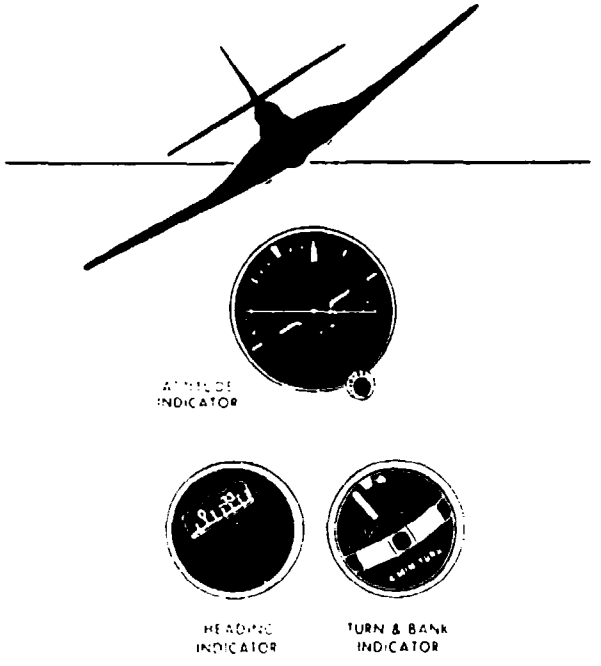


Figure 6–4. Attitude instruments in a left turn

proper instrument interpretation is essential to precision instrument flying, you must apply yourself fully in order to attain the desired precision. The first step, of course, is learning the construction and principle of operation of each flight instrument. This reduces the difficulty of learning to use the instruments and usually results in higher standards of proficiency.

The final step is being able to interpret each instrument indication automatically in terms of the attitude of the aircraft. If the position of the nose is to be determined, the airspeed indicator, the altimeter, the vertical-speed indicator, and the horizon indicator must be interpreted. (See Figure 6–1 and 6–2.) If the position of the wings is to be determined, the indications of the horizon indicator, the heading indicator, and the turn-and-bank indicator must be interpreted. (See Figures 6–3 and 6–4.) The indications on the flight instruments should be interpreted in terms of the attitude of the aircraft at all times. Each pilot should use primary and secondary instruments for proper instrument interpretation.

Aircraft Control. The third attitude instrument flying skill is aircraft control. In visual flight, you know the relationship between your movements of the controls and the attitude of the aircraft. You know what control pressures to use, for you see the results, and you coordinate the controls to place the aircraft in the desired attitude.

Instrument flying is essentially the same with the instruments substituted for the visual reference points. Your control movements necessary to produce a given attitude by reference to instruments are the same as those in visual flight and so are your thought processes.

Aircraft control is composed of four coordinated steps: (1) pitch control, (2) bank control, (3) power control, and (4) trim.

Pitch control is controlling the movement of the fuselage about the lateral axis; it is accomplished by movement of the elevators. After interpreting the pitch attitude of the aircraft from the proper flight instruments, you exert control pressures on the elevators to effect the desired pitch attitude with reference to the earth's surface.

Bank control is controlling the angle made by

the wing and the earth's surface; in other words, the movement of the wings about the longitudinal axis. After interpreting the bank attitude from the proper instruments, you exert the necessary control pressures to attain the desired bank attitude.

Power control, which is control of the powerplant, is used to achieve the desired airspeed and flight path.

Trim control is achieved by relieving all possible control pressures after the desired attitude has been attained. Precision instrument flying is difficult when pressures must be held manually; therefore, trim control must be exercised to relieve as many control pressures as possible.

Remember, of course, that pitch, bank, power, and trim control are performed in a coordinated manner, and the breakdown given here is only an analytical treatment of the subject. Remember, too, that good instrument flying techniques are difficult when you are tense. Tenseness results in erratic and abrupt control movements and in holding pressures on the controls in opposition to the trim. One way of overcoming tenseness is to hold the controls lightly and trim the aircraft to maintain the desired attitude.

APPLIED AERODYNAMICS

If a flat plate is moved through the air (Fig. 6-5), the airstream which strikes the plate is given a downward force by the impact against the plate. The reaction to this downward force produces a resultant force upward (lift) and backward (drag). A slightly arched or cambered surface is much more efficient than a flat plate, but the most efficient type—the one that gives the most lift with the least drag—is an airfoil shape with a rounded nose, smooth cambered top, and sharp tail.

As this airfoil (wing) moves through the air, part of the airstream is forced to flow up over the leading edge while the remainder flows below. The air which flows over the airfoil has a longer path to travel and has to flow faster in order to make it in the same time as the air below. By Bernoulli's Theorem, the air which flows the faster has the lesser pressure. Thus the air which flows over the airfoil exerts less pressure on it than the air which flows under it, and lift is created, pushing the airfoil up.

Lift is also produced at the leading edge. The leading edge is so designed that the approaching

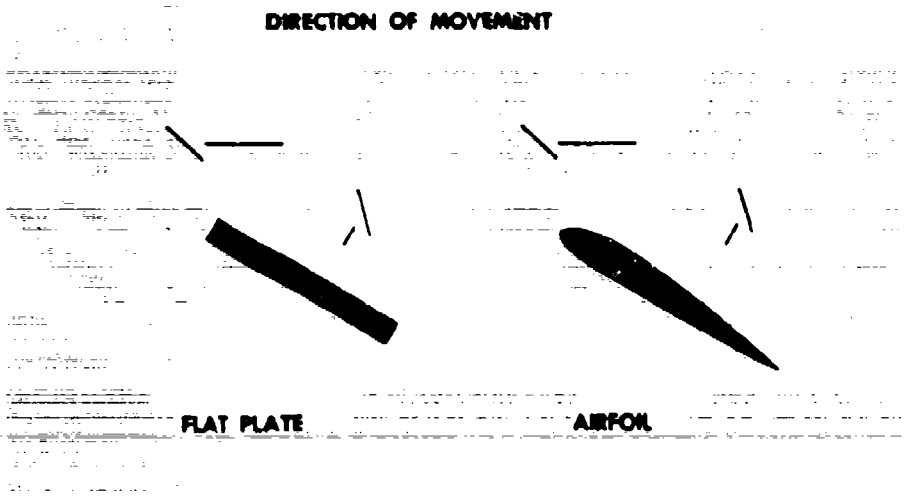


Figure 6-5. How moving air acts upon a flat plate and upon an airfoil

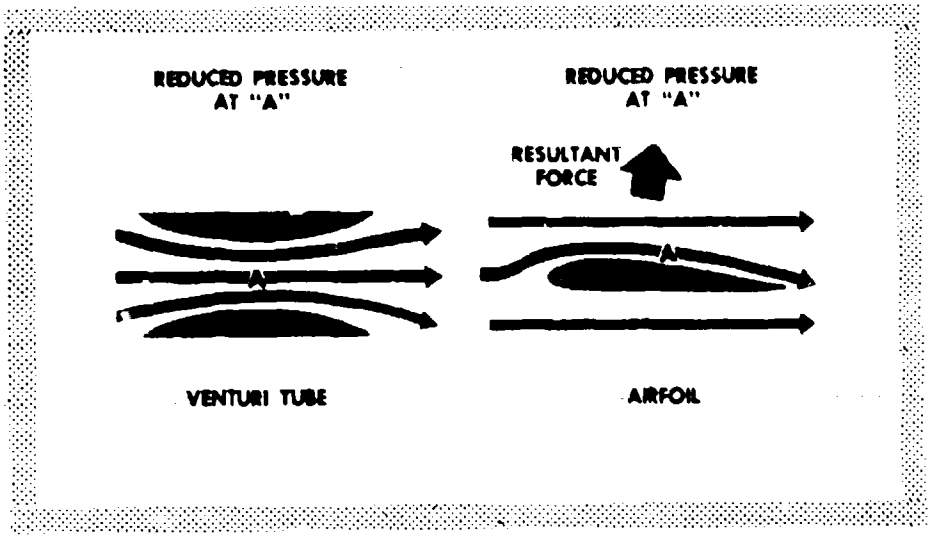


Figure 6–6. Reduced pressure at "A", caused by increased speed, produces lift

air stream is split near the bottom. The air is completely stopped here, and a stagnation point or high pressure area is formed. It is important that the stagnation point be created at the bottom of the leading edge and contribute to lift instead of being created at the center of the leading edge and merely constitute an increase in the drag.

The trailing edge is also very important. Here the air coming over the airfoil is about to meet the high-pressure air stream from the lower surface. If the trailing edge were rounded, the lower stream would tend to curve around to the upper surface. This would result in a second high-pressure stagnation point on the upper surface of the airfoil that would oppose lift. As a result of making the trailing edge sharp, the air stream does not make the turn to the upper surface and no undesirable forces are produced on the after part of the airfoil.

With this basic action in mind, consider now the other forces affecting flight and how they can be controlled and changed to produce the desired reaction of the aircraft.

Relative Wind

The relative wind in aerodynamics is the motion of the air relative to the airfoil. The air can be moving past the airfoil or the airfoil can be passing through the air. The relative wind is parallel and opposite the flight path of the aircraft.

The Angle of Attack

The angle of attack (Fig. 6–7) is the acute angle measured between the chord of the wing and the relative wind—not between the chord and the earth's surface. The chord line of an airfoil is merely a conveniently chosen reference line in the wing to measure the real or theoretical width of the wing.

Lift

The force of lift always acts in a direction perpendicular to the relative wind and to the lateral axis of the aircraft (wing-tip to wing-tip axis). Its direction relative to the earth's surface can be changed by banking the aircraft or entering climbs and descents. The magnitude of the force of lift is directly proportional to the density of the air, the area of the wings, and the airspeed. It also depends on the type of wing and the angle of attack. Lift increases with an increase in the angle of attack up to the stalling angle, at which point it decreases with any further increase in

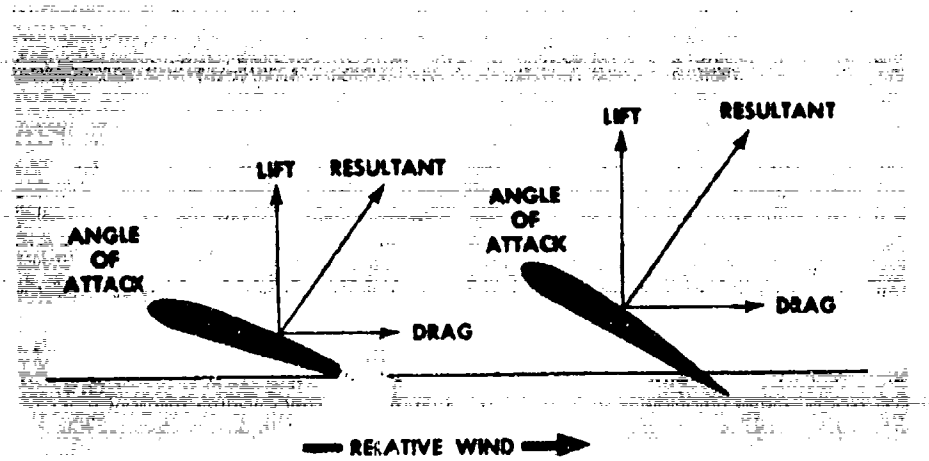


Figure 6-7. The effect of angle of attack

angle of attack. The amount of lift can be controlled by varying any of the factors just mentioned.

Stalls

As explained before, the whole matter of lift involves the smooth flow of air over and under the wing. Bearing this in mind, you can easily form a clear picture of what takes place when a wing is in a stall. As the angle of attack of the wing is increased, the air particles are forced to make sharper and sharper changes in direction in order to follow the "up-over-and-down" contour of the wing. At moderate angles of attack, the particles can negotiate the initial turn of the leading edge, but cannot follow the wing contour completely, and separation occurs near the trailing edge. As the angle of attack is increased, the point at which this separation occurs moved forward. Finally, the separation point moves rapidly forward toward the leading edge. This amount of separation is too much for the wing to tolerate. Lift is destroyed and flight characteristics disappear with the formation of turbulence; the wing is in a stall. (Fig. 6-8.)

Drag

Drag is the total resistance of the air to the passage of the aircraft through it. Drag acts in the opposite direction to the flight of the aircraft, and it is parallel to the relative wind. Induced drag is the drag resulting from the inherent aerodynamic forces of flight. Parasite drag is drag caused by the disruption of the streamline air flow, skin friction, and various minor projections extending into the air stream. Total drag is the sum of the induced drag and the parasite drag.

The amount of induced drag produced by the wing depends on the same factors as lift. Parasite drag depends on airspeed and air density as well as those factors that cause skin friction, and the like. Parasite drag can be increased by extending the landing gear, opening the bomb bay doors, speed brakes, and so on. Flaps are known as high-lift devices, but since as an increase in lift results in an increase in induced drag, flaps also increase the drag considerably. This increase in lift and drag facilitates steeper gliding angles and lower landing speeds.

Thrust

Thrust is the forward pull created by the propeller and its resulting slip stream. In the

case of jet aircraft, thrust is the reaction to the emission of gases through the tailpipe. The amount of thrust depends on the power output of the engine; for all practical purposes it acts parallel to the longitudinal axis of the aircraft. With thrust, you can control the airspeed and flight path of the aircraft.

Weight

Weight is the force of gravity acting on the aircraft and its cargo. Its direction is always toward the center of the earth and does not change even though the aircraft changes attitudes and flight paths. Its magnitude, which depends on the mass of the aircraft and its cargo, is changed by consuming fuel, dropping bombs, and so on.

STRAIGHT-AND-LEVEL FLIGHT

In every condition of flight the forces acting on the aircraft have a definite relationship. In straight-and-level flight, weight acts downward toward the center of the earth; lift acts perpendicular to the relative wind and is equal and opposite to weight; drag acts parallel to the relative wind; and thrust acts forward, parallel to the longitudinal axis, and is equal and opposite to drag. Thrust in this case is considered as acting along the flight path. All these forces must be balanced for straight-and-level, unaccelerated flight. (See Figure 6-9.)

In maintaining straight-and-level flight, three factors affect attitude—airspeed, air density, and the weight of the aircraft. The attitude of the aircraft, of course, is the relationship of its longitudinal and lateral axes with the earth's surface. (See Figure 6-10.) Do not confuse it with either the flight path or the angle of attack.

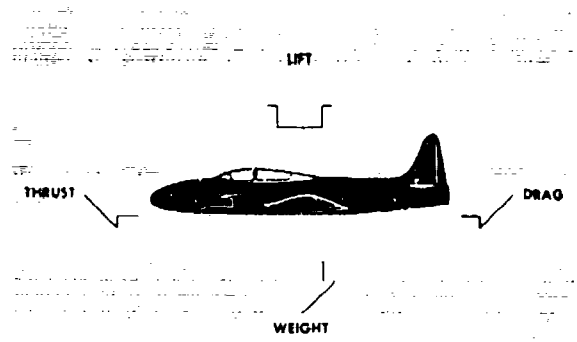
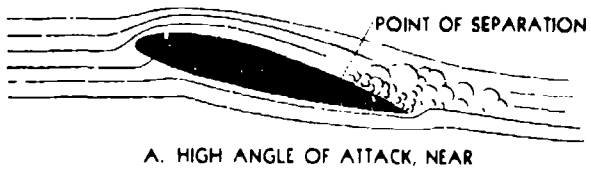
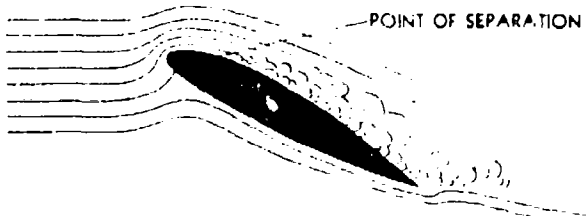


Figure 6-9. Forces acting on an aircraft in straight-and-level flight



A. HIGH ANGLE OF ATTACK, NEAR CRITICAL INCIDENCE



B. CREATION OF TURBULENCE DUE TO WING PASSING STALLING ANGLE OF ATTACK. STALL CONDITIONS

Figure 6-8. Creation of turbulence and stall conditions

Airspeed

At low airspeeds, the angle of attack of an airfoil must be relatively large to produce the lift necessary to maintain level flight. The aircraft must therefore be flown in a nose-high attitude.

As power is increased and the aircraft is accelerated, the nose must be lowered, because the angle of attack necessary to produce sufficient lift to maintain level flight becomes smaller. Remember, any change in airspeed requires a change in attitude to maintain straight-and-level flight.

Air Density

The density of the air decreases as either altitude or air temperature increases. To maintain a given amount of lift, therefore, the angle of

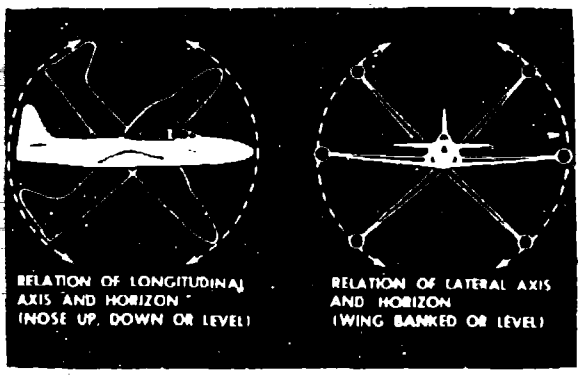


Figure 6-10. Attitude of an aircraft

attack of an airfoil must be increased as the density of the air decreases. Thus, at high altitudes and in regions of very warm free-air temperatures, the attitude of the aircraft must be relatively nose-high to maintain level flight.

Weight of the Aircraft

At normal weight, an aircraft requires a definite angle of attack to maintain straight-and-level flight at a given airspeed. However, to sustain a heavier load at the same airspeed, the angle of attack must be greater to provide the increased lift required. In addition, more power must be added to overcome the increased drag resulting from the increased angle of attack, if the same airspeed is to be maintained.

CLIMBS

For all practical purposes, the lift in normal climbs is the same as in level flight at the same airspeed. Though the flight path has changed (from the horizontal), the angle of attack of the wing with respect to the flight path remains the same, and so does the lift. There is a momentary change, however. In going from straight-and-level flight to a climb, the forces acting on the aircraft go through a definite sequence of changes. It starts with a change in lift when back pressure is applied to the controls. Raising the nose increases the angle of attack and momentarily increases the lift. Lift is now greater than the weight of the aircraft and forces it upward toward a higher altitude. As a result, the flight path is inclined upward and the angle of attack and the corresponding lift again stabilize. (See Figure 6-11.)

As the climb is started, the airspeed gradually diminishes. The thrust which maintained the airspeed in straight-and-level flight is not sufficient to maintain the same airspeed in a climb. The change in airspeed is gradual rather than immediate because of the momentum of the aircraft. It is due to the fact that a component of the weight acts in the same direction and parallel to the total drag of the aircraft so that the total drag is increased by an amount equal to the component of the weight. If the power is not increased to make up for this added drag, the airspeed becomes less. This reduction in airspeed, in turn, causes a reduction in drag until the drag is reduced to the point where the total drag (including the component of weight acting in the same direction) is equal to the thrust. The airspeed is now stable—at a lower point than in straight-and-level flight with the same power. To go from level flight into a climb at the same airspeed, you must increase the power output (thrust) of the engine.

Lift is equal in magnitude to the component of weight that is perpendicular to the flight path. In a climb, this is only part of the weight, for one component of the weight acts toward the rear and parallel to the total drag of the aircraft. This component is balanced by a part of the thrust. For normal rates of climb, it does not amount to very much, since the angle of attack changes very little. In aircraft which climb at large angles of attack, however, it is important.

DESCENTS

When you start a descent from straight-and-level flight, the forces acting on the aircraft go through definite changes just as they do when you start a climb. When you apply forward pressure to the controls, the angle of attack is reduced and, as a result, the lift of the airfoil is reduced. The lift is now less than the weight of the aircraft, and this causes the aircraft to follow a descending flight path. As the flight path changes to a descent, the angle of attack of the airfoil again reaches the original value, and lift and weight stabilize.

Thus the change in lift is momentary. Not so the change in airspeed. As the descent is started, the airspeed gradually increases. This is due to the fact that a component of the weight is now acting forward along the flight path parallel to the thrust, which has the overall effect of increasing the thrust. That's why making a descent without reducing power causes an increase in airspeed. To descend at the same airspeed as you had in straight-and-level flight, you must obviously reduce the power as the descent begins.

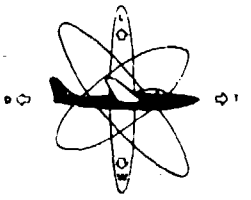
The component of the weight acting forward along the flight path increases as the rate of descent increases and decreases as the rate of descent decreases. Therefore, the amount of power reduction for a descent at the same speed as cruise is determined by the rate of descent desired.

Vertical-Speed Characteristics

For any given attitude, the vertical speed is greater at higher airspeeds than at lower airspeeds. A small change in attitude results in large changes in vertical speed at high speeds and in smaller changes at lower speeds. For any given change in attitude under normal conditions, the vertical speed is directly proportional to the airspeed. This is true for both climbs and descents.

ELEVATOR ACTION

The raising and lowering of the nose of the aircraft is made possible, of course, by the use of



the elevators; but the position of the elevators alone does not tell the whole story of pitch control. The use of the elevators differs with any change in power and airspeed. The slip stream striking the elevators in a downward direction creates a negative angle of attack for the elevators and causes them to exert negative lift. Changing power and airspeed changes the amount of downwash and the resulting amount of negative lift exerted by the elevators.

As power and airspeed increase, slip-stream velocity and downwash lift on the elevator increase. At the same time, the lift on the wing also increases, and the aircraft has a tendency to assume a nose-high attitude. If you want to maintain straight-and-level flight, you must hold forward pressures on the controls, or retrim the aircraft, as you increase the power.

Any decrease in power or airspeed has an opposite effect. The negative lift on the elevators and the lift of the wing decrease, and the result is a tendency of the aircraft to assume a nose-low attitude. As you reduce power or airspeed, therefore, you must hold back pressures on the controls

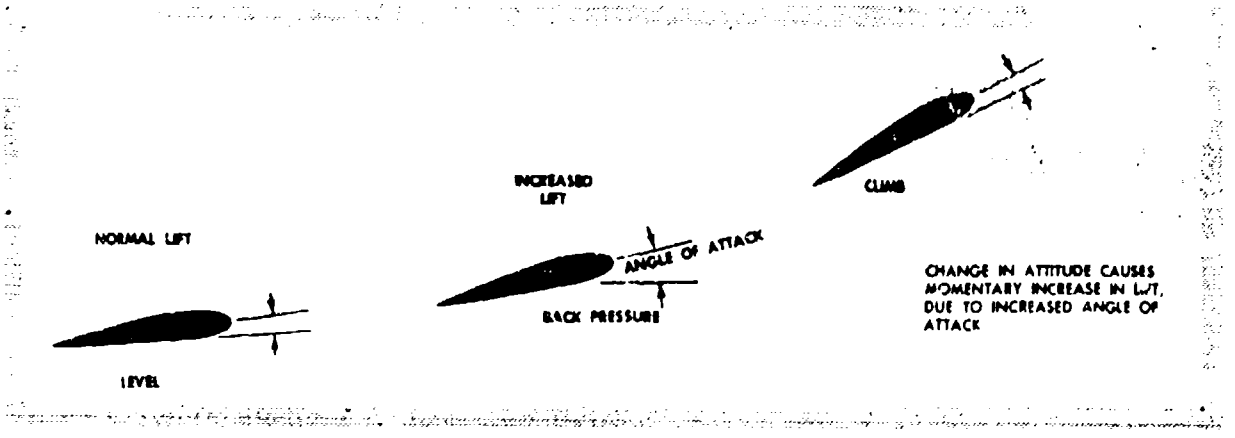


Figure 6-11. Climbing flight

or retrim the aircraft in order to maintain straight-and-level flight.

TRIM CHARACTERISTICS

An important factor of lift and weight that has not been discussed yet is their point of action. Weight always acts through a point in the aircraft called the center of gravity. This point is always on the center line of the aircraft and slightly behind the leading edge of the wing. Lift always acts through a point called the center of pressure which is in the aft portion of the wing chord behind the center of gravity. Since these two points do not coincide, the forces of lift and weight exert a twisting force on the aircraft, and the result is a normal nose-heaviness. This twist is balanced by the negative lift produced by the horizontal stabilizer and elevator surfaces. However, the amount of negative lift produced by the elevators depends on the airspeed and power. You can see, then, that if you reduce power with a constant airspeed, you decrease this negative lift and must use nose-up trim to keep the aircraft in trim; conversely, increased power requires nose-down trim. If you increase the airspeed, holding constant power, nose-down trim will be necessary; conversely, decreasing airspeed requires nose-up trim.

In prop aircraft, when power is applied, torque yaws the nose of the aircraft to the left. The same result occurs if the airspeed is reduced while the power remains constant. Torque is overcome by the rudder in essentially the same way as the natural nose-heaviness of the aircraft is overcome by the elevators and the horizontal stabilizer. The force on the rudder depends on the control setting and the air flow. The air flow depends on the airspeed and the slip-stream velocity. Here is a rule which will help you trim an aircraft to correct torque effects.

In a prop aircraft, if you reduce power (airspeed constant), add left rudder trim, and conversely, if you increase power (airspeed constant), and right rudder trim. If airspeed is decreased (power constant), add right rudder trim, and, conversely, if airspeed is increased (power constant), add left rudder trim. These rules do not apply, of course, to jet aircraft.

TURNS

There are many misconceptions about the aerodynamics of a turn. One of the basic misconceptions is that lift acts entirely in a direction opposite to that of weight. That is not so. (See Figure 6-12.) Lift acts inward toward the center of the turn as well as upward. This is one of the basic facts to remember in consideration of turns.

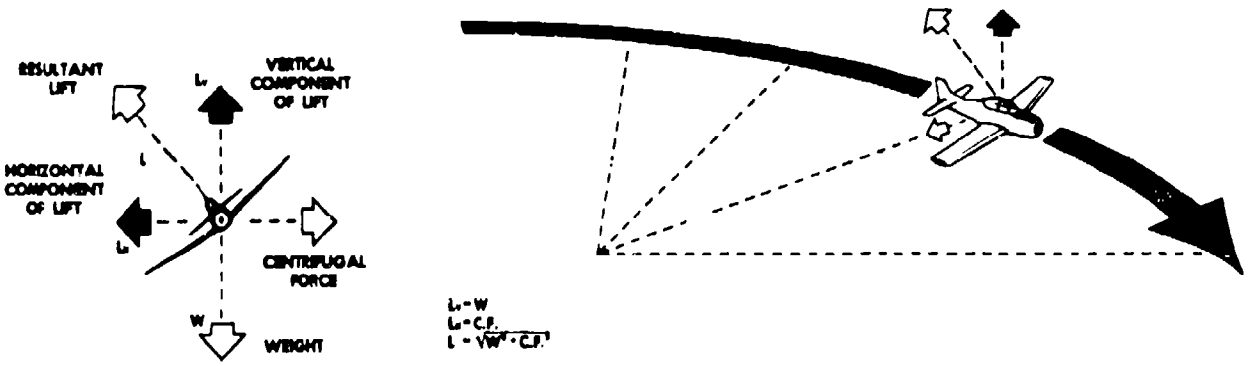


Figure 6-12. Forces acting on an aircraft in a normal turn

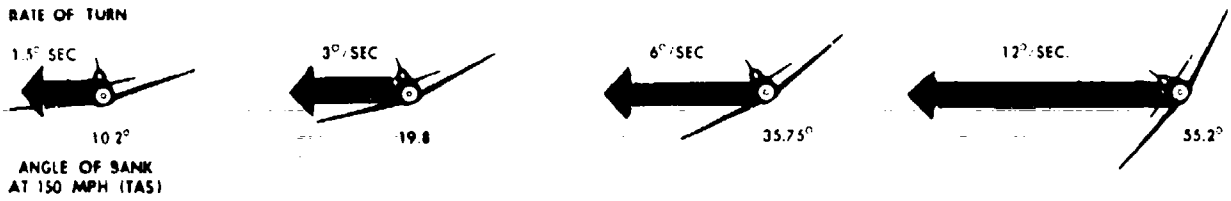


Figure 6–13. Rate of turn at 150 kts

Forces Acting on Aircraft in Turns

An aircraft, like any moving object, requires a sideward force to make it turn. In a normal turn, this force is supplied by banking the aircraft so that lift is exerted inward as well as upward. The force of lift in a turn is thus separated into two components at right angles to each other. The component which is vertical and opposes the weight is called the "vertical component of lift." The other, which is horizontal toward the center of the turn, is called the "horizontal component of lift." *The horizontal component of lift is the force that causes aircraft to turn.* It is opposed by the centrifugal force, which is the equal and opposite reaction of the aircraft to the change in direction.

In a correctly executed turn, the force to turn the aircraft is not supplied by the rudder. An aircraft is not steered like a boat or an automobile; in order to turn properly, it must be banked. If the aircraft is not banked, there is no force available that will cause it to deviate from a straight flight path, provided it is not skidding. Conversely, when an aircraft is banked, it will turn, provided it is not slipping. Good directional control is based on the fact that the aircraft will turn if banked. Always remember this while attempting to hold the aircraft straight and level by reference to instruments. If you get an indication of a bank from the flight instruments, correct this immediately by a roll-out of the bank in order to maintain the desired heading and flight path.

Changes in Lift in a Turn

Banking the aircraft in order to turn produces no change in the amount of lift. It does, however, divide the lift into two components, one vertical and the other horizontal. This division reduces the amount of lift which is supporting the weight of the aircraft; consequently, the aircraft loses altitude unless you increase the total lift by increasing the angle of attack until the vertical component of lift is equal to the weight. The degree to which the angle of attack must be increased depends on the angle of bank. The greater the angle of bank, the weaker is the vertical component of lift. *As you increase the angle of bank, therefore, you must increase the angle of attack in order to produce sufficient vertical lift to support the weight of the aircraft and keep it from losing altitude.*

Angle of Bank Versus Rate of Turn

At any given airspeed, the rate at which an aircraft turns depends on the magnitude of the horizontal component of lift. Since the horizontal component of lift is proportional to the angle of bank, it increases or decreases as the angle of bank increases or decreases. Consequently, as the angle of bank is increased, the horizontal component of lift increases, and the rate of turn increases. Thus, at any given airspeed, you can control the rate of turn by the angle of bank. In a correctly executed turn at a constant airspeed, the aircraft will turn more rapidly as the angle of bank is increased. (Figure 6–14.)

The Increase of Drag in a Turn

As explained before, holding altitude in a level turn requires an increase in the angle of attack in order to increase the lift. Since the drag of the airfoil is directly proportional to the angle

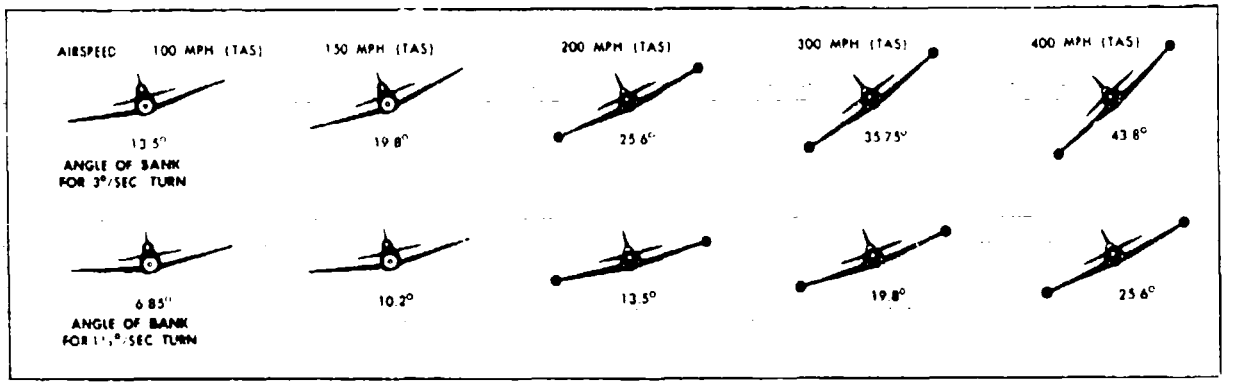


Figure 6–14. Angles of bank for constant rate of turn at various airspeeds

of attack, the drag increases as the lift increases. This results in a loss of airspeed which is proportional to the angle of bank. A small angle of bank results in a small reduction in airspeed and a large angle of bank results in a large reduction in airspeed. Additional power must therefore be added to prevent a reduction in airspeed in level turns. The amount of additional power required is proportional to the angle of bank.

Executing Turns at a Constant Rate

If the airspeed is increased in a turn, the angle of attack must be decreased or the angle of bank increased to maintain a constant altitude. However, holding the angle of bank constant and decreasing the angle of attack would decrease the rate of turn. Therefore, to maintain a constant rate of turn at an increased airspeed, hold the angle of attack constant and increase the angle of bank. (Figure 6–14.)

Another way of looking at the situation is to consider it from the point of view of centrifugal force. In a correctly executed turn, the horizontal component of lift must be exactly equal and opposite to the centrifugal force. However, as the airspeed is increased in a constant-rate level turn, the radius of the turn increases. So does the centrifugal force, for centrifugal force is directly proportional to the radius of turn. This increase in the centrifugal force must be balanced by an increase in the horizontal component of lift, which can be accomplished only by increasing the angle of bank. To maintain a given rate of turn, therefore, the angle of bank must be varied with the airspeed.

This is particularly important in jet aircraft when you rely on the indications of the turn needle. At 400 miles per hour, for example, an aircraft must be banked approximately 44° to execute a standard rate turn (3° per second) on the turn indicator. At this angle of bank, only about 79% of the lift of the aircraft comprises the vertical component of the lift; the result is a loss of altitude unless the angle of attack is increased sufficiently to compensate for the loss of vertical lift.

The Load Factor and the Angle of Bank

The load factor is the ratio between the load acting on the aircraft in level flight and other possible loads that may be exerted on the aircraft. It depends on the weight of the aircraft and the maneuver to be executed. For a coordinated turn, the load factor is equal to the total lift of the airfoil divided by the weight of the aircraft. Since the weight of the aircraft must be supported by the vertical component of lift, an increase in the angle of bank results in an increase in the load factor. In level flight, the load factor is 1, and in 60° bank, the load factor is 2. This means that the wings must support a load equal to twice the weight of the aircraft; to do this, the angle of attack must be increased. If the load factor becomes so great that the angle of attack cannot

produce sufficient lift to support the load, the aircraft stalls. This is called a "high-speed stall."

In instrument flight, especially, it is unwise to make steep turns at low airspeeds. The increase in stalling speed is always important but is particularly significant in special situations. When ice forms on an aircraft, for instance, its stalling speed is increased. Since the stalling speed of the aircraft increases as the load factor increases, any further increased load factor because of a turn may result in a stall. Additionally, in extremely turbulent air the load factor on the wings may be increased by vertical gusts, and this increase may be sufficient to make an aircraft stall during a steep turn, whereas it would not have stalled in a moderately banked turn.

Aileron Drag

The rudder plays an important part in correctly executed turns. As the aircraft is rolled into a bank, the ailerons are deflected. This has the effect of increasing the lift on the outside wing and decreasing the lift on the inside wing. The drag on the outside wing is also increased, and this increased drag, known as "aileron drag," produces a yawing effect toward the outside of the turn if aileron is used exclusively to make the turn. Aileron drag is counteracted and minimized by rudder pressure in a correctly executed turn. However, once the bank is established in a turn and the aileron pressures are adjusted so as to maintain the desired bank, the rudder plays no part in the turning of the aircraft and serves as a stabilizing element only.

Slips and Skids

An aircraft points directly along its flight path, except when it is slipping or skidding. The aircraft may be yawed toward either side of the flight path by use of the rudder or by an incorrect adjustment of the rudder trim tab. The same yawing effect can be caused by the ailerons. If one aileron is deflected slightly downward and the other is aligned properly, the maladjusted aileron causes more drag on that side of the aircraft. In a correctly trimmed aircraft, directional stability of the aircraft plays an important part in returning the aircraft to its proper position in straight-and-level flight after a slip or skid. This directional stability is normally brought about by the restoring moment created when the relative wind strikes the side of the rudder projected into the wind during a slip or skid.

To maintain straight flight in prop aircraft without slipping or skidding, the adjustments of the rudder trim tab must be varied for different power settings, because the changing torque varies the air stream over the vertical tail surfaces and varies the directional control. In many instances, the pilot inadvertently holds rudder pressures or sets the rudder trim tabs improperly and causes the aircraft to fly in a skid or slip. This, in turn, gives rise to many problems in directional control that would not be present if the aircraft were properly trimmed or if rudder pressures were not held.

In a straight slip, the aircraft is banked. This bank normally results in a turn, because the force exerted on the aircraft in the direction of the bank

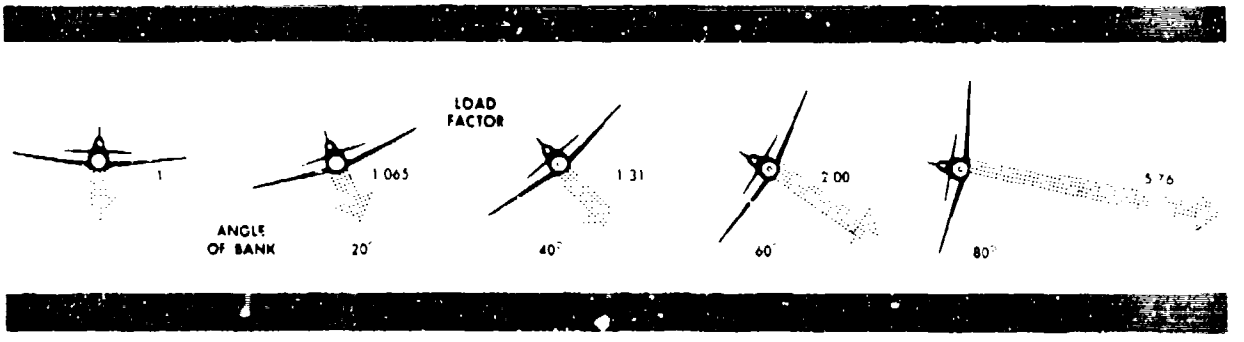
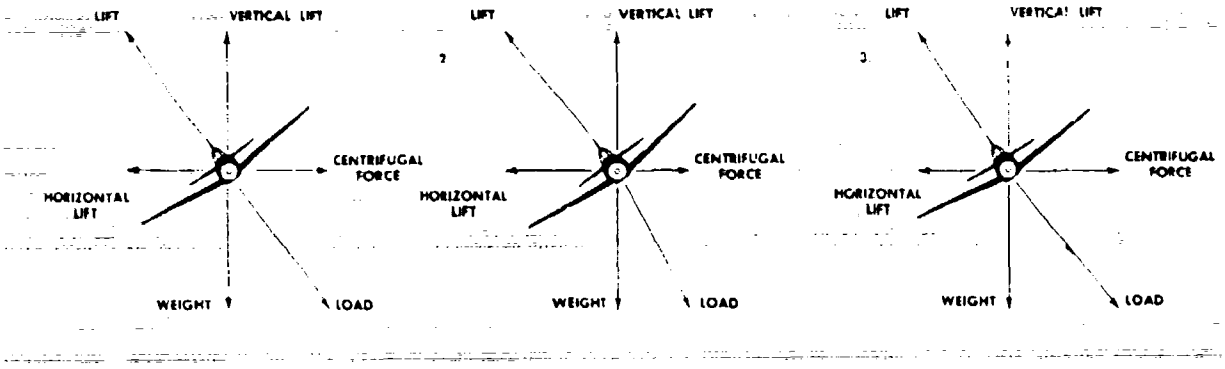


Figure 6–15. Relation of load factor to angle of bank



1 Normal turn
Centrifugal force equals horizontal lift

2 Slipping turn
Centrifugal force less than horizontal lift

3 Skidding turn
Centrifugal force greater than horizontal lift

Figure 6-16. Relationship of forces in normal and slipping turns

pulls the aircraft out of its straight flight path, and the aircraft, responding to this force, changes its direction of motion and begins to turn. If these forces continue to act in this manner, the aircraft continues to turn. In a slip, however, the aircraft is prevented from turning away from the original heading by the rudder action; thus, the bank of the aircraft merely results in its being pulled sideward. This is indicated on the flight instruments by the fact that the ball in the turn-and-bank indicator is displaced in the direction of the bank.

Slipping Turns

A slip in a turn is similar to a slip in straight flight—the aircraft is not allowed to turn at a rate proper for the angle of bank. In a slipping turn, the rate of turn is not great enough for angle of bank, because the aircraft is not allowed to head directly along its turning flight path but is yawed to the outside of the path followed in the turn. The yaw may be the result of top rudder pressure, or, in some aircraft, drag of the top aileron on entering the turn. As in straight slips, a slip in a turn is indicated by the displacement of the ball to the inside of the turn, or in the direction of the bank. This indication results from the fact that the aircraft is banked too much for the rate of turn, so that the horizontal component of lift is greater than the centrifugal force. You can see the relationship of these forces in Figure 6-16.

Skidding Turns

In a skidding turn, the rate of turn is too great for the amount of bank. Consequently, the centrifugal force is greater than the horizontal component of the lift. This results in a net force toward the outside of the turn and carries the aircraft outward from the desired flight path and away from the direction of turn. The fact that the aircraft is skidding is indicated by the displacement of the ball in the turn and bank indicator to the outside of the turn. A skidding turn can be corrected either by reducing the rate of turn and holding the same angle of bank or by increasing the angle of bank and holding the rate of turn constant.

Coordinated Use of Rudder and Ailerons in Turns

Most aircraft can be banked by use of either ailerons or rudder alone. However, if the aircraft is banked by the ailerons only, it tends to slip, because the outside aileron causes more drag than the inside aileron. The amount of slipping depends on the violence with which the controls are used, since the more the ailerons are moved out of a neutral position the greater is the yawing effect of the aileron drag. If the ailerons are used more slowly, the slipping is negligible.

An aircraft banked by the use of the rudder only is yawed toward the inside of the turn, which

increases the lift of the outside wing to a value greater than the lift of the inside wing. At best, the effect of the rudder is slow; if the rudder is used with any force, considerable skidding accompanies the increase in the angle of bank. It is difficult to bank an aircraft flying at high speeds by the use of the rudder alone, because the yawing effects of the rudder do not materially increase the lift of the outside wing. In jet aircraft, the radius of the turn is so great that the increase in the speed of the outside wing over that of the inside wing is extremely small and has little effect upon the relative lift of both wings.

An aircraft is correctly banked only by the coordinated use of both the rudder and the ailerons. The relative use of these two controls depends on the characteristics of the particular aircraft and the airspeed at which the maneuver is executed. The indications of the turn needle and the horizon indicator provide an accurate gauge for determining the correct use of these controls. After the aircraft has been banked for a turn, the angle of bank should be held constant without skidding or slipping. This requires some adjustment of both ailerons and rudder pressure, depending on the characteristics of the aircraft and its speed. No general rules can be set for determining in advance the exact amount of rudder and aileron pressure to be used in turning any specified aircraft; the pressures must be learned from actual experience.

CONTROL AND STABILITY

As you have seen, an aircraft can move about any of its three axes. As shown in Figure 6-17, it pitches about axis AA', rolls about axis BB', and yaws about axis CC'. The controls are capable of inducing motion about any of these axes.

The rudder enables the aircraft to yaw to the right or left. The elevator varies the load on the tail, thereby serving as the pitch control, making the aircraft rise or descend. The ailerons move in opposition to each other, varying the load on the wings and causing the aircraft to roll. The remaining control, the throttle, is used to vary the thrust.

Besides providing the means for exerting control of the aircraft, the design of the various surfaces is important in imparting stability to the aircraft. The aircraft must not only be capable of holding a normal flying position when little or no control force is exerted, but it must also have the inherent ability to exhibit what might be called "return characteristics." Should a sudden gust lift the nose, it is desirable that the tail surfaces act to dampen this effect and return to a level position. This is also true in the case of an aircraft being rotated about its roll axis when one wing is lifted by a gust of wind. In such cases, the wing that dips encounters increased lift; the opposite occurs to the raised wing. As a result, the roll is checked very rapidly. In some cases, the aircraft is left with a list, which can result in a slideslip. To counteract this, many aircraft are designed with a lateral dihedral as shown in Figure 6-18. The dihedral, together with the slideslip velocity, effectively produces a greater angle of attack on the wing that is dipping, and a rolling motion is produced that returns the aircraft to its normal position. Return characteristics such as these should be present in yawing and pitching as well as in rolling.

The degree to which this stability should be

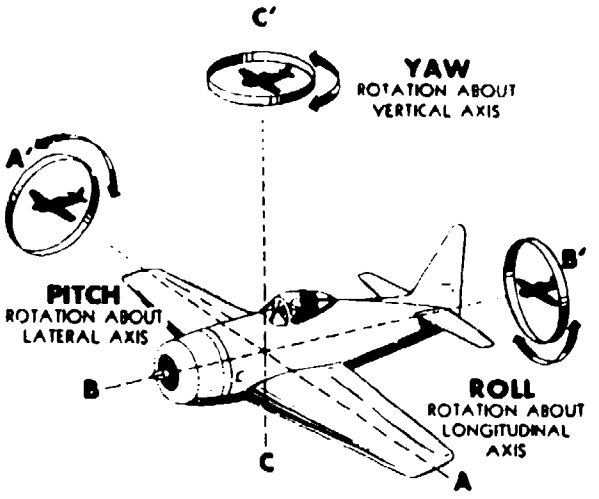


Figure 6-17. Control axes of an aircraft

present depends on the use for which the aircraft is intended. An aircraft designed for a high degree of stability may have "heavy" or sluggish controls. In passenger craft this may be of advantage; in fighter craft, on the other hand, a low degree of stability is desirable. This results in an extremely sensitive aircraft, and consequently the pilot has little difficulty in imposing his will on the aircraft and obtaining rapid reactions.

Of course, an aircraft, particularly a prop aircraft, does not react immediately to changes in performance characteristics as a result of attitude changes. Instead, the change is a gradual one, and there is a transition period between the two performances. Inertia is responsible for this delay in aircraft response to attitude changes initiated by the pilot.

Simply stated, inertia means that a body at rest tends to stay at rest and a body in motion tends to stay in motion. Force is required to put a body in motion and force is required to slow it down, to stop it, to increase its motion, or to change its direction of movement.

Inertia is ever-present; it is present in every attitude-power combination, and manifests itself in the reistance which an aircraft offers to any force that would stop it, or change its present condition. Therefore, it takes the aircraft a little time to overcome the influence of inertia and to establish its new performance. This factor of inertia, as well as the other factors in control and stability, are of major importance in transonic and supersonic flight.

SPEED OF FLIGHT

The various speeds of flight are generally classified according to their relationship to the speed of sound. To present this relationship accurately, it is generally given as a Mach number. The Mach number of a moving body is equal to the speed of the moving body divided by the speed of sound at the place where the movement occurs.

Subsonic flight is flight in which the air flow over the surfaces of the aircraft does not reach the speed of sound. The subsonic region starts at M 0 and generally extends to M 0.75; the upper limit varies with the design of the aircraft.

Transonic flight is flight in which the air flow over the surfaces of the aircraft is partly subsonic and partly supersonic. The limits of this region, too, depend on the design of the aircraft, but generally the transonic range is considered to be between M 0.75 and M 1.2.

Supersonic flight is flight in which all the air flow over the surfaces of the aircraft is supersonic. This starts at the upper limit of the transonic region and extends to infinity.

Figure 6-18. Lateral dihedral

TRANSONIC FLIGHT

The effects of transonic flight are varied, for they depend mainly on the type of aircraft involved. With aircraft specifically designed for flight in the transonic region, the effects are usually not too objectionable. With aircraft not so designed, however, a venture into the transonic range is definitely dangerous. The nose may "tuck under," for example, and the pilot will exhaust his strength trying to pull the nose back up. Some pilots have been able to pull out successfully in such a predicament—many have not. In some aircraft, the wing and control surfaces may begin to vibrate or "buzz" upon entering the transonic range. Sometimes, when using left rudder and a small amount of left aileron, pilots have been astounded to find their aircraft turning to starboard. Other equally weird effects may be experienced, depending on the design of the aircraft

concerned. One thing is generally true—when the limiting Mach number is exceeded, the majority of the effects encountered are detrimental to pilots and aircraft alike.

The basic reason for these effects is the compressibility of air. When air is compressed, its nature is changed so far as aerodynamic considerations are concerned. Of course, there is some degree of compression, even at low speeds, and some slight changes in the aerodynamic characteristics of the air as a result of this slight compression.

At low speeds, however, these changes are small and can be neglected. Thus, for air flow below Mach 0.3, the air can be considered as if it were incompressible. As the speed increases, though, these changes in the nature of the air also increase and can no longer be ignored, especially above Mach 0.75. In the transonic range, compressibility is capable of producing catastrophic effects. At those speeds, therefore, the air must be considered as a compressible fluid, and the wing is said to be in compressible flow.

The Nature of Compressibility

When an object moves through the air, it continuously creates small pressure disturbances in the air stream as it collides with the various air particles in its path. Each such disturbance—actually a small change in the pressure of the air—is transmitted outward in the form of a weak pressure wave from the point where it was created. (See Figure 6-19.) This expanding pressure wave travels at a constant rate—the speed of sound. This is logical since sound waves themselves are nothing but very small pressure waves. Large pressure waves, like those created by an explosion, often travel faster than the speed of sound.

Although each pressure wave expands equally in all directions, the important direction is that in which the object is traveling. This is because the pressure wave effectively serves as an advance warning to the air particles in the path of the object that the object is on its way.

As long as the object is traveling at low subsonic speeds, the pressure wave travels upstream well ahead of the object that created it, and causes the air particles to change direction and conform to the shape of the object before it arrives on the scene.

As the speed of the object approaches the speed of sound (see b and c in Fig. 6-20), the object comes closer and closer to the air particles before they are warned by the advancing pressure wave and can start to change direction. This means that the greater the speed of the object, the fewer the number of air particles that will be able to move out of its path. As a result, the air begins to pile up in front of the object and the air density increases.

When the speed of the object has reached the speed of sound (see d in Fig. 6-20), the pressure waves can no longer warn the air particles ahead of the object because the object keeps right up with the wave. Therefore, the air particles in the path of the approaching object are not aware of its presence until they collide with the particles that are piled up in front of it. As a result of these collisions, the air stream directly in front of the object slows down very rapidly, while its density and pressure increase correspondingly.

As the speed of the object is increased beyond the speed of sound, the pressure and density of

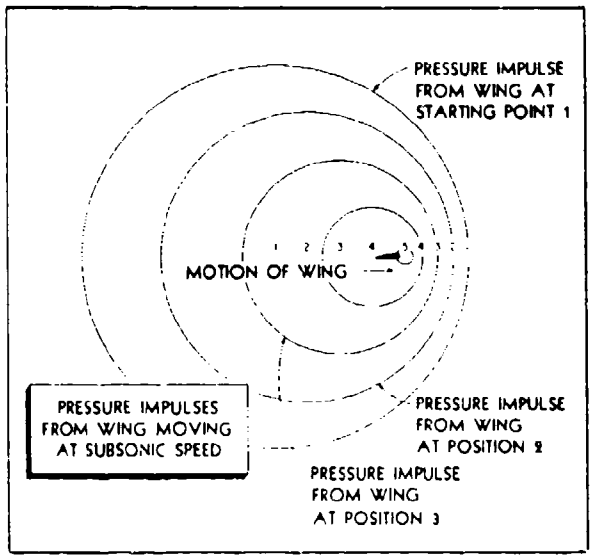


Figure 6-19. Pressure impulses from a wing moving at subsonic speed

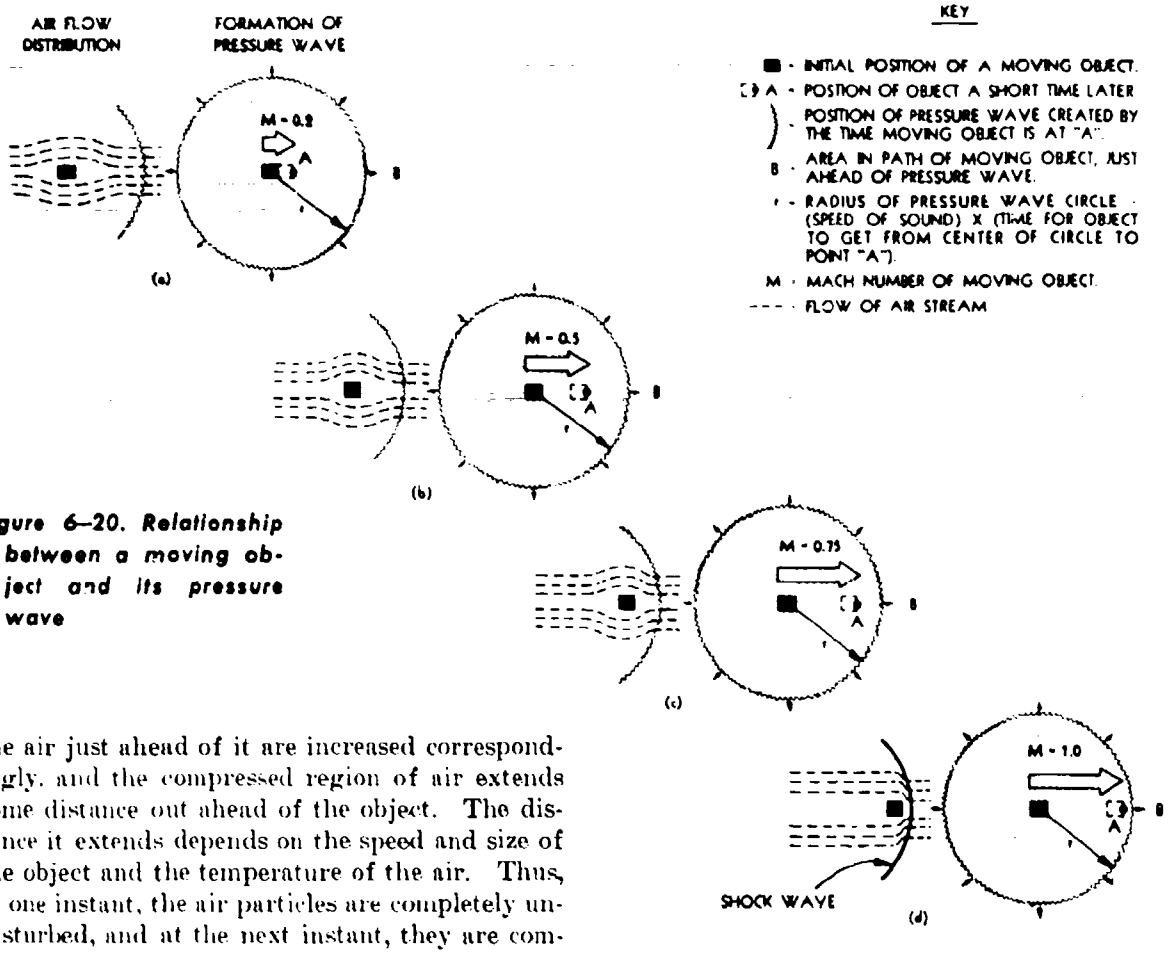


Figure 6–20. Relationship between a moving object and its pressure wave

the air just ahead of it are increased correspondingly, and the compressed region of air extends some distance out ahead of the object. The distance it extends depends on the speed and size of the object and the temperature of the air. Thus, at one instant, the air particles are completely undisturbed, and at the next instant, they are compelled to undergo drastic changes in temperature, velocity, pressure, and density. Because of the sudden nature of these changes, the boundary line between the undisturbed air and the compressed region is called a shock wave.

In summary, then, the greater the speed of a blunt body moving through the air, the greater the air density and air pressure directly in front of it, and the less smooth the flow of air around it. In an air stream flowing at a speed less than Mach 0.3, the density changes of the air due to its compressibility can be ignored. Above this speed, the density changes are large enough to affect the performance of the aircraft. In general, this effect is an aid to lift, until the air stream at any point on the wing's surface exceeds the speed of sound. When this happens, shock waves are created and "compressibility effects" begin to appear.

Remember, now, this discussion involves the speed of the air stream—not the speed of the aircraft. The speed of the air flowing over the wings of an aircraft is greater than the speed of the aircraft itself. In fact, the speed of the air over the wing may be more than twice the speed of the aircraft. For this reason, the air flowing over the wings may reach the speed of sound, and shock waves may be formed, even though the aircraft is flying at a speed of only Mach 0.75. *That's why the limiting Mach number of today's transonic operational planes and the start of the transonic region lie below the speed of sound, Mach 1.0.*

Shock Waves

There are several different types of shock waves, each with its own particular characteristics.

All shock waves, though, have these characteristics--

1. The density and pressure of air flowing through a shock wave increase suddenly. (That's why shock waves are often called compression waves.)

2. The velocity of the air measured perpendicularly to the shock wave decreases suddenly from supersonic speed to subsonic speed.

3. The temperature of the air flowing through the shock wave increases suddenly.

One type of shock wave is the normal shock wave. It gets its name from the fact that it lies perpendicular (or normal) to the direction of air flow. This type of compression wave is always a strong shock wave, since the changes that occur across the wave are great.

A normal shock wave can be formed by putting a blunt object in a supersonic stream, as shown in Fig. 6-21. Note in this illustration that at A, the air is traveling at supersonic speed, completely unaware of the approaching object. At B, the air has "piled up" and is traveling at subsonic speed, simply trying to slip around the front of the object and merge with the air stream. As it reaches B, the supersonic air from A slows up immediately, increasing in pressure, density, and temperature. The center part of the shock wave, lying perpendicular (or normal) to the direction of the air stream, is the strong normal shock wave. Notice that above and below this portion of the wave, the air stream strikes the shock wave in an oblique direction, giving rise to an oblique shock wave.

Like the normal shock wave, the oblique shock wave in this region is a strong shock wave, since the air passing through it is reduced to subsonic speed. The primary difference is that the air stream passing through the oblique shock wave changes its direction, and the air stream passing through the normal shock wave does not.

The broken lines in Fig. 6-21 outline the area of subsonic flow created behind the strong shock wave. Particles passing through the wave at C, outside this area, do not slow up to subsonic speed. They decrease somewhat in speed, and emerge at a slower, but still supersonic, velocity. At C the shock wave is a weak oblique shock wave. Further out from the point at which the shock wave is normal to the flow, the effects of the shock wave decrease until air is able to pass the object without being affected. Thus, the effects of the shock wave eventually disappear, and the line cannot properly be called a shock wave at all. At this point it is called a Mach line.

Normal shock waves occur whenever air slows down from supersonic to subsonic speeds without a change in direction. Consequently, a normal shock wave can be created without an interfering body in the air stream. A good example of this occurs in airflow through a constricted tube, as shown in Fig. 6-22. Subsonic air enters the tube, and increases in speed as the area of the tube decreases until the air stream reaches the speed of sound. When the area of the tube increases again, the air stream increases in speed for a short distance, and then suddenly drops to subsonic speed by passing through a strong shock wave.

Similarly, normal shock waves can occur over the wing surfaces of a subsonic aircraft that exceeds its limiting Mach number, as shown in Fig. 6-23. The high-speed (but still subsonic) air stream flows up over the leading edge of the wing, increasing in velocity as it does so and passing the speed of sound. This corresponds to the flow in the constricted tube just beyond its narrowest section. The air flowing over the wing increases in speed for a short distance and then passes through

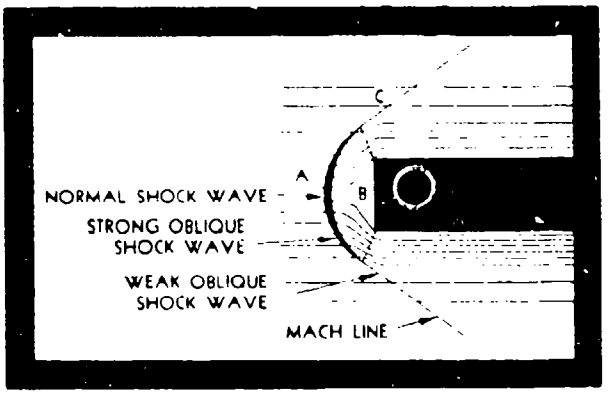


Figure 6-21. Normal shock wave created by a blunt object

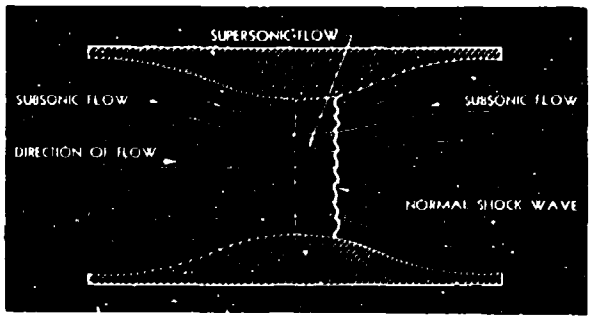


Figure 6–22. Airflow through a constricted tube

a normal shock wave, decreasing from supersonic to subsonic speed in the process. Notice that the shock wave was formed only during the instantaneous decrease in speed from supersonic to subsonic flow, and not during the gradual increase in speed over the leading edge.

When an aircraft flies fast enough, the air flowing over the leading edge of the wing may increase in supersonic speed smoothly, but when this air decreases in speed as it flows over the rest of the wing a shock wave is formed. That's why the shock wave forms near the middle of the wing when an aircraft is in transonic flight, moving just fast enough to cause supersonic airflow over the top of the wing.

Now consider what happens as the speed of the plane increases still further. Looking at figure 6–24, you can see that as the speed of the air over a typical wing increases, the area of supersonic flow increases, and the shock wave moves back toward the trailing edge. In addition, supersonic flow develops below the wing, and another shock wave is formed there as the airflow reduces

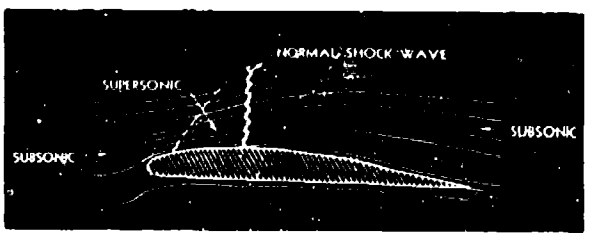


Figure 6–23. Airflow over a wing

in speed to subsonic flow. Finally, when the wing itself reaches supersonic speed, the shock waves on both the top and bottom of the wing have moved all the way back to the trailing edge. At the same time, a new shock wave forms in front of the leading edge because of the air piling up at that point.

The shock wave formed on the leading edge of the wing is separated from the wing by a small area of subsonic air, like the shock waves created in front of blunt objects described before. A shock wave that is separated from an object in this manner is called a "detached shock wave."

When it is first formed, a detached shock wave lies in a plane perpendicular to the airflow. As the speed of the air stream is increased the shock wave bends toward the object, forming what is known as a "Mach cone." The sharpness of the Mach cone created by an object is an indication of both the speed of the air stream and the shape of the object. Increasing either the speed of the air stream or the sharpness of the leading edge creates a sharper Mach cone.

Eventually, under the proper conditions of airspeed and object shape, the shock wave forms on the object itself; it is then said to be an "attached shock wave."

These conditions are illustrated in Figure 6–25. In a, you see the formation of a detached shock wave. When the speed of the object is increased, the Mach cone becomes sharper and the attached shock wave is formed, as shown in b. The same situation can be achieved by increasing the sharpness of the object, as in c.

COMPRESSIBILITY EFFECTS DUE TO NORMAL SHOCK WAVES

When normal shock waves first appear on the wings of an aircraft, the air passes through the shock wave in the same direction for a short distance. As the speed of the aircraft increases, further, the shock wave begins to move toward the trailing edge, and separation of the air stream occurs immediately behind the shock wave. The air cannot continue to follow the normal flow pattern created by the wing surface and, as a result, it tumbles in a random, turbulent motion.

When this turbulence starts to grow, it makes

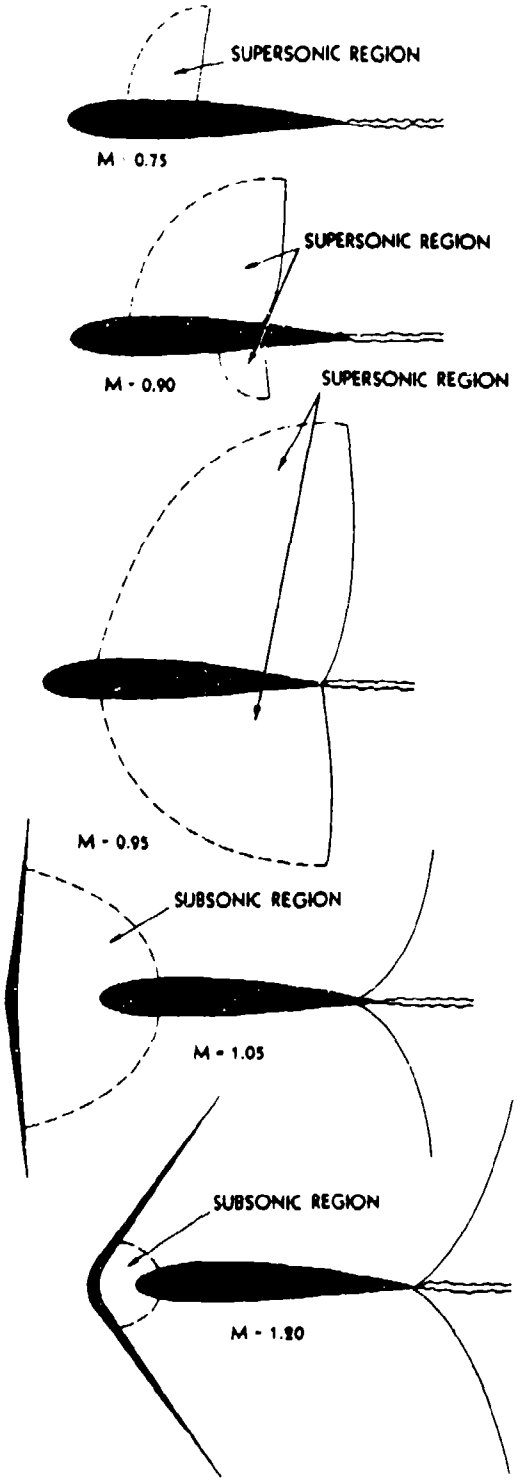


Figure 6–24. Shock waves at various speeds on a typical wing section

itself known by certain very annoying compressibility effects. Since these compressibility effects occur in flights at high subsonic Mach numbers, aircraft afflicted with them are often referred to by pilots as having the "Machs." Here are a few "Machs" that you can take as a warning that the worst is yet to come unless you take prompt action to get back below the limiting Mach number of your aircraft.

Lateral trim changes. These are due to the fact that any tendency to roll that has been corrected by trim tab adjustment may reappear as the trim tab loses its effectiveness at high speeds. Small differences in wing construction, for example, that would be unnoticed at low speeds may suddenly announce themselves at high speeds by producing rolling motion.

Rapid vibrations of the ailerons may produce what is known as "buzz."

Noticeable twisting of the wings.

Loss of longitudinal stability—"tuck up" or "tuck under".

Sometimes these effects occur in one part of the aircraft and sometimes in another. Different types of aircraft naturally exhibit slightly different effects.. In any event, whenever you notice these compressibility effects, the one sure way to cure the situation is to reduce your speed by throttling down, climbing carefully, and using the speed brakes. At this point it might be well to emphasize the need for being familiar with the characteristics of your dive brakes at different speeds. Some may cause buffeting or "tuck under" at high speeds.

At any rate, if you don't succeed in reducing your speed you will probably be sorry because worse effects are yet to come. The separation of the air flow over the wings will produce severe turbulence, and this will create more trouble.

Buffeting is a compressibility effect that is almost sure to show up. The turbulent air, striking the horizontal surfaces of the tail in an irregular manner, makes the aircraft pitch unpredictable. Part of the buffeting effect may be transmitted directly to you through the stick and pedals.

Another undesirable compressibility effect that usually shows up at about this time is a loss of longitudinal stability. The aircraft may either

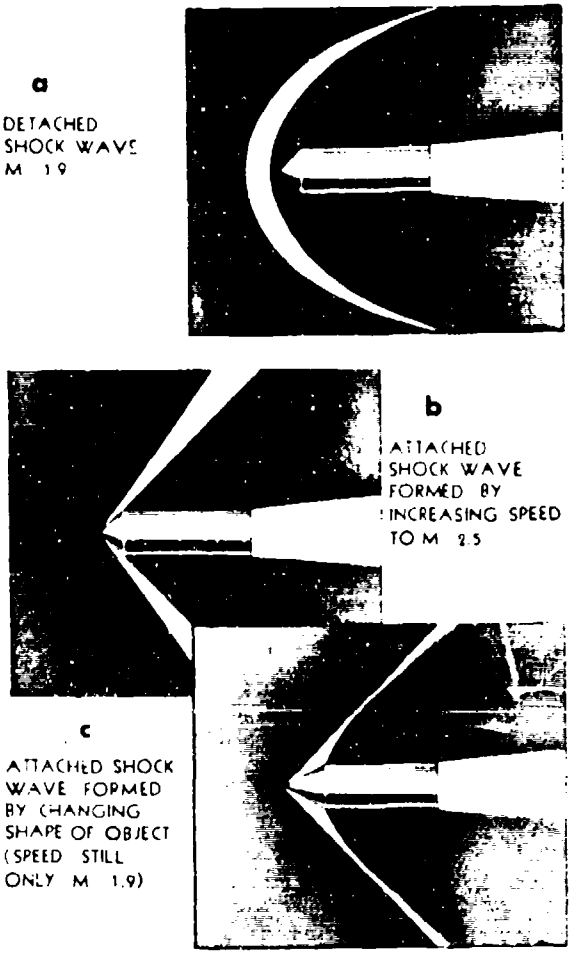


Figure 6–25. Attached and detached shock waves

"tuck up" or "tuck under," depending on its design. Of the two, the latter is considerably more dangerous because it tends to increase the speed.

Tuck under can be attributed to two causes—"shock stall" and loss of downwash on the tail surfaces. "Shock stall" is similar to the stall that occurs in subsonic flight. It is caused by the large amount of separation of the airflow over the wings. The larger share of the blame for tuck under, however, must be placed on loss of downwash to the tail surfaces. When the flow of air over the wings is smooth, the air stream striking the tail surfaces has a downward direction; when separation occurs, downwash is lost, and the normal force pushing down on the tail surfaces disappears. As a result, the tail goes up, the nose dips, and down you go.

The important thing to realize is this: the first sign of buffeting or tuck under calls for immediate action. As any pilot knows, the thing to do is to reduce airspeed and get the nose up. Action has got to be fast, for just as soon as the nose tucks under and the aircraft starts going into a dive, the situation is going to get worse, not better. As the aircraft picks up speed in the dive, the separation becomes more pronounced, and it becomes harder and harder to pull out of the dive. The greater the turbulence of the air stream, the greater the elevator angle and stick force required to pull out.

In case you might be tempted to experiment in the critical Mach number region, look at the graph in Figure 6–26. This graph represents a typical example of the stick force required to trim a subsonic aircraft in level flight as the Mach number increases. Beyond Mach 0.6, an increasing push force is required to trim. As compressibility effects occur above Mach 0.7, the aircraft starts to tuck under, and both a large stick movement and an increasing pull force are required to prevent immediate entry into a dive. The rapid rate at which the stick-force curve shoots upward on the graph makes it clear that fast corrective action is needed.

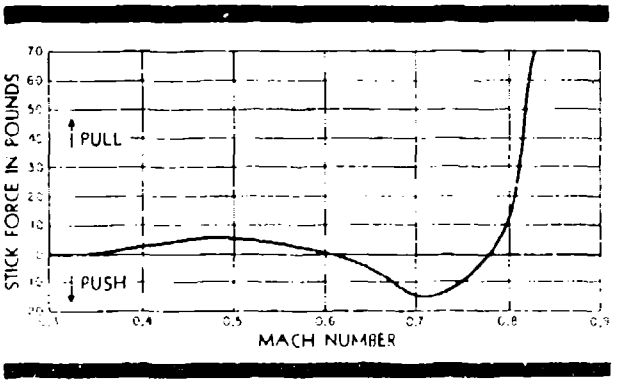


Figure 6–26. Stick forces required to trim subsonic aircraft

Bear in mind that this situation varies with the aircraft in question. The stick forces encountered in other aircraft when the limiting Mach number is exceeded depend entirely on the design of the aircraft; some may tuck under; others may develop tuck up characteristics.

Now there is one more very important fact in connection with tuck under: While it is perfectly possible to get into tuck under difficulties by exceeding your limiting Mach number at level flight or shallow dives, the effects are even more serious if you exceed the limiting Mach number during maneuvers, especially at high altitudes. This stands to reason because:

1. During maneuvers, the angle of attack is exaggerated, producing greater separation effects.

2. In the thin air at high altitude you can pick up speed very, very rapidly.

Under certain conditions, tuck up can be equally dangerous. When an aircraft decides to tuck up, it may do so even though the stick is being pushed forward as hard as possible and full down trim tab is rolled in. In the case of a fast, steep dive, the sudden development of extreme tuck up characteristics may cause a violent pull out that will injure both pilot and aircraft.

Eliminating Compressibility Effects

The obvious solution to the problem of compressibility effects is to keep your airspeed below that at which such effects occur. In this connection, it is important to distinguish between *Tactical* Mach number and *Limiting* Mach number:

Tactical Mach number is the highest speed (Mach number) at which neither buffet nor trim changes affect a gunnery run.

Limiting Mach number is generally considered the Mach number at which the compressibility effects produce a noticeable lack of control in the plane.

Of the various reasons for tuck under, the effect of the turbulence and lack of downwash from the wings seems to be the most powerful. Solution: Position the horizontal tail surfaces as far as practical from the turbulence off the wings. As you can see from looking at any modern jet aircraft, this solution has been put into effect by positioning the horizontal tail surfaces on the vertical tail surfaces so that they are considerably above wing level. (Figure 6-27.)

By alleviating turbulence effects on the horizontal tail surfaces in this way, the designers also beat the problem of pitch buffeting. At the same time, though, they created a new compressibility effect, for the separation of the air flow over the horizontal stabilizer now took place at the junction of the stabilizer and the rudder fin. The result is rudder buffeting. In addition to giving the rudder a severe pounding, this may induce a yawing effect.

Compressibility effects can be further eliminated by increasing the limiting Mach number. The accepted methods of doing this are to use thinner wing sections, sweptback wings, and low aspect ratio--that is, short and stubby wings. These features are now present in many jets.

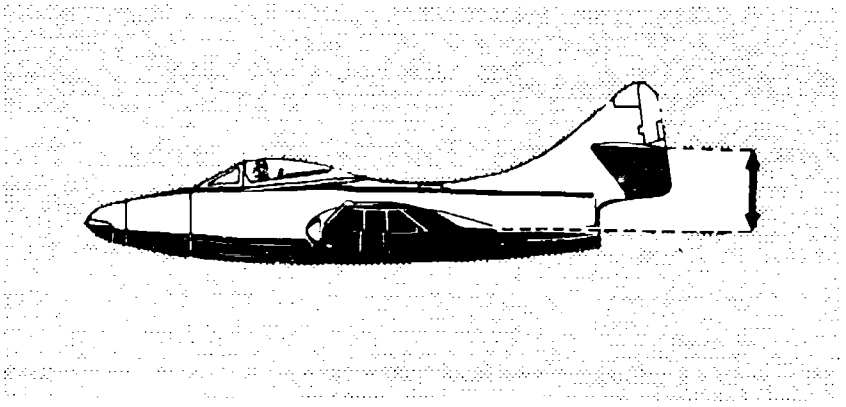


Figure 6-27. High tail surfaces help prevent "tuck under"

CHAPTER 7

RADIO EQUIPMENT

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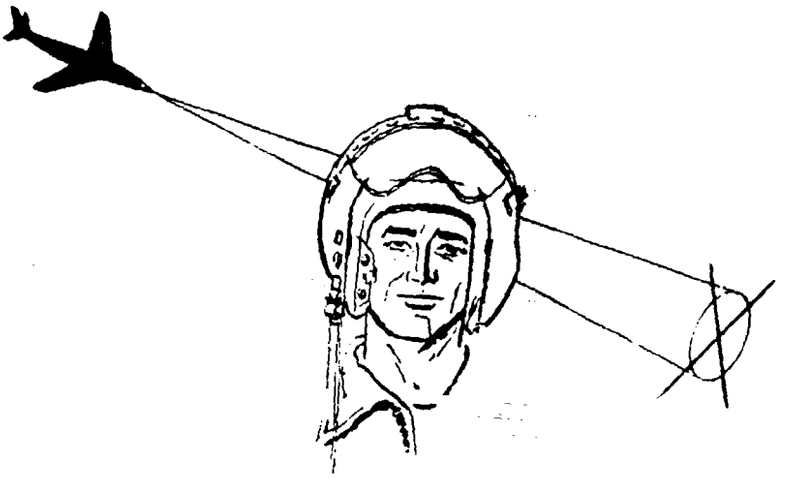


CHAPTER 7

RADIO EQUIPMENT

THIS chapter describes some of the radio equipment used in instrument flight. However, it does not cover engineering or theoretical data, nor does it tell you how to use the equipment. Two of the types of the equipment, however—the radio compass and the VOR/Omni Range—are so important in all-weather flight that they are each covered in special chapters later on.

FREQUENCIES

All radio equipment transmits or receives signals on a certain frequency or frequency range. The receiver must be tuned to the frequency of the transmitter in order to receive the transmitted signal. Frequencies are measured in cycles per second, but even the lowest radio frequencies are at least in thousands of cycles per second, called kilocycles, and higher frequencies are measured in millions of cycles per second, called megacycles. A megacycle is thus equal to a thousand kilocycles, and 3,105 kilocycles, for example, is the same as 3.105 megacycles.

For convenience, radio frequencies have been classified into a spectrum ranging from Very Low to Super High (Fig. 7-1), with their reception characteristics differing according to the frequency. All radio transmissions are radiated into infinite paths. Those which travel along the surface of the ground are called *ground waves*. The ground waves may follow the surface of the earth for a distance, depending on the conductivity of

RADIO FREQUENCY SPECTRUM

Frequency in Kilocycles	In Megacycles	Designation	Abbreviation
10-30	0.01-0.03	Very low frequency	VLF
30-300	0.03-0.3	Low frequency	LF
300-3,000	0.3-3	Medium frequency	MF
3,000-30,000	3-30	High frequency	HF
30,000-300,000	30-300	Very high frequency	VHF
300,000-3,000,000	300-3,000	Ultra high frequency	UHF
3,000,000-30,000,000	3,000-30,000	Super high frequency	SHF

Figure 7-1. Radio Frequency Spectrum

the terrain (sea water is a good conductor; rocky, desert, and jungle lands are poor). They may travel directly from transmitter to receiver (line of sight); or they may be reflected upward from the ground and become sky waves. *Sky waves* are signals which have travelled upward until they hit the ionosphere (Fig. 7-2). They are bent toward the earth by refraction, the angle of bending depending on their frequency. Low-frequency waves that hit the ionosphere are reflected back to the earth and go on for a long distance, but the highest frequency waves penetrate the ionosphere and are lost.

The *very low frequency* (VLF) (10-30 kc) and the *low frequency bands* (LF) (10-300 kc) are used chiefly for long distance transmission, particularly for transoceanic service. The attenuation of these frequencies is always low, and their ground wave is stable, with little seasonal variation.

In the *medium frequency band* (MF) (300-3000 kc), the lower frequencies are far more dependable than the higher ones. At the lower frequencies, the ground waves can be received up to 300 or 400 miles, and the sky waves will travel for thousands of miles. At the higher frequencies, the ground waves can be received only for short distances, and the sky waves are dependable only at night, when they can be received at practically any distance from the transmitter. Only the lower half of the medium frequency band is widely used. The frequencies from 100-500 kc are used for marine communications, aircraft radio, and direction finding; the frequencies from 550-1600 kc are used for commercial broadcasting.

At frequencies in the *high frequency band* (HF) (3-30 mc), transmission depends chiefly on the sky waves rather than on the rapidly attenuated ground wave. However, the sky waves at these frequencies are not always refracted from the ionosphere. It depends on the frequency and the condition of the ionosphere. Since conditions in the ionosphere change with the time of day and with the season, the distances that can be reached with high frequency transmission vary greatly.

Frequencies in the *very high frequency band* (VHF) (30-300 mc) have no usable surface wave, and their sky waves are not slightly refracted by the ionosphere. Distant transmission is successful, though, if the transmitting and/or receiving antennas are high enough to allow the use of direct waves. Sometimes, special conditions in the ionosphere permit long range transmission at such frequencies. This does not happen often enough, though, to depend on it for regular long distance transmission. The VHF band is used for short distance, line-of-sight transmissions such as in television, police radio, portable equipment, and aircraft landing beacon transmissions and aircraft communications.

In the *ultra high frequency band* (UHF) (300-3000 mc), and the *super high frequency*

band (SHF) (3000-30,000 mc), only the direct waves can be used. Communications at these frequencies are therefore limited to a short distance beyond the horizon. Still, the lack of static and fading in these bands makes their use very desirable. Generally, these frequencies are transmitted by highly directive antennas to concentrate the energy into narrow beams and increase their field intensities. By the same means, UHF and SHF transmissions can be focussed on one small area very much like a beam of light.

Aircraft have come to use the VHF and UHF bands very widely in recent years for two reasons: (1) A need for more frequencies to avoid overcrowding, and (2) the security from enemy "eavesdropping" which is gained by line-of-sight transmissions. Certain undesirable effects have been the price of this progress. Both VHF and UHF sets have limited range. However, just as you can see farther at higher altitudes, so you can use your VHF or UHF radio at longer ranges when flying at higher altitudes (Fig. 7-3.) This means, for example, that you should call your next landing field before beginning your letdown. It means that you should send distress messages before too much altitude is lost. Furthermore, UHF waves radiate in a pattern relative to the antenna. Every different installation has different lobe characteristics, and you must learn from practice how to orient your aircraft relative to the party with whom you wish to communicate in order to get good reception. You must learn to "aim the lobes" of your UHF transmission. A good tip to remember is that when you are in a position which lets you hear the other station or aircraft transmit clearly, you are also in a good position to be heard by him when you transmit. Avoid trying to communicate with a UHF set which is hidden from your "line-of-sight." If a hangar or a mountain lies between a UHF transmitter and receiver, reception is poor or impossible.

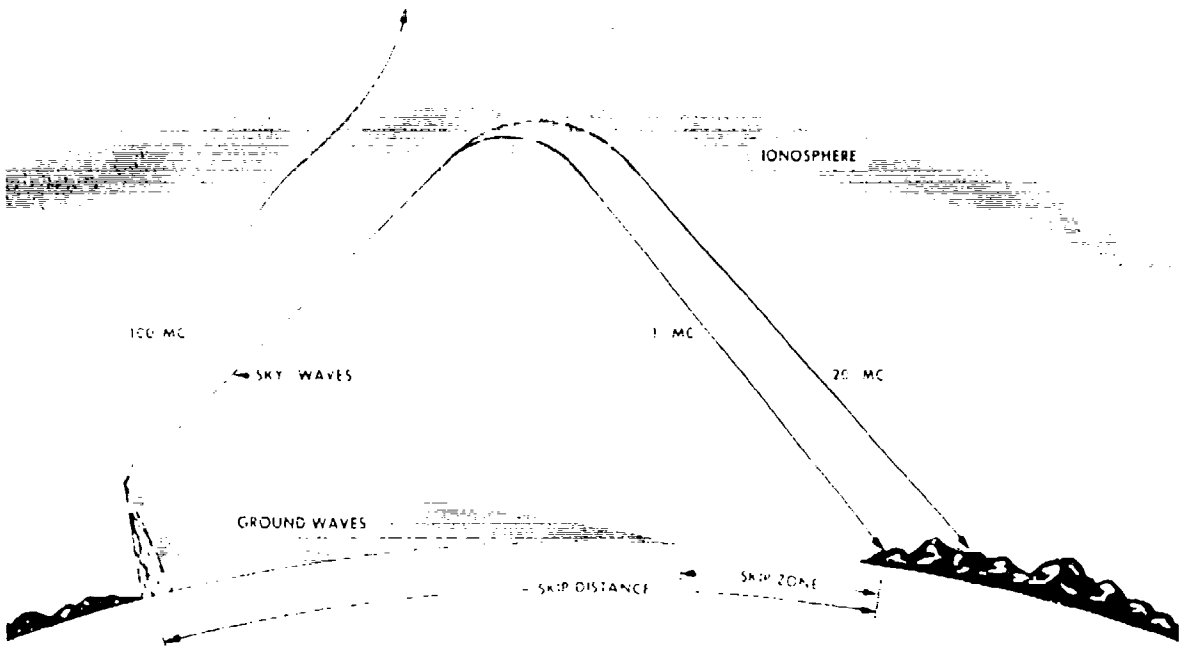


Figure 7-2. Sky waves

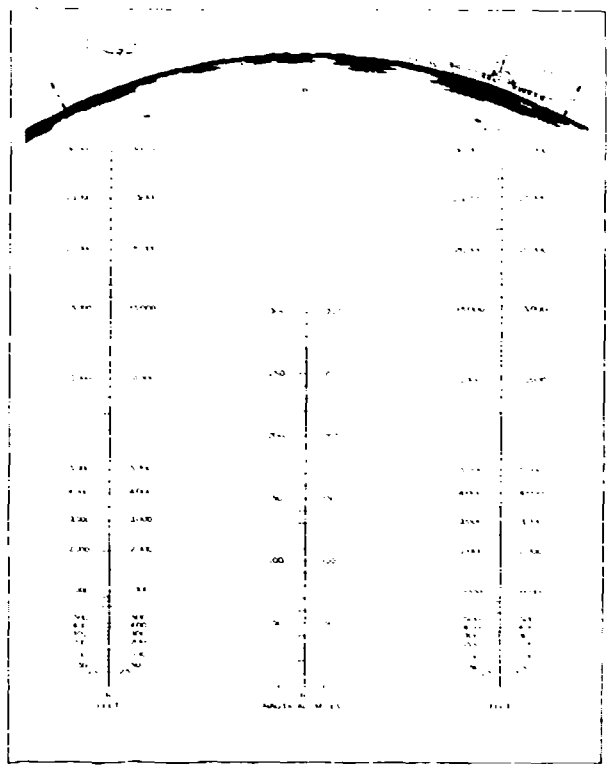


Figure 7–3. Range of UHF/VHF communication. By means of this line-of-sight nomograph, you can read UHF/VHF maximum range. Connect the plane's altitude (h) by means of a straightedge with the altitude (H) of the other transmitter-receiver. Read maximum range in the center column (R)

COMMUNICATIONS EQUIPMENT

Naval aircraft often have two or more radio transmitter-receivers for communication purposes. These may be the same or different types. Larger aircraft, of course, have more equipment than small ones.

AN/ARC-1

The ACR-1 is a VHF transmitter-receiver capable of operation on ten pre-set channels, including a guard channel. When the ARC-1 is to be used, both pilot and co-pilot junction boxes should be set to "ARC-1." Turn the power switch on, but wait at least 45 seconds before transmitting. (Earlier use will draw too much current and may cause damage or blow a fuse.) Set the channel control switch to the desired channel, and adjust the volume control as desired. Set the three-position switch on the transmitter control box as required:

MAIN T/R: To receive and transmit only on selected channel

BOTH: To receive on both the selected channel and the guard channel, but transmit only on the selected channel.

GUARD: To transmit and receive on guard channel, regardless of channel selector position. Used for emergency messages.

AN/ARC-5

The ARC-5 is another communications set found in naval aircraft—a two-channel assembly in which two transmitters are provided, each set to a predetermined medium frequency used for aircraft communications.

The question may arise as to when to use the VHF-UHF or the MF equipment. Normally VHF gives better reception than MF in daytime, but at night greater range is obtained from the MF equipment whose emissions are readily reflected from the ionosphere and permit greater range. Of course, when you are beyond the line-of-sight range from the other station, you cannot use VHF or UHF.

UHF Equipment

Naval aircraft equipped for UHF usually have the ARC-27, 19-channel transmitter-receiver or possibly the ARC-12, 10-channel transmitter-receiver.

The ARC-27 equipment consists of a receiver transmitter and one or more control units. Basically the control units are of two types: those on which the operator can select certain preset channels, and those on which the operator can tune any of the 1,750 channels between 225 and 339.9 megacycles. You can get a good idea of the set from the following typical, small-aircraft set-up.

A common ARC-27 installation consists of three units. The receiver-transmitter unit, shown in Figure 7-4, and the master control unit, in

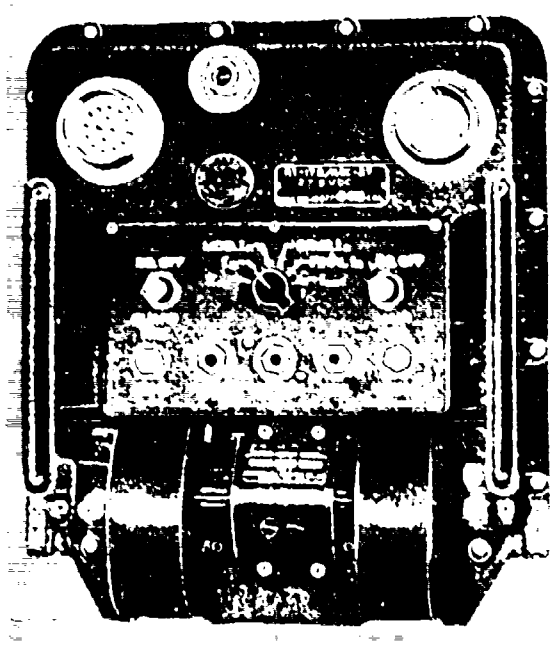


Figure 7-4. Receiver-transmitter RT-178/ARC-27

Figure 7-5, are together but clear of the cockpit. The control unit C-626 is used to set up the channels the pilot can select on his remote control box. Where the C-626 is located near the receiver-transmitter, it is possible to receive and transmit from that location by plugging the mike and phones into the receiver-transmitter, setting the C-626 control to LOCAL, and setting up the desired channel. Normally, however, as a pilot, you use only your remote control box, which may be any of several types; a typical one is the C-628A shown in Figure 7-6. On this box you can select any of the 18 channels plus the guard channel; the frequencies assigned to these channels are shown on a card nearby. You select the type of operation by another switch—OFF, T/R (transmit and receive), T/R+G REC (transmit and receive, plus receive guard channel), or ADF (automatic direction finding via Direction Finder Group, AN/ARA-25). The purpose of the volume control (VOL) is obvious. The sensitivity control (SENS), available only on later models, permits sensitivity adjustment (up to the maximum sensitivity preset on the receiver unit itself). Other types of control boxes are similar, all using the same receiver-transmitter and offering the same quality of reception except as antenna installations may create differences. The ARA-25 Direction Finder Group is covered later in this chapter.

RADIO COMPASSES

This section discusses the three most common types of radio-direction-finding equipment in general use, how to tune and adjust them, and how to use the various antenna positions. It does not discuss flight procedures using the radio-compass; these are covered in Chapter 18. The three radio direction finding sets discussed are the ARN-6 and ARN-7, which operate over a range from 100 to 1750 kc, and the ARA-25 UHF/DF gear, which is usually found in conjunction with the ARC-27 UHF communications console. The ARN-6 and the ARN-7 are similar, but the ARN-6 is the newer, smaller, and better of the two.

Loop Receiving Antenna

The operation of a radio compass depends chiefly on the characteristics of a loop antenna. A loop antenna, supported vertically, gives maximum reception when the plane of the loop is in line with the transmitting station. As the loop

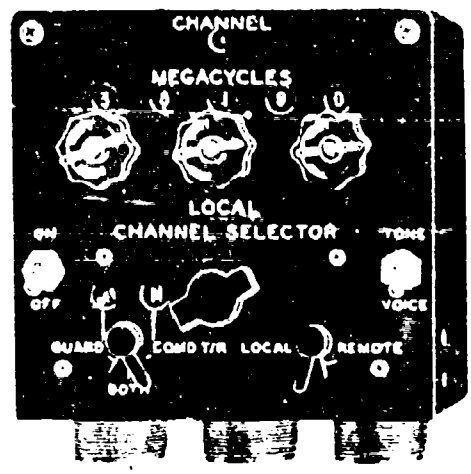


Figure 7-5. Master control unit C-626/ARC-27

is rotated from this position, volume gradually decreases, reaching a minimum when the plane of the loop is perpendicular to a line from the station. This is known as the minimum reception area, commonly referred to as the "null" of the loop. As rotation is continued, the volume gradually increases and again reaches a maximum value when the plane of the loop is once more in line with the radio station. (See Fig. 7-7.)

Use of the Null Position

It is very difficult to determine at exactly which position of the loop a signal received is at a maximum. The exact position of the loop that gives a minimum signal is much easier to determine. Consequently, in using the loop antenna for direction finding, the point of minimum reception (null) is sought instead of the point of maximum reception. With a well-designed loop antenna, the exact *minimum* can be obtained within $\frac{1}{2}^\circ$ of loop rotation. As you can see from Figure 7-8, it would be difficult to obtain the exact *maximum* within several degrees of loop rotation.

When you rotate the loop to a null position either by rotating the aircraft or the loop, you know definitely that the station being received is on a line perpendicular to the plane to the loop. However, though you know the direction of this line, you don't know whether the station is ahead of or behind the aircraft along this line. This is called the 180° ambiguity.

Automatic Radio Compass

The automatic radio compass equipment includes a loop, a non-directional antenna, a radio receiver, and a 360° scale to indicate the position of the loop with reference to the longitudinal axis of the aircraft. It has, in addition, a loop motor mechanism for rotating the loop, and loop control circuits for automatically controlling the loop motor mechanism. The loop control circuits and the loop motor mechanism automatically rotate the loop to a null position. By electronic means, they resolve the 180° ambiguity and cause the indicator to show the correct direction of the radio station being received.

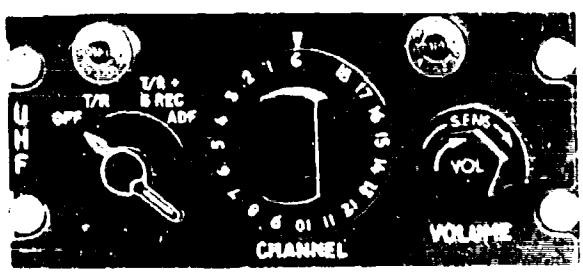


Figure 7-6. Radio set control C-628A/ARC-27

RADIO COMPASS AN/ARN-7

The principal components of radio compass ARN-7 are the receiver, non-directional antenna, directional antenna (loop) assembly, two indicators, two control boxes, and an inverter.

Antenna Assemblies

The non-directional antenna may be one of several types. The exact length of this antenna does not matter, but the greater the proportion of its vertical length to its horizontal length, the better it works. Vertical antennas, supported by stubmasts, are satisfactory. The antenna and its lead-in should be at least three feet away from the loop.

The loop antenna of the ARN-7 is an 8-turn coil with a center tap that is grounded. It is electrostatically shielded by an aluminum shield split at the top, and is housed in a plastic teardrop housing. The loop assembly is installed on either the top or belly of the aircraft, generally on the fore-and-aft center line of the fuselage, as far away as practicable from sources of interference in the aircraft. The loop is mounted on a rotatable shaft which is driven by a motor through a gear train.

The autosyn transmitter electrically transmits the angular position of the loop to one or two autosyn indicators (receivers), causing the pointer on each indicator to rotate as the loop does, so that the exact position of the loop can be read at either of the indicators.

Interference by wings, engines, and other parts of the aircraft may cause distortion of the radio waves striking the loop and keep the loop from lining up properly with the station. The error caused by these factors is known as "quad-

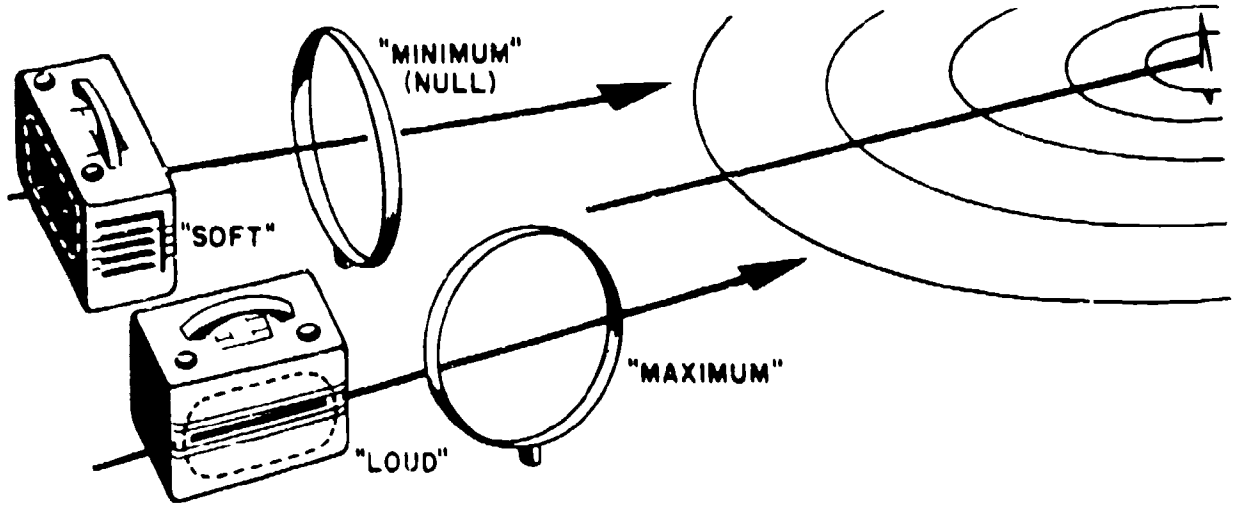


Figure 7-7. Loop position characteristics

rantal error" radio compass deviation). Correction for quadrantal error is applied through the compensator unit which couples the loop shaft to the autosyn motor. The compensator does not turn the autosyn motor to the exact position of the loop but to a corrected position. The corrected position is then transmitted to the indicators.

Control Boxes

Radio compass AN/ARN-7 is remotely controlled from one or two control boxes, depending on the type of installation. In the lower right hand corner of each control box is a control switch. When pressed, this switch operates a relay which transfers control from one box to another. A green light is lit on the box which is in control. (See Figure 7-9.)

A band-selector switch on each box controls a band change motor which switches in the tuned circuits for the desired bank. Radio compass AN/ARN-7 has a 4-position band selector switch with the following bands: 100-200 kc, 200-419 kc, 410-850 kc, and 850-1750 kc.

A tuning crank turns the tuning condensers in the radio compass unit to the exact frequency desired. It also turns the dial. A tuning meter helps make tuning accurate. Maximum deflection of the pointer to the right indicates best receiver tuning.

A four-position function switch controls the manner in which the compass operates. On the OFF position, the compass is inoperative. On COMP position, both the sensing (non-directional) and loop antennas, and all the loop control circuits are used. In this position, the loop is automatically rotated to face the station to which the receiver is tuned. The indicator shows the direction in which the loop faces.

On ANT position, only the non-directional antenna is in the circuit, and the radio compass is used as any other communications receiver. On LOOP position, only the loop antenna is used. When the switch is on LOOP, the position of the loop antenna is shown on the indicator, *but the loop is not rotated automatically.* On this posi-

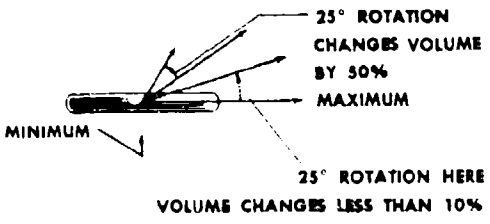


Figure 7-8. Loop signal patterns

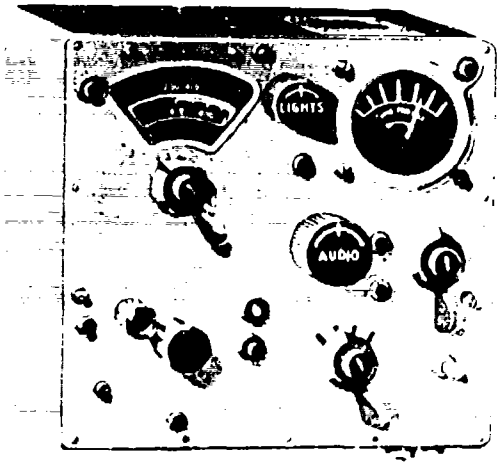


Figure 7–9. AN/ARN–7 control box

tion, the equipment is used as a compass with a manually controlled loop.

The LOOP L-R switch operates only when the function switch is on LOOP. It causes the loop to be rotated in a clockwise or counterclockwise direction, depending on whether the switch is turned to the left or right. The AN/ARN–7 has two speeds of rotation which are possible in either direction. Merely turning the switch to the left or right causes the loop to rotate at a slow speed. Turning the switch and at the same time pressing the button in the center of the switch causes the loop to rotate rapidly.

The AUDIO control knob controls the loudness of the signal. On COMP position, it varies a resistor in the headset circuit which controls the level of the audio signal in the headset, but it does not affect the sensitivity of the receiver. On this position, sensitivity depends solely on the Automatic Volume Control (AVC). Since this tends to keep the signal intensity constant, it makes it hard to get the best tuning either by sound or by tuning meter. The COMP position should therefore not be used for radio range flying. The AVC can cause course-widening, and signal reversing, and can make volume builds or fades difficult to detect. On ANT and LOOP positions, the audio control varies a resistor in the radio circuits and determines the level of the audio signal by controlling the sensitivity of the receiver. Where two control boxes are used, it is possible to vary the volume at the box not in control, only if its function switch is on COMP or OFF position.

Two spare instrument lamps are mounted on the control box. Between them appears the word SPARES. The LIGHTS control regulates the brilliance of the instrument lamps on the control box.

The CW-VOICE switch on the control box enables you to control the set for either continuous wave reception or voice reception.

Indicators

Two types of indicators are used with the ARN–7. They are both driven by an autosyn receiver mechanism which is almost exactly the same as the autosyn transmitter mechanism at the loop. Both indicators show the angular position of the loop with reference to the longitudinal axis of the aircraft.

Indicator I–81, known as the pilot's indicator, is generally installed on the pilot's instrument panel (Fig. 7–10). The scale divisions on this indicator each represent 5°. The zero is omitted in all the number indications. Thus, 30° is indicated by 3, 60° is indicated by 6, and so on. The line marked 0, like the lubber line on a magnetic compass, indicates the longitudinal axis of the aircraft.

Indicator I–82, known as the navigator's indicator, is generally installed in the navigator's or radio operator's position. The scale divisions of this indicator each represent 1°. The scale may be rotated by turning the knob marked VAR. On this indicator, the triangular index arrowhead is in line with the longitudinal axis of the aircraft and represents the nose of the aircraft.

Power Supply

Radio compass AN/ARN–7 requires both a DC and an AC power supply. The DC power is used for the operation of the control relays and band-switching motor, and is supplied directly by the central power system of the aircraft (CPS). The 400-cycle, 115-volt, AC power used for the receiver, loop motor, and autosyn transmitter is supplied by an inverter unit.

An inverter is a DC motor and an AC generator combined in one machine. The inverter ob-

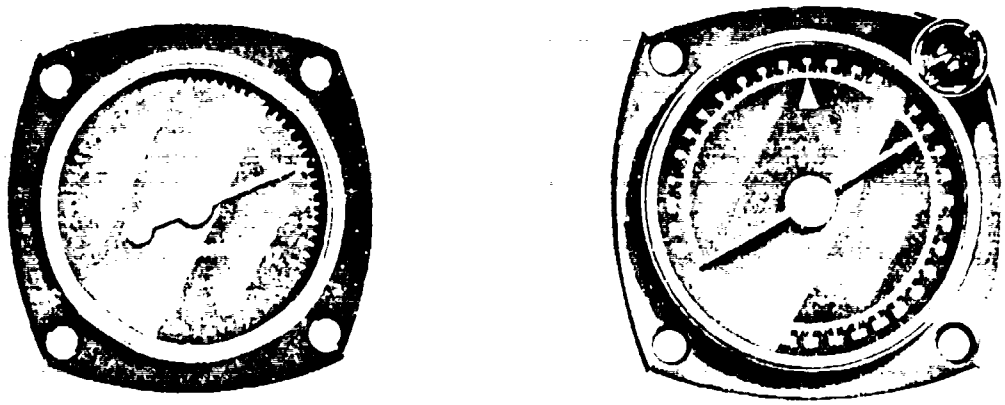


Figure 7-10. Radio compass indicators I-81 (left) and I-82 (right)

rains DC power from the CPS and converts it into 400-cycle, 115-volt, AC power. In most aircraft, the inverter is turned on by a separate switch, but in some it is turned on by the function switch of the radio compass.

RADIO COMPASS AN/ARN-6

Radio compass AN/ARN-6 differs from the ARN-7 only in a few respects, mostly in the circuits. It does not use an inverter to supply AC to a high voltage rectifier or to the automatic circuits. Instead, a vibrator unit built into the receiver unit provides alternating current for automatic operation.

Like the ARN-7, the ARN-6 uses non-directional antennas of several types. These may be belly or top mounted but must be at least three feet from the loop antenna. The loop antenna of the ARN-6 (Fig. 7-11) is electrostatically shielded and is located in a hermetically sealed glass dome filled with dry nitrogen. The loop is rotated by a drive motor through a reducing gear train. The entire loop unit is placed in a housing and may be located either on the top or bottom of the aircraft. The autosyn system in the ARN-6 is essentially the same as the autosyn system in the ARN-7.

Like the ARN-7, the ARN-6 may be remotely controlled from one of two remote control boxes. The button for switching control is in the center of the band change switch, and control of the equipment is indicated by the functioning of the Dial lights (Fig. 7-12). In some installations, as in fighter aircraft, only one control box is used. The degree to which the LOOP L-R switch is turned to the left or right controls the speed of the rotation of the loop.

Two indicators are used with the ARN-6 radio compass. The pilot's indicator has an adjustable scale and has calibration markings. The navigator's indicator is identical to the I-82. A pilot's night indicator with the pointer and numerals covered with luminescent material is also available for AN/ARN-6 installations.

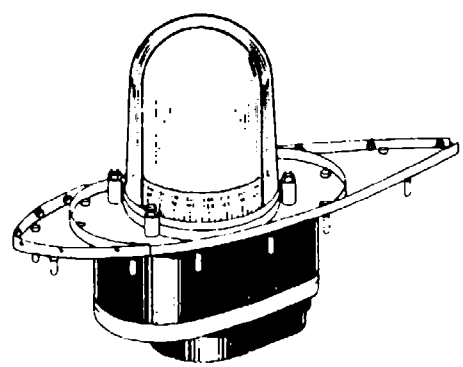


Figure 7-11 ARN-6 loop antenna

UHF/VHF HOMERS

Sometimes direction finding adapters are provided for the VHF or UHF receiver. These are called "homers." The AN/ARA-8 adapter, for example, permits homing on a VHF station which transmits on any frequency between 120 and 140 mc, whether it is an aircraft or ground station. This instrument is not suitable for 360° direction finding other than homing and is not in general naval use. The AN/ARA-25 is a direction finder for UHF which is sometimes provided as part of the ARC-27 console.

The ARA-25 is always used in conjunction with some sort of UHF receiver such as the ARC-27 because it has no receiver of its own. When the ARC-27 control is set to ADF, signal reception is transferred from the regular UHF antenna to the ARA-25 antenna (Fig. 7-13), and the electronic control amplifier is turned on. (If the ARC-27 is OFF when you want to switch to ADF, wait 3 minutes for warm-up, but, if the ARC-27 is at any setting except OFF no warm-up is required.)

The antenna has a heart-shaped field pattern. The termination of the antenna is switched from one end of the antenna to the other 100 times per second, thus reversing the field pattern 100 times each second. Through use of what is known as a square wave, a phase-sensitive motor control unit controls an antenna drive motor which rotates the antenna until the two levels of signal voltages at the output of the antenna become equal. This reduces the square wave control voltage to zero and stops the motor. Thus the machine seeks a certain antenna orientation in relation to the signal being detected.

There are actually two such "zero points", in other words 180° ambiguity again, but if the antenna stops on the wrong one, the first vibration or swing of the plane sets the motor going and antenna turning again until it hits the right "zero point". In other words, the false null is unstable. The angle of the stable null is measured by a synchro-generator in the antenna assembly and transmitted to the dial of the indicator.

The ARA-25 uses either the ID-90A indicator or the ID-250 indicator. The latter is often called the RMI and is the same one that is used for Tacan or Omnirange bearing information. If used with the RMI, the ARA-25 readings will usually be on the single needle. The RMI indicator is discussed in connection with its compass unit, the MA-1, in Chapter 4 of this manual.

Figure 7-12. AN/ARN-6 control box

The ARA-25 is used in the same way as other direction finders except for the line-of-sight limitation on its range, which is the same as for any other VHF-UHF equipment. (See Figure 7-3.)

Areas of Inaccurate Readings on ARA-25

Directly Above the Signal Source. Directly above the signal source there is a cone-shaped area in which the equipment may show an unstable indication on the indicator.

Below the Signal Source. If the signal source is a higher flying aircraft, reflections from its surfaces may cause inaccurate indications.

Below the Horizon. If the signal is too weak for good results and you suspect that the horizon appears between the source of signal and the aircraft, fly higher to increase signal strength.

Maneuvering. Some bearing instabilities occur in normal maneuvering because of the propagation characteristics of the received signal.

OMNIRANGE AND DME EQUIPMENT

Chapter 19 covers the Omnirange and DME ground equipment and how to use them in flight. At this point, however, you should know what airborne equipment is carried in your aircraft for use of Omni and DME, and how to operate it. This is part of the cokpit check-out and ground-school training which precedes the part of the instrument course in which you engage in instrument flight practice.

The AN/ARN-30 VHF navigational receiver provides limited VOR (omnirange) reception, and is often found in older or training aircraft. It is not designed to indicate distance from DME stations. The ARN-14 receiver, using the ID-249 course indicator and the ID-250 radio magnetic indicator, is the more modern instrument. It also does not indicate distance from DME stations.

Omni receivers currently in production are properly called VHF navigation receivers because they are multi-purpose receivers designed to receive other signals in addition to those of the omnirange itself, including VAR ranges and ILS signals. They receive frequencies from 108 to 136 mc.

DISTANCE MEASURING EQUIPMENT (DME)

The DME operates on the principle of IFF with the position of the airborne and ground com-

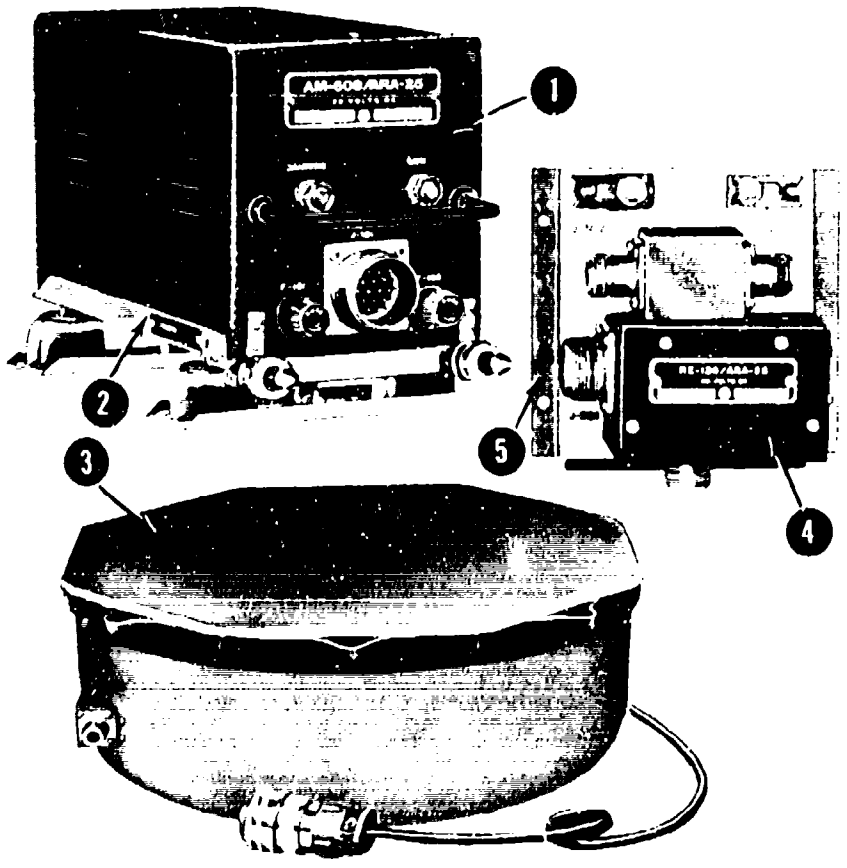


Figure 7-13. Direction-finder group AN/ARA-25

1. Electronic control amplifier
2. Amplifier mounting
3. Antenna assembly
4. Solenoid relay
5. Mounting plate

ponents reversed. The initial signal pulses are transmitted from the aircraft. The ground unit (Transponder) receives these pulses and then retransmits them back to the aircraft over a different frequency. The airborne component then measures the time differential between the transmitted signal and the "received" signal and converts the pulse time differential into nautical miles. The mileage information is presented on a dial similar to that used in automobile speedometers.

The mileage received is "slant mileage." However, the difference between slant mileage and actual horizontal mileage is not more than the instrument error except when the aircraft is in the vicinity of the station and at high altitudes. If it is found desirable in the future, a component solver may be included in the airborne component to convert this slant mileage to horizontal mileage.

VORTAC, A COMMON SYSTEM

The distance-measuring equipment described above, serving only some 300 aircraft which are equipped to use it, is being phased out of service and by 1960 will be entirely replaced. In its stead will be used a system of air navigation called Vortac, which includes continued and expanded use of the omnirange (VOR) azimuth navigation system with its voice and ILS localizer features. Integrated with VOR under the Vortac system will be a new DME which is compatible with Tacan. This is Tacan DME. Tacan is an ultra high frequency navigation system developed by the Navy and described in detail in later paragraphs of this chapter. The Vortac system becomes a part of the national air navigation common system, serving both civil and military aviation. For military aircraft, Tacan equipment provides both azimuth and distance information; for civil aircraft, azimuth information is provided by existing VOR facilities, while Tacan DME provides distance information. Vortac thus provides the United States with a comprehensive and modern distance-measuring and directional navigation system.

Under the continuing program of providing distance equipment at ILS stations, Tacan-compatible DME will be used.

The older DME gear now being phased out of service, when used with VOR, provides the rho-theta or distance-bearing information needed for the operation of present-day civil and some military aircraft. However, the combined VOR-DME system, for technical reasons, cannot be used at sea in carrier aircraft operations. Moreover, directional information provided by Tacan is more accurate than that provided by VOR. Tacan provides the degree of accuracy needed to fly, for example, a precise intercept course to attack an intruding aircraft. Thus with military aircraft requiring low error tolerance and with naval aircraft requiring a system usable in carrier operations, it became apparent that Tacan was the best navigational system in existence for military aircraft. Moreover, an expanding civil aviation in the United States made it obvious that a common system was needed. It was seen that an unaccept-

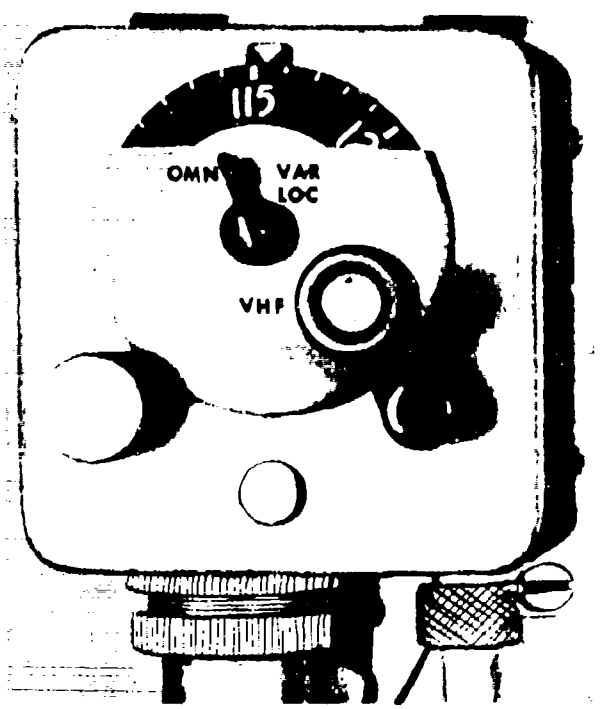


Figure 7-14. Frequency selector

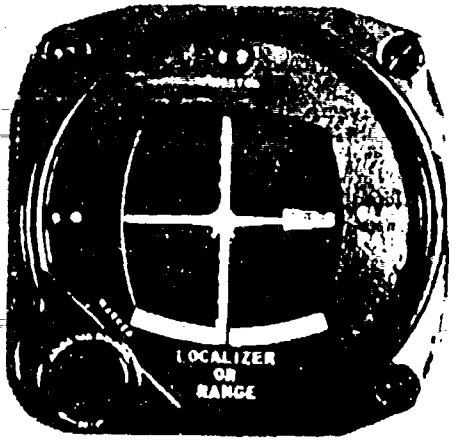


Figure 7-15. Deviation indicator

able situation on the airways could result as early as 1959—when civil jet transport flights will begin—if the military used one system and the airlines and private pilots another. The common system is Vortac, which fulfills military requirements and is compatible with the existing VOR facilities which will continue to serve civil aviation.

AN/ARN-30 RECEIVER

The ARN-30 receiver operates by measuring the electrical phase relationship of two signals received from the transmitting range station. It presents the information to the pilot in the form of visual indications of magnetic bearings either to or from the range station. The receiver has been designed so that any malfunction will completely disrupt the circuit. In other words, it works correctly or not at all. Faulty operation is indicated to the pilot by a "flag" alarm on his cross pointed indicator.

The Frequency Selector (Fig. 7-14) is of the old "coffee grinder" type, turning to any frequency between 108-136 megacycles. You tune to the station desired by "peaking" the signal received. To turn the equipment on, you turn the round black knob at the lower left corner of the frequency selector to the right and then continue right to increase the volume. As a general rule, you have to listen to the range only when identifying it on initial tuning and when listening to the usual 15 and 45 minute past the hour weather broadcasts.

The small switch in the center of the frequency selector is a two-position switch marked OMNI-VAR LOC. When using the Omnirange, put this switch on the left, or OMNI position. The right, VAR LOC, position is used when the equipment is tuned to receive either a VAR range or the ILS localizer.

The deviation indicator (Fig. 7-15) is also referred to as the ILS cross pointer, or the course deviation indicator. You select the course line by choosing the desired course on the selector. Then you control the flight of the aircraft by observing the vertical needle of the course deviation indicator. You use the same technique in guiding the aircraft as you do with the ILS localizer during an ILS approach. You fly your right-left needle on the deviation indicator, for this needle always points toward the desired course line. If the aircraft is off course to the right, the needle points to the left, indicating that the desired course line or radial is located to the left of the aircraft. You know, then, that the aircraft should be maneuvered to the left to get on the desired course.

If you are familiar with localizer flying, you will remember that when an aircraft flies a reverse heading on a localizer, the deviation indicator sensing is reversed. *This is not the case in omnirange flying.* When you complete your procedure turn and reverse your selected course as described, not only does the selector tell you the course to the station, but it likewise reverses the deviation indicator readings so that the following-the-needle type of sensing is still correct.

The bearing selected may be a reciprocal. In that case, the sensing of the deviation indicator needle will be reversed. To prevent this, always consider your course of action with reference to the station and observe the following rules: If you

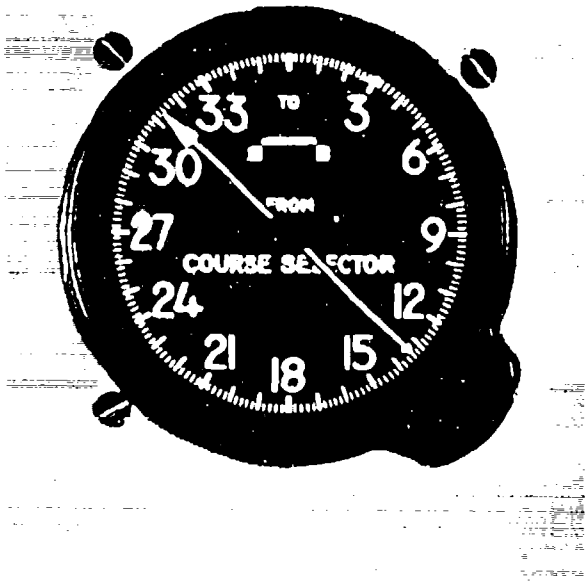


Figure 7–16. Course selector

are proceeding to the station on a selected bearing, the TO–FROM indicator should be in the TO position. If it is not, rotate course selector 180°. If you are proceeding from the station, the TO–FROM indicator should be in the FROM position

You can select any course from 1 to 360° by turning the knob on the lower right hand corner of the course selector (Fig. 7–16). The TO–FROM indicator (a small window on the face of the instrument) shows whether the omni-bearing selected leads TO the station or away FROM the station. For example, if you were southeast of Corpus Christi, and wished to fly up the course line to Corpus Christi, you would set up 315 on your course selector; that is, you would set up a course leading away from you at an angle of 315° and passing directly over Corpus Christi. The TO–FROM indicator at the top of the course selector would then move up and point to the word TO, indicating that the instrument should be read, "course 315 TO the station." If you continue to fly on the desired course, the aircraft will pass over the station.

Station passage in the VOR system is recognized by the movement of the TO–FROM indicator. On passage over the station, the indicator moves from TO to FROM, and you then read the course selector as "315° *FROM* Corpus Christi", which is an accurate description of your angular position with respect to the Corpus Christi station. Continuing northwest from Corpus Christi on the course line 315°, you may wish to execute a procedure turn and return to Corpus Christi along the same course. At an appropriate distance out on the 315° course, you execute your procedure turn, and somewhere during the last half of this turn, you rotate the course selector 180° to indicate 135°. At the same time, an internal switch in the instrument switches the TO–FROM indicator so that it points TO. You then read your omni-bearing selector as magnetic 135° to the station.

AN/ARN-14 RECEIVER

With the AN/ARN–14 VOR receiving set, a control box and two instruments, the Course Indicator (ID–249) and the Radio Magnetic Indicator (RMI), are available to the pilot for flying VOR. (See Figure 7–17). The control box consists of a TONE-PHASE switch, two frequency selector knobs, a frequency window, and a volume control. By rotating the outer frequency knob, you select the frequency in tenths of megacycles. The TONE-PHASE switch serves as an ON-OFF switch and allows reception of phase-type ILS facilities or tone-type ILS and VAR facilities.

The radio magnetic indicator (RMI) (ID–250) consists of a rotating compass card actuated by the MA–1 compass and two pointers similar to the pointer on the conventional LF/MF radio compass indicator. The magnetic heading of the aircraft is shown under the heading arrow at the top of the instrument, and the RMI is used in the instrument cross-check in place of the gyro heading indicator. The double-barred VOR pointer performs the same function as the radio compass pointer. Because of the directional qualities of the instrument, the magnetic bearing to the VOR station is shown under the pointer. The spare needle may be connected to the conventional LF/MF Radio Compass or used in conjunction with a dual Omni-receiver installation.

This is the installation assumed to be standard in this manual. However, some naval aircraft have the RMI installation connected somewhat differently. They have the VOR on the single or spare needle which is usually red colored, and have the double (usually green colored) needle connected to the ARA-25 UHF/DR) or to the LF/ADF (ARN-6 or ARN-7). Others which have no Omni equipment have the ADF on the double needle and the ARA-25 on the single needle. You must find out what the installation is on your aircraft. At least, if the aircraft has the ID-249 course indicator, you may assume Omni is on one of the RMI needles, probably with the standard arrangement, that is, on the double or green needle.

The course indicator (ID-249) instrument consists of a bearing selector knob, a bearing window, and a TO-FROM window, a bearing deviation needle (vertical needle), a glide path needle (horizontal needle), and a gyrosyn-compass actuated heading pointer. The bearing-selector knob permits selection of a desired bearing, and this is displayed in the bearing window. The TO-FROM indicator indicates whether the bearing selected will take the aircraft TO or FROM the station. A deviation indicator, or localizer needle, shows the position of the aircraft in relation to the desired bearing. The glide path needle is used when flying an instrument landing system. The heading pointer and scale show the heading of the aircraft relative to the selected bearing. When the head-

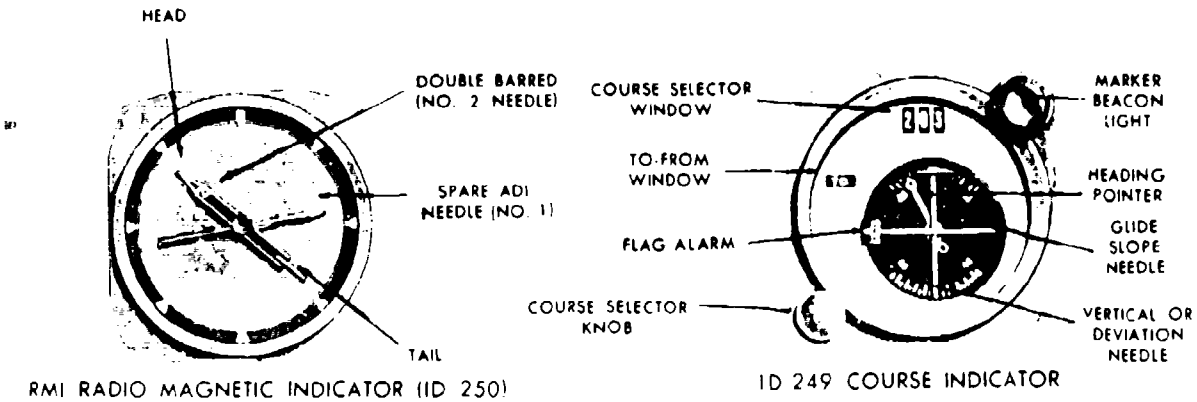


Figure 7-17. AN/ARN-14 instruments

ing pointer is centered, the heading of the aircraft is the same as the bearing shown in the bearing window. If the pointer is deflected to the left or right, the aircraft's heading is also to the left or right the number of degrees indicated on the pointer scale.

Operation of the VOR equipment is simple. Turn the set on and rotate the outer and inner knobs of the frequency selector until the frequency you want is shown in the frequency window. Set the TONE-PHASE switch in the TONE position except for reception of phase-type ILS localizers.

After you tune in the desired VOR station, the closest magnetic bearing to the station shows under the head of the double-barred pointer on the RMI. The closest magnetic bearing from the station shows under the tail of this pointer. If you want to proceed directly to the station, you make a turn toward the double-barred pointer. As the aircraft turns, both the compass card and the pointer will rotate toward the heading arrow at the top of the instrument. If the RMI is inoperative, you can obtain the closest bearing TO or FROM the station by rotating the bearing selector knob until the deviation needle (localizer needle) centers. When the needle centers, if the indication in the TO-FROM window is not the one desired, rotate the bearing selector 180°.

Over the station, there is a cone of confusion similar to the cone of silence over the radio range station. This cone of confusion at high altitudes may be wide enough to require 2 minutes for an aircraft to pass through it. When the aircraft passes over the station the TO-FROM indicator changes to FROM, and the double-barred RMI needle moves to the tail position. At high altitudes these indications may change several times before stabilizing. When the TO-FROM indicator changes, the sensing of the receiver is automatically changed and corrections to regain the desired bearing are still made toward the deviation needle. If you desire to track away from the station on the same bearing, no change in instrument setting or procedure is necessary. When you want a different bearing away from the station, make a turn to that bearing immediately, and set the bearing in the bearing indicator.

When you fly the reciprocal of the bearing shown on the bearing indicator, the heading

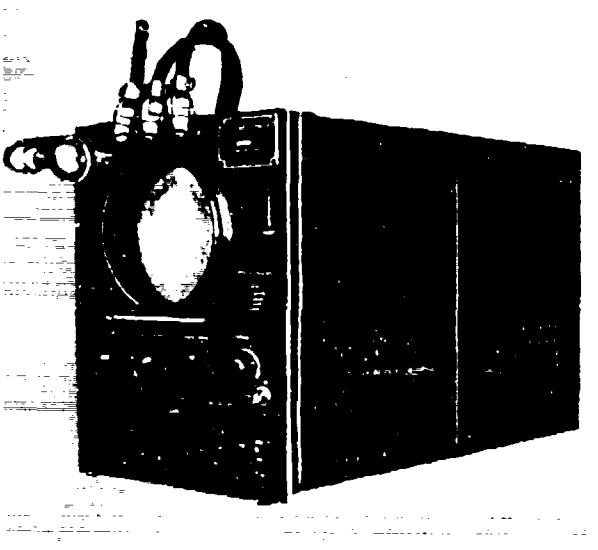


Figure 7-18. Airborne loran indicator

pointer will be on the tail position and you must make corrections away from the needle. This procedure is undesirable and should not be used. Simply reset the bearing indicator to this reciprocal, and, as you do so, the TO-FROM indicator will change appropriately.

To eliminate confusion, the position of an aircraft if referred to as on a certain bearing either TO or FROM the station. Thus, for example, the 137° bearing is the course line which extends southeast at 137° magnetic. A pilot on this bearing inbound refers to his position at 317° TO the station, while a pilot on the same bearing outbound refers to his position as 317° FROM the station. This means that when you are not directly over the station, you simply read positions on the Course Indicator.

You can get voice reception on any channel between 106-135 mc by tuning to the desired frequency. When frequencies above 118 mc are tuned, the alarm flags of the course indicator instrument remain in view, but voice communication is normal.

When tuned to an ILS or VAR station, the TO-FROM window remains blank, and the double-barred pointer of the RMI does not operate. It turns with the compass card. The only indications

of malfunctioning equipment are the following:

1. The alarm flag of the deviation needle does not disappear.

2. The aural signal cannot be heard or is erratic.

3. The double-barred pointer of the RMI circles aimlessly.

Marginal operation is indicated by fluctuation of the deviation-needle alarm flag. If this is due to weak signal strength, it should improve as flight is continued toward the station.

In summary, the deviation indicator provides a precise method of flying a selected course, while the RMI provides continuous ADF style orientation plus a simple means of displaying heading information to the pilot.

LORAN

Loran is a LOng RAnge Navigation system which was developed primarily for maritime use, but it has been found equally well-adapted to trans-oceanic air navigation. Technically, Loran is classified as a hyperbolic navigation system. All hyperbolic navigation systems are based on the reception of synchronized radio signals of known velocity from different points.

Loran transmitting stations operate in pairs. One station is known as the "master" and the other station is known as the "slave." Master and slave stations are located at opposite ends of a base line from 100 to 600 miles long. Both master and slave stations transmit pulses at the same rate, but since the master pulse must be received by the slave station before the slave pulse can be transmitted, the master pulse always leads the corresponding slave pulse regardless of where the two are received.

Airborne Equipment

Airborne Loran equipment consists of a Loran radio receiver, an electronic time-measuring unit

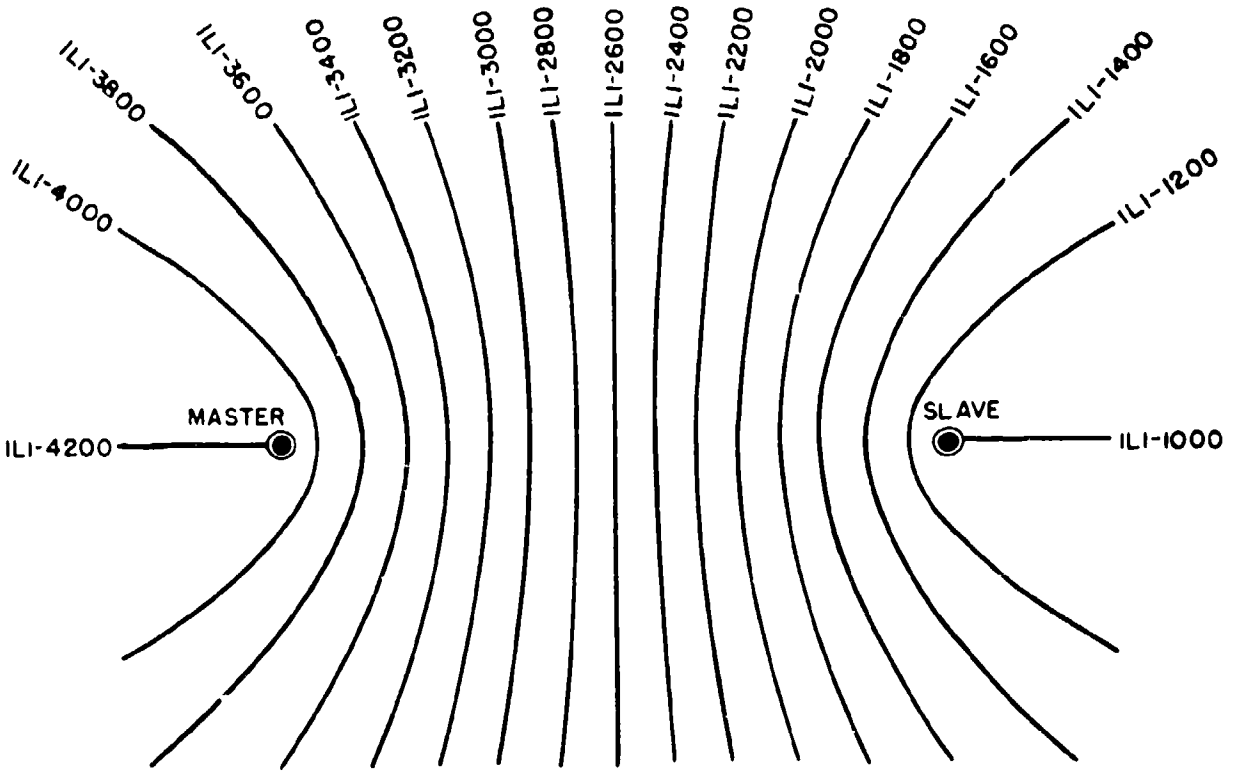


Figure 7-19. Loran lines of equal time difference from a single transmitting pair

known as the Loran indicator, and Loran charts and tables. The receiver is a superheterodyne receiver in which Loran signals are detected, amplified, and then passed to the Loran indicator. The Loran indicator is an electronic stop watch which measures the time difference, in millionths of seconds, in the arrival of a pair of pulses. (Fig. 7–18.) The Loran charts or tables are necessary for utilization of the equipment, since only by their use may the time difference be translated into a line of position. The lines of position for each pair of stations are printed in a particular color on Loran charts and are clearly marked for easy identification.

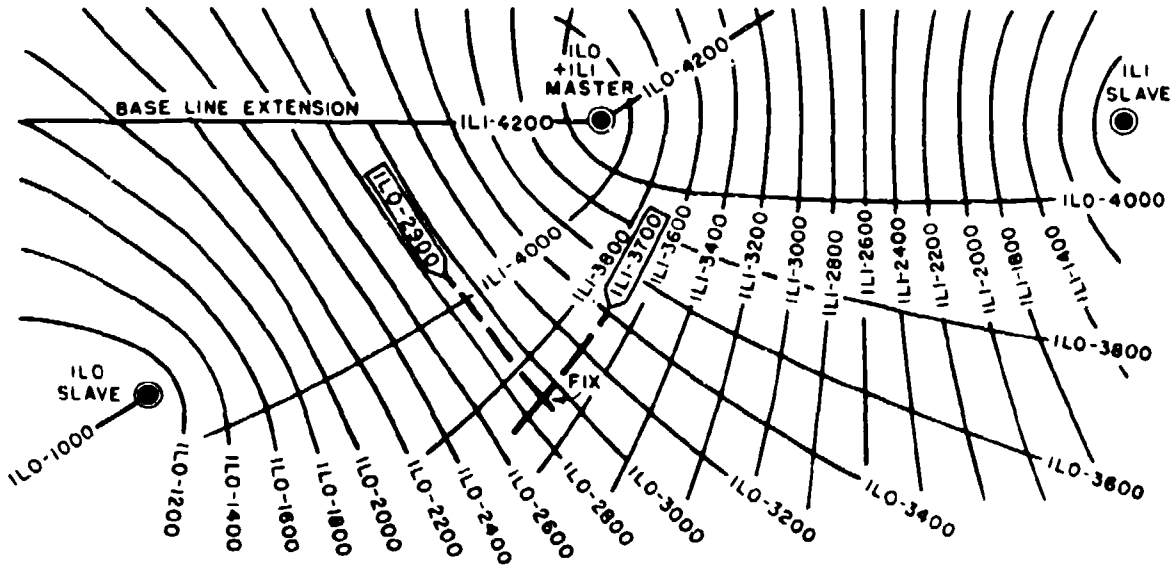
Loran stations do not transmit identifying letter, number, or audio signals. Station pairs are identified by a combination of radio frequency and pulse repetition rate (PRR). Frequencies between 1700 and 2000 kilocycles are used. Loran charts have been made with lines connecting the points of equal absolute time differences (a series of hyperbolas). (See Figure 7-19.)

Determination of Line of Position (LOP)

Pulses are radiated in all directions from the transmitting station and travel approximately 186,000 miles per second. The pulses from a given pair of stations are synchronized to allow a definite time difference in their arrival at any geographical point. This time difference of arrival is measured in micro-seconds (millionths of a second) and is constant for all points on the earth's surface whose difference of distance from the two stations is the same. The navigator measures the time difference in the arrival of a pair of impulses at his position. From a Loran chart he determines his line of position on the earth's surface without calculation. The intersection of two such lines determines a Loran fix (Fig. 7–20).

Homing

Loran signals may be used for homing purposes. The receiver may be pre-set for a station pair transmitting a line of position which passes through a desired objective. A heading which



WHEN TUNED TO STATION PAIR 1L1, NAVIGATOR SECURES A TIME-DIFFERENCE MEASUREMENT OF 3700 MICROSECONDS. REFERRING THIS DATA TO THE LORAN CHART, POSITION IS SOMEWHERE ON NUMBERED LINE 1L1-3700. (LINE SHOWN BY INTERPOLATION IN THIS EXAMPLE) SWITCHING TO STATION PAIR 1LO, NAVIGATOR OBTAINS TIME-DIFFERENCE MEASUREMENT OF 2900 MICROSECONDS, CORRESPONDING TO A POSITION SOMEWHERE ON NUMBERED LINE 1LO-2900. INTERSECTION OF LINES 1L1-3700 AND 1LO-2900 INDICATES POSITION OF AIRCRAFT. (LINES OF POSITION FOR DIFFERENT STATION PAIRS ARE SHOWN IN DIFFERENT COLORS ON ACTUAL LORAN CHARTS FOR GREATER CLARITY.)

Figure 7–20. Determination of a loran fix

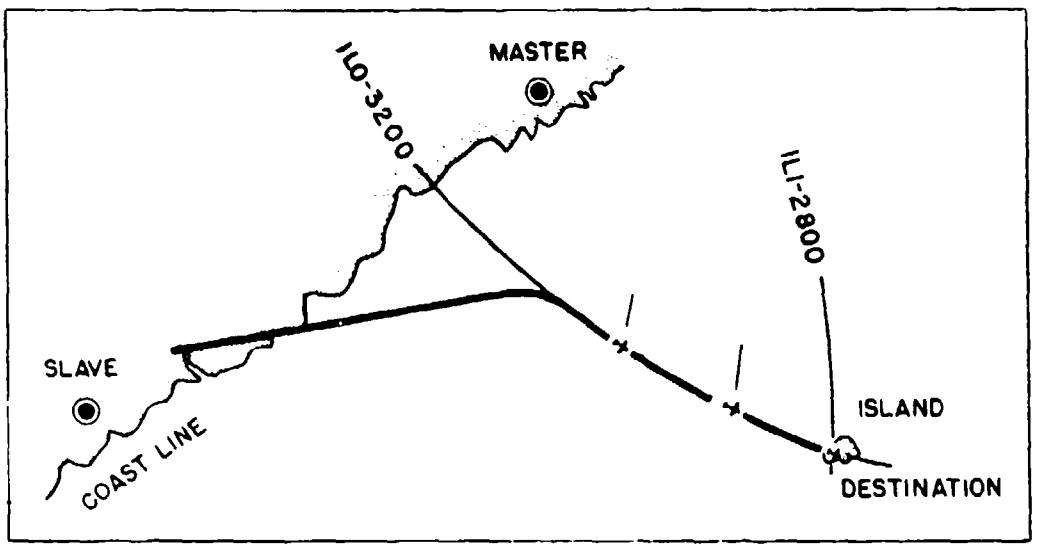


Figure 7–21. Loran homing procedure

will intercept this line is taken up. When the desired pulses are matched on the receiver scope, the aircraft is on selected line. The selected line of position is then followed to the objective. (See Figure 7–21.)

Signal Reception

The received pulses are typical forms of ground (direct) waves. However, over long distances, especially at night, the received pulses may be sky (reflected) waves. Loran stations have a daytime range of approximately 700 nautical miles over water (predominantly ground waves). At night, reflected sky waves increase the range of Loran transmitters to about 1400 nautical miles. The refraction of these waves, however, decreases the reliability of the signals slightly for navigational purposes.

When matching Loran signals, care must be taken that only like waves are matched. The critical area is a zone approximately 500 to 700 miles from either station. Within 500 miles of either station, it is fairly certain that the first signal that falls on the scope is a ground wave. When over 700 miles from either station, the first signal is generally a sky wave. Within the 500 to 700 mile area, either type of wave may be the

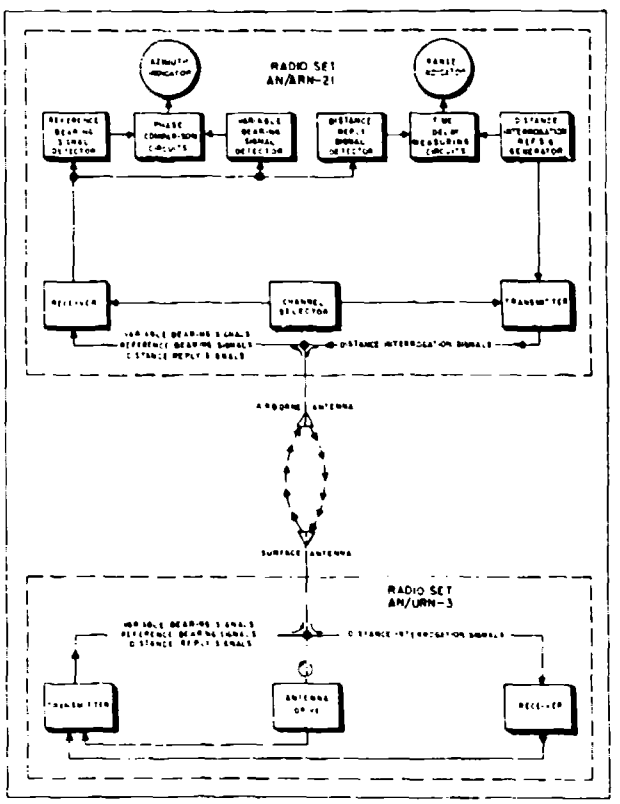


Figure 7–22. Tacan system simplified block diagram

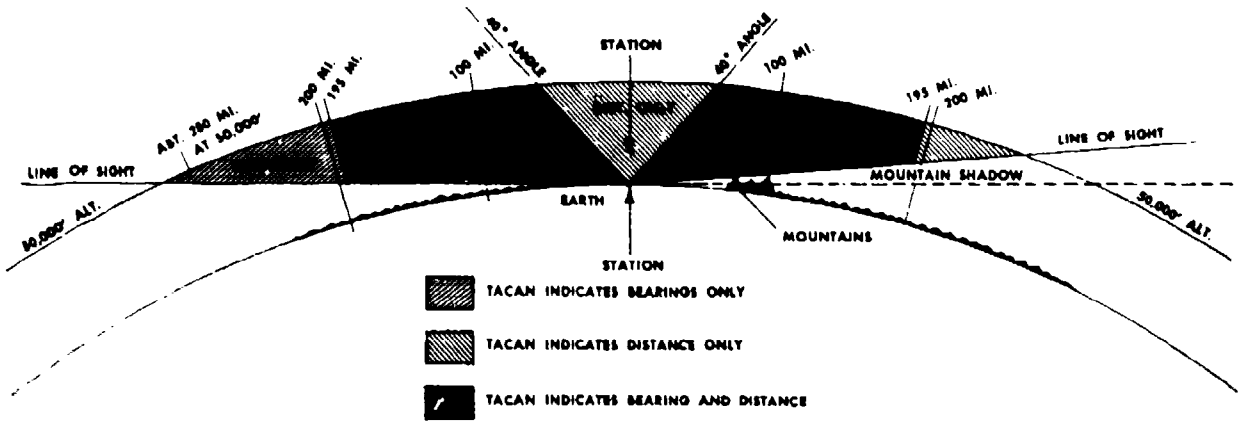


Figure 7-23. Limits of Tacan reception

first to fall on the scope, and unless extreme care is taken, an inaccurate position may be determined from matching a ground wave with a sky wave, or a second sky wave with a first sky wave. However, by taking a fix of three Loran lines of position, possible error may be avoided. A "pin point" 3-station Loran fix is always right.

TACAN, AN-ARN-21

Tacan, Radio Set AN/ARN-21, was developed by the Navy as a navigational device to provide bearing and distance from a carrier or other movable base, just as Omni/DME does from a shore station. It has a high degree of accuracy, and yet the base station is small. Some are portable. Tacan provides the pilot with slant range distance (just as DME does) to an accuracy of plus or minus 600 feet plus 0.2% of the distance reading. For example, if it reads 100 nautical miles, the actual distance will be between 99.7 to 100.3 nautical miles. Tacan determines the magnetic bearing of a station from the plane within ¾'s of a degree or less. The aircraft unit weighs about eighty pounds, and the base station dual equipment consists of four units mounted in six cabinets. Smaller portable station equipment, consisting of single units, is available for combat use.

Theory of Tacan

The station constantly transmits omni-directional signals on its assigned channel on an infinite number of radials. These are picked up and identified by the aircraft receiver, and indicated on the panel as the relative magnetic bearing from the aircraft to the station. Meanwhile, the aircraft transmitter sends a signal to the station which is relayed back by the station. The aircraft equipment measures how long it took the signal to make the trip, and from that computes distance in nautical miles and shows this information on an indicator, which is discussed later. (See Figure 7-22.)

Figure 7-23 shows the limitation of Tacan coverage. The designed altitude limit is 50,000 feet. The maximum range at which both bearing and distance may be determined is (1) line of sight, or (2) within 196 nautical miles of the station but not at a vertical altitude from the station in excess of 40°, *whichever is least*. When you are so high over the station that you are above a 40° vertical altitude from the station, you receive distance, but the bearing data is inaccurate. For example, at 12,000 feet altitude and directly over the station, the bearing needle will rotate aimlessly and the distance will read 2 miles, for that is your direct line distance from the station (12,000 feet). At more than 196 miles from the

...on, but within line of sight, you will continue to get bearing data but the distance reading is not accurate. This is shown by a bar dropping over the readings to indicate the inaccuracy.

Use of Tacan

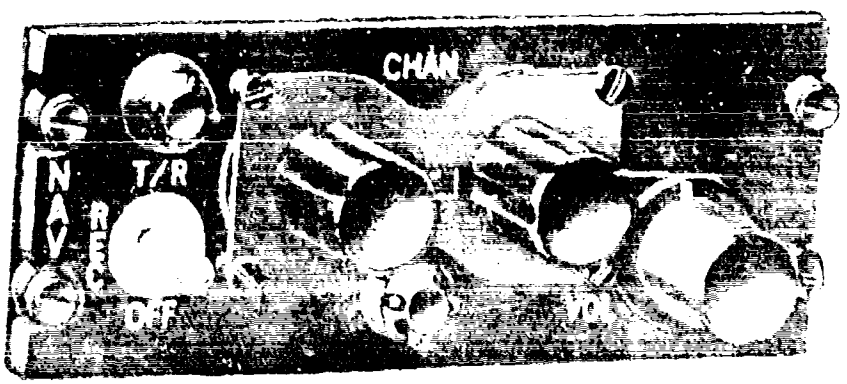
The airborne equipment consists of a transmitter-receiver, antennas, a control panel, a range indicator, and some form of bearing or azimuth indicator. The equipment operates on any of 126 UHF channels. To operate it, turn the control panel switch from OFF to REC (receive). (See Figure 7-24.) Select your channel by rotating the two knobs until the proper channel number appears between the two knobs. However, never try to set to any channel below "01" nor above "126". Wait about 90 seconds for warm-up. During warm-up, the bearing indicator needle will rotate. When warmed-up, the needle settles down on the proper bearing.

To determine distance, after the azimuth indicator has warmed up, turn the switch to T/R (Transmit Receive) and wait about 90 seconds for the distance equipment to warm-up. At the end of the warm-up, the bar across the distance scale will rise to indicate that the distance indication is now correct. There is no need to listen constantly to the Tacan station, but right after tuning in a station and every now and then while flying on that station, you should listen to the Morse code identification of the station which is heard every minute.

The previous section discussed two instrument presentations used for Omnirange. The bearing indications from Tacan are presented in the same manner. The bearing is shown either by an Azimuth Indicator (ID-307 ARN), shown in Figure 7-25, or by the RMI (ID-250). The ID-249 Course Indicator may or may not appear with the Tacan installation. When the RMI is used, the Tacan is generally on the double needle (marked "2"), and some other type of DF or Bearing Indicator utilizes the other, single needle. The Tacan bearing shown by the needle is *magnetic*.

The range or distance indicator (Fig. 7-26) is very simple. The slant range from the aircraft to the station is shown in nautical miles. As you fly near to or farther from the station, the numerals turn, as on the odometer of your car's speedometer unit, to let the next numeral appear. The only important fact is that this is slant range

Figure 7-24. Tacan control box



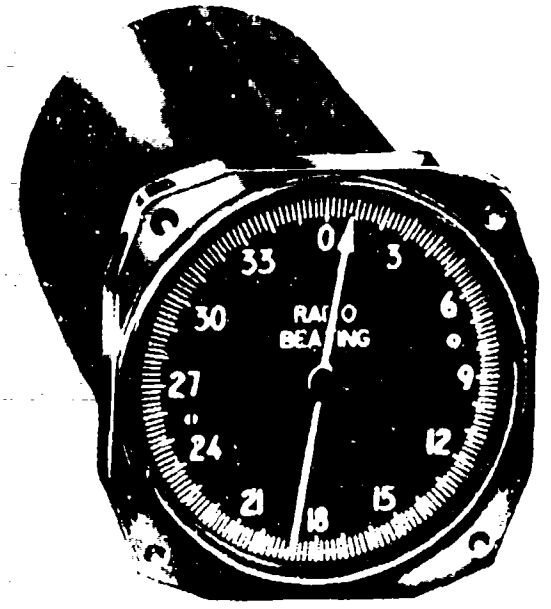


Figure 7-25. Azimuth indicator ID-307/ARN

distance, which is not greatly different from ground distance except as you get close enough to the station so that your altitude (in miles) becomes about half the actual range. (See figure 7-27.) In other words, at 12,000 feet flight altitude, you need not consider the slant range vs. ground range factor until you are within about 4 miles of station. As you reach about 2 miles from the station at such altitude, the bearing data on the Tacan becomes unreliable and the bearing needle rotates. As you get right over the station, the range indicator will still be reading 2 miles, your altitude. In short, whatever error is caused by slant ranges reaches its maximum at station passage, at which time it equals altitude. At more than 20 miles from station, at this altitude, it is negligible for air navigation purposes.

Flying with the aid of Tacan is to all intents and purposes the same as flying with Omni. Anything you can do with Omni, you can also do with Tacan.

There are a few Tacan flight techniques which are new to carrier operating practice. For example, a formation of aircraft can let down to the ship on a predetermined bearing. The leader can read off his altitude and distance by Tacan as they go. Each following aircraft can know when he is following too close or lagging behind, and maintain his assigned interval. Thus collisions are avoided without elaborate letdown patterns. Holding is easily established on any radial. The station or ship assigns a bearing to the station for holding, assigns an altitude, right or left turns, and a distance for the turns. Inbound, fly on that bearing; outbound fly the reciprocal heading.

Carrier aircraft can take-off and climb out on an assigned radial (bearing *from* the ship) to an established distance and altitude. On reaching this point, the leader can slow down and await the others as they continue on the bearing.

Additional uses and procedures will probably be developed as the potentialities of the equipment are fully explored. (See Vortac, p. 7-12.)

Limitations of Tacan

Like Omni and other VHF/UHF radio equipment, Tacan is limited to line of sight. If you fly so a mountain or other obstruction lies between you and the station, the indicators will indicate

Figure 7-26. Range indicator ID-310/ARN

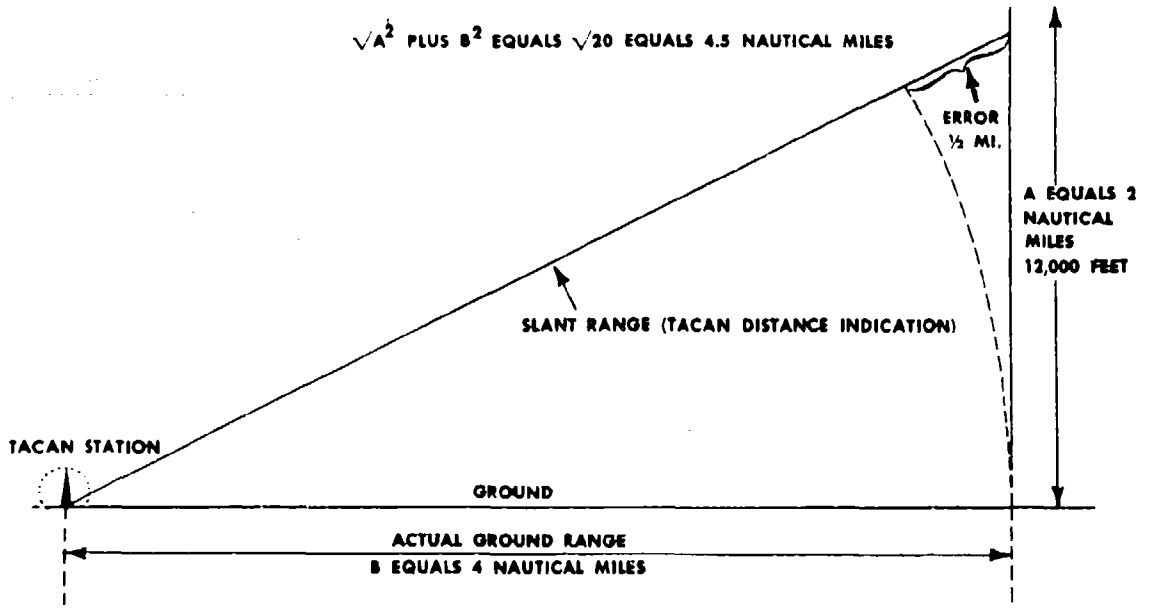


Figure 7-27. Slant range error is insignificant in distance calculations until altitude in miles is equal to one-half of actual range (30°-60°-90° triangle) where error begins to exceed 1/9 of slant range. Therefore, even at 50,000 feet, error is not over two miles until 18 miles or less is shown on the range indicator. At that point, correct range is about 16 miles

inaccurate readings—the bearing needle will rotate aimlessly, the distance indicator will show a bar across the numerals, and the course indicator (localizer), if installed will show the OFF flag.

These indications may also be caused by certain malfunctions. Occasionally, a tube failure or other trouble may cause the indicators to become motionless--the bearing won't change when the aircraft is turned or the distance won't change as you fly on toward or away from the station. If you exceed the range (196 miles or line of sight), at which the distance indicator will read, the same bar obscures the mileage figures. In violent maneuvers when part of the structure of the aircraft cuts off signals from reaching the antenna, the set holds the existing reading for ten seconds, and then indicates inaccurate readings as previously described.

CHAPTER 8

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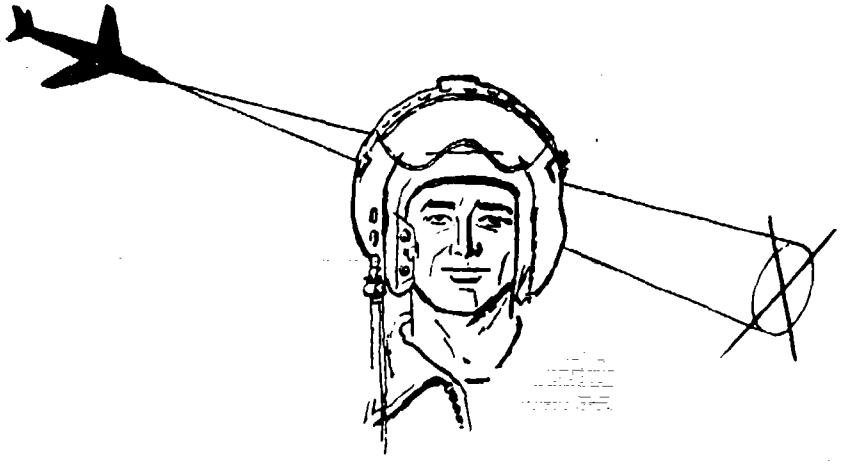

CHAPTER 8

BASIC INSTRUMENT FLYING—CONVENTIONAL AIRCRAFT

THIS chapter deals with the basic procedures and considerations of instrument flying for prop aircraft. It does not give you the specific procedures for each type. It assumes a typical assortment of instruments and presents and explains the typical procedures to be followed. To apply this information in practice, be sure to consult the operating handbook for the particular aircraft you fly and follow the specific procedures given there.

INSTRUMENT COCKPIT CHECK

One basic requirement for a successful instrument mission is the proper operation of all the instrument flying equipment in the aircraft. The only way to be sure of this is to make a thorough instrument check before take-off, following the procedures specified in the handbook provided with the airplane. In general, however, here are some of the main points involved in the instrument check.

Suction Gauge (or Inverters). Check the source of motivating power for the gyro instruments to make sure the output is proper. If the gyros are driven by a vacuum system, check the suction gauge for the proper indications of 3.75″ to 4.25″. If the gyros are electrically driven, check the generators and inverters for proper operation.

Airspeed Indicators. The airspeed indicator needle should indicate zero. Check the airspeed

calibration card for any deviations at the speed range that you intend to fly.

Heading Indicator. Uncage the suction-driven heading indicator before starting the engine(s). Allow 5 minutes after starting engine(s) for the gyro rotor to attain its proper speed. Then cage the gyro, and while uncaging it, simultaneously pull out and turn the knob. If the card continues to turn after the knob is pulled out, the gyro is not operating properly and should be replaced. If it is operating properly, set the gyro to a known heading while taxiing straight. Recheck the accuracy of this heading just before take-off. If the error is large, the instrument is unreliable.

Horizon Indicator. Uncage the suction-driven horizon indicator before starting the engine(s). After starting engine(s) allow the instrument five minutes to attain rotor speed. Then adjust the miniature aircraft so that the hairline is barely visible on the staff below (unless a different position is required for the particular aircraft). If the horizon bar erects quickly to the horizontal position and remains at the correct position for the attitude of the aircraft, or if it begins to vibrate after this attitude is reached and then slowly stops vibrating altogether, the instrument is operating properly. If the horizon bar fails to remain in the horizontal position while you are taxiing straight, the instrument is unreliable. If the horizon bar tips in excess of 5° during a taxiing turn, an unbalanced condition is indicated, probably caused by a low rotor speed or clogged erection mechanism.

If you have allowed sufficient time for gyro warm-up, the horizon indicator should have erected to a wings level attitude, and should indicate the nose attitude of the aircraft on the ground. Set the miniature aircraft level with the 90° marks on the side of the case. This should give approximately the level flight attitude at normal cruising airspeed.

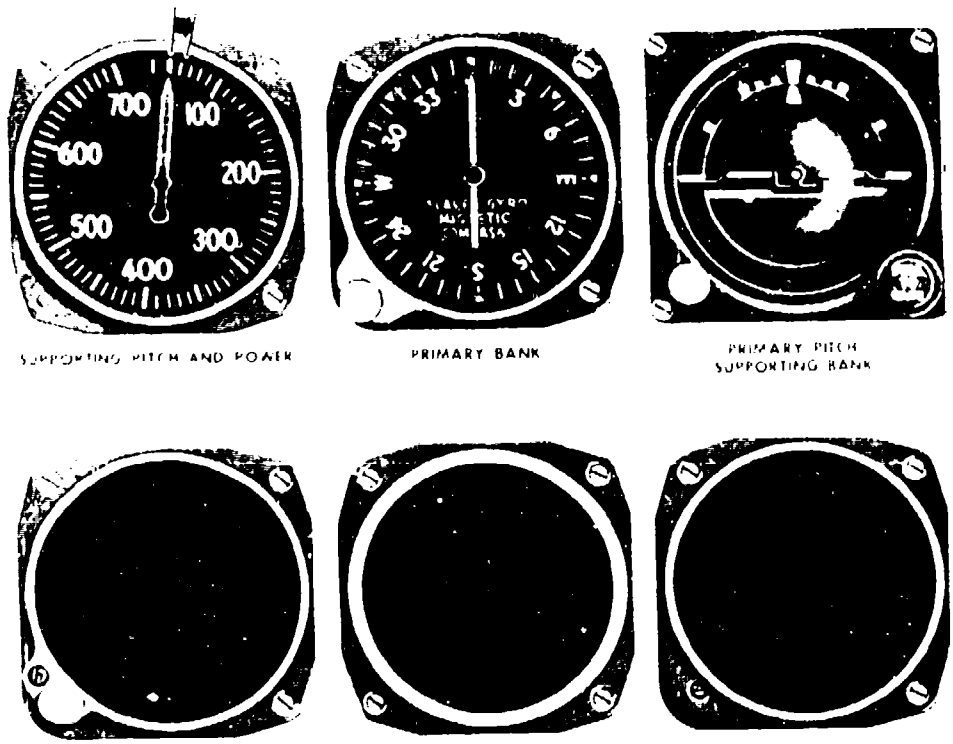

Figure 8-1. Instruments used before leaving ground on instrument takeoff

Altimeter. Set the altimeter to the station altimeter setting as reported by the tower and check to determine if the altimeter indicates the altitude of the field. If there is a difference between the actual field elevation and the indication on the altimeter, either the altimeter setting is incorrect or there is a scale error in the instrument. If the error is more than 75 feet, the instrument should be replaced. If the deviation is less than 75 feet, set the altimeter at field elevation and note the difference between the tower altimeter setting and the reading in the Kollsman window. Apply this figure to all subsequent altimeter settings received.

Turn-and-Bank Indicator. Turn the aircraft to the right and left while taxiing and note the reaction of the turn needle. If its indications are not positive, or if the needle is sluggish and does not return to the center promptly when the turn is stopped, the instrument is not operating properly. If the instrument is mounted in a shock-mounted panel, you can make this same check when the aircraft is not moving by pressing in one side of the panel and then releasing it. Check the ball to be sure it moves freely in the race, and that the tube is filled with liquid.

Vertical-Speed Indicator. With the aircraft on the ground, the needle should indicate zero. If it does not, gently tap the panel. If it does not return to zero, adjust it by using a small screw driver to turn the screw in the lower left corner of the instrument. While making this adjustment, gently tap the panel to check the accuracy of the new setting. If you cannot adjust the needle to zero, you must use its ground indications as the zero position in flight.

Panel Magnetic Compass. Check to see whether the magnetic compass has sufficient fluid. Determine its accuracy by comparing its indications with a known heading while the aircraft is taxiing straight. If a Remote Indicating Compass is installed, check its indications in the same way.

THE INSTRUMENT TAKE-OFF

Instrument take-off techniques vary slightly with different types of aircraft, but the techniques discussed here are successful for any type of aircraft if you consider the original attitude on the ground.

Before attempting an instrument take-off, complete an instrument cockpit check as specified in the aircraft handbook. After being cleared for take-off, align the aircraft with the center of the runway and allow it to roll straight for a short distance before stopping, making sure that the nose wheel or tail wheel is straight. Lock the tail wheel if the aircraft is so equipped, and hold the brakes firmly to prevent creeping. Set the suction-driven heading indicator on the 5° mark nearest the published runway heading, and recheck to be sure that it is uncaged. If you use the electric heading indicator rotate it so that the heading needle is under the index at the top of the instrument.

Advance the power to an rpm that will provide partial rudder control. Release the brakes, and advance the throttle(s) smoothly to take-off power. During the take-off roll, hold the heading constant on the heading indicator by use of rudder. If necessary, in multi-engine propeller-driven aircraft, use the throttles to assist in maintaining directional control. Use the brakes only as a last resort because braking usually results in over-controlling and lengthening the take-off roll. You must counteract any deviation in heading immediately to return to the desired heading.

As flying speed is approached adjust the nose attitude to make the desired take-off attitude show on the horizon indicator. Establish this attitude by raising the nose of the aircraft (with tricycle landing gear) or by allowing the tail of the aircraft to rise slightly if it is equipped with conventional landing gear. As the aircraft approaches flying speed, and immediately after leaving the ground, control the nose and bank attitudes by reference to the horizon indicator. Continue to maintain the heading by reference to the heading indicator. Maintain the nose attitude by reference to the horizon indicator until the altimeter and vertical speed show a positive rate of climb. When a predetermined safe altitude (generally, about 100 feet) is attained or when the aircraft cannot make a safe wheels-down landing, raise the landing gear. Once you raise the gear, the horizon indicator is the primary pitch instrument until the climbing airspeed is attained. However,

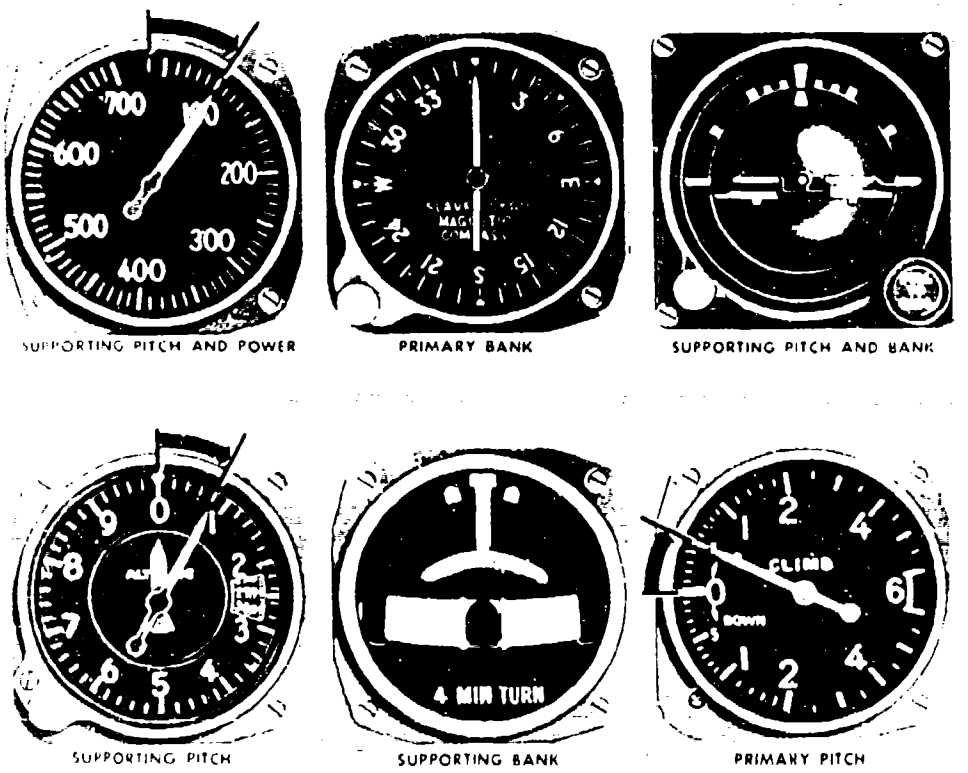

Figure 8–2. Instruments used right after leaving ground on instrument takeoff

the altimeter, vertical-speed indicator, and airspeed indicator are the secondary instruments and you must scan them closely at this critical time.

Maintain a nose attitude on the horizon indicator that will result in a continuous climb and a smooth increase in airspeed. As soon as you attain a safe altitude and airspeed, raise the flaps if they are down. Cross-check the indications of the altimeter and verify the altitude by the limit switch of the radar altimeter. After you attain single-engine airspeed and reach an altitude of 200 to 400 feet above the terrain as shown on the altimeter, reduce power to climbing settings and accomplish the climb-out as a constant airspeed climb. When you raise the gear and flaps, the nose attitude may change unless you counteract it by control pressures.

Adjust the trim tabs for take-off before starting the take-off roll. Don't change this setting until after the aircraft becomes airborne. After the aircraft is airborne, use the trim tabs to relieve control pressures as described before.

Common Faults in Instrument Take-Off

1. Failure to make an adequate cockpit check of all instruments before take-off.

2. Swerving and failure to maintain accurate directional control on the ground. Remedy this by making adequate small movements of the rudder pedals the instant the heading indicator shows a change. Neutralize the rudders after the correction has been made.

3. Failure to maintain take-off attitude after becoming airborne. This is just an invitation to a stall.

4. Nosing down after take-off, thereby flying back into the ground.

5. Failure to scan instruments after take-off.

6. Reducing power too soon after take-off.

PITCH CONTROL FOR LEVEL FLIGHT

The pitch (or nose) attitude of an aircraft is the angular relation of the longitudinal axis of the aircraft to the true horizon (Fig. 8-3). In level flight, the pitch attitude varies with airspeed. The aircraft flies nose-high at low speeds and nose-low at high speeds. The pitch attitude of the aircraft for level flight at a constant airspeed also changes with differences in load.

The instruments that are used for pitch control are the horizon indicator, altimeter, vertical-speed indicator, and airspeed indicator.

Horizon Indicator

The aircraft you fly may have an electric horizon indicator or it may have a suction-driven horizon indicator. One or the other of these instruments is installed in an aircraft, sometimes both. For instructional purposes and for better reading in this chapter, the phrase *horizon indicator* will be used for both electric and suction-driven indicators.

In visual flight, you attain the proper pitch attitude by raising or lowering the nose in relation to the horizon. In instrument flight, the horizon indicator supplants the real horizon. You follow exactly the same procedure in raising or lowering the nose of the miniature aircraft on the artificial horizon. With the horizon indicator, you can quickly place the aircraft in approximately the correct pitch attitude for any condition of flight (Fig. 8-5). However, you cannot know the exact attitude in advance. You must determine this by the movement or lack of movement of the other pitch instruments.

For reliable indications and maximum upset limits, you must uncage the horizon indicator only in straight-and-level attitude, as indicated by the other attitude instruments. Of course, the electric horizon indicator has no tumble limits; however, you should not rely on the suction-driven horizon indicator after exceeding 70° of pitch, up or down.

When you make pitch corrections, your control pressures should be extremely light and you should observe the horizon indicator to attain the

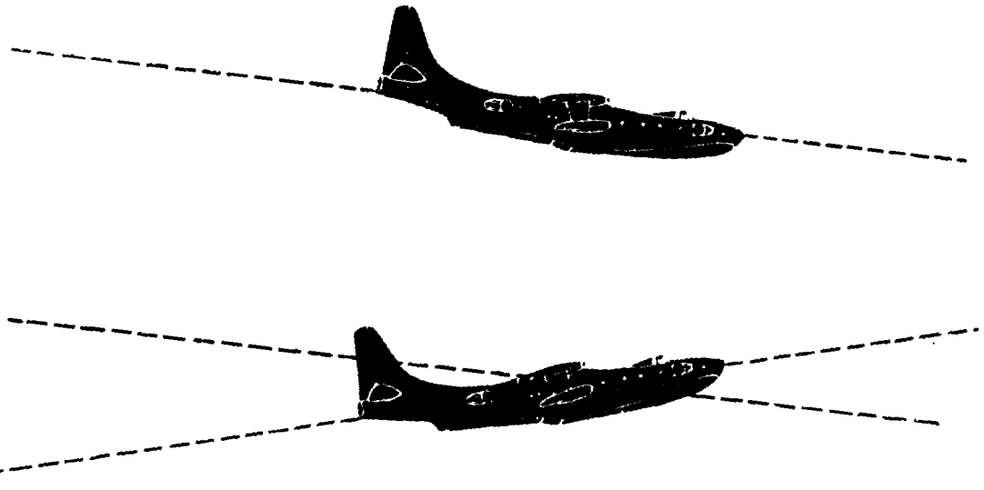

Figure 8-3. The pitch attitude of an aircraft is the angular relation of the longitudinal axis of the aircraft to the true horizon

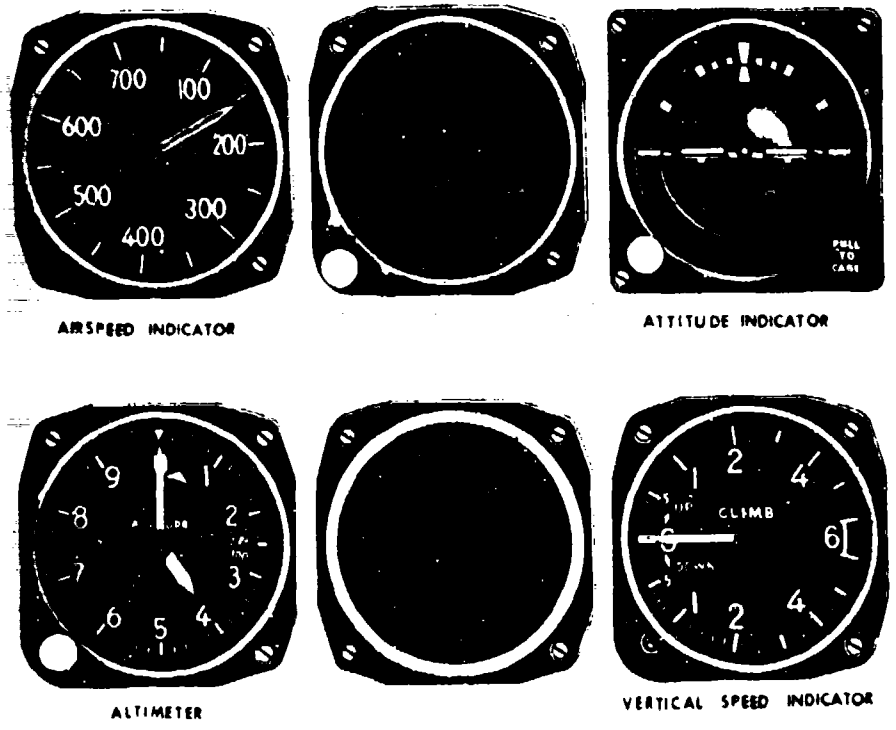

Figure 8-4. Pitch instruments

correct pitch attitude. The normal movement of the horizon bar should not exceed one to one and a half times the width of the bar. Use the vertical-speed indicator in conjunction with the horizon bar to determine over-controlling in pitch attitude.

Altimeter

The altimeter gives you an indirect reading of the pitch attitude of the aircraft in straight-and-level flight. Since the altitude should remain constant in level flight, any deviation from the desired altitude shows a need for a change in pitch. If you are losing altitude, raise the nose; if you are gaining altitude, lower the nose. (Fig. 8-6.)

The rate at which the altimeter is moving aids you in determining the pitch attitude. A slow movement of the altimeter indicates a small deviation from the desired pitch attitude; a fast movement indicates a large deviation. Take corrective action promptly, with light control pressures. Remember, too, that movement of the altimeter should always be corrected by two distinct changes of attitude. The first is a change of attitude to stop the altimeter; the second, a change of attitude to return smoothly to the desired altitude.

At low altitudes, however, for example in carrier landings, the barometric altimeter has too much lag to be safe. The radar altimeter is much better.

Vertical-Speed Indicator

The *initial* movement of the vertical-speed needle is usually almost instantaneous. It indicates the trend of the vertical movement of the aircraft. You must realize, however, that it takes a little while for the vertical-speed indicator to reach its maximum point of deflection after a correction has been made. This time element is commonly referred to as *lag*. The lag is directly proportional to the speed and magnitude of the pitch change. Train yourself to use smooth control techniques by using light pressures to make any adjustment in pitch attitude; then, the vertical-speed indicator will be easy to interpret. You can stop over-controlling by relaxing pressure

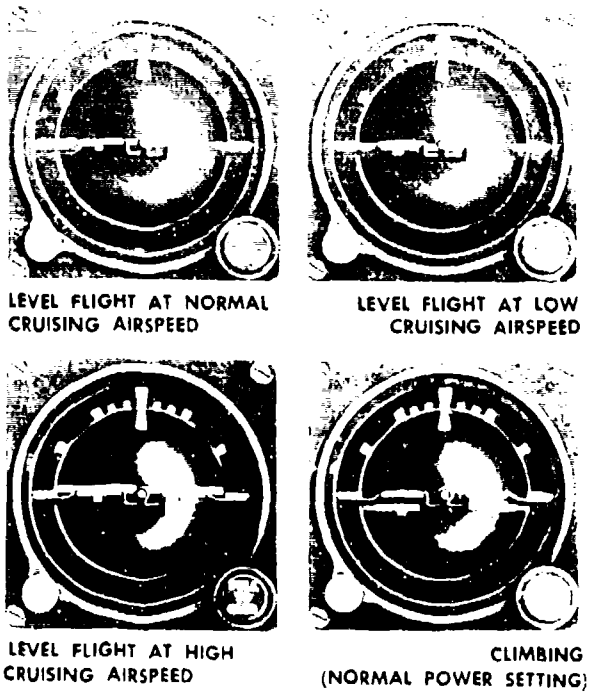

Figure 8–5. Pitch attitudes for various conditions

on the controls, allowing the pitch attitude to stabilize, and then re-adjusting the pitch attitude by utilizing the indications of the other pitch instruments.

Occasionally, the vertical-speed indicator may be slightly out of calibration and indicate a slight climb or descent when the aircraft is really in level flight. If you are unable to readjust the vertical-speed indicator properly, take this error into consideration when you use the vertical-speed indicator for pitch control.

Airspeed Indicator

The airspeed indicator gives you an indirect reading of the pitch attitude (Fig. 8-8). With a given power setting and pitch attitude, the airspeed remains constant. If the airspeed increases, the nose is too low and should be raised; if the airspeed decreases, the nose is too high and should be lowered. A rapid change in airspeed indicates a large change in pitch, and a slow change in airspeed indicates a small change in pitch. There is very little lag in the indications of the airspeed indicator, so when you make pitch changes, they are reflected immediately by a change of airspeed. Altitude, however, is a function of power. Remember—nose attitude controls airspeed, power controls vertical speed, (in other words, altitude).

Scanning

The interpretation of the individual pitch instruments has been discussed in the preceding paragraphs. Observing and interpreting two or more of these instruments to determine and maintain the attitude of the aircraft is known as scanning. The importance of scanning cannot be over-emphasized. Even in visual flight, you must scan the flight instruments to see whether you are holding the proper attitude. As an example, though you can maintain a level attitude by visual reference, you must also check the altimeter to see

Figure 8–6. Indications of attitude by altimeter

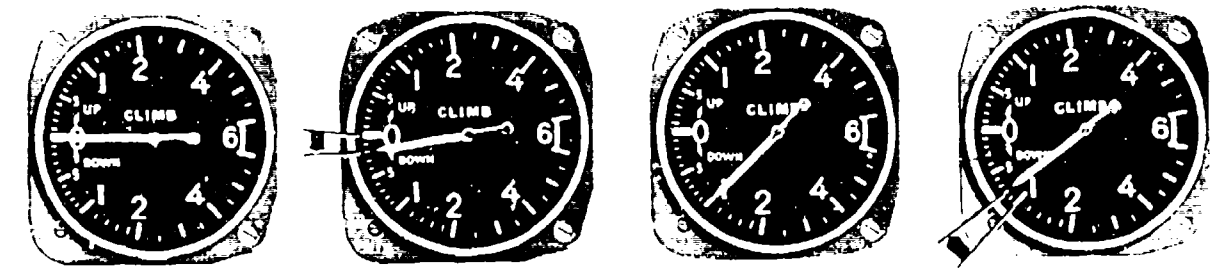

Figure 8–7. Vertical-speed indicator

whether this attitude is maintaining level flight. During instrument flight the instruments serve a dual purpose. They permit you to visualize the attitude of the aircraft, and also to determine whether that attitude will maintain the desired condition of flight. The control technique is identical with that of visual flight. Accurate control during instrument flight depends on your ability to scan and properly interpret the instruments most important for the maneuver you are executing.

Individual pilots may differ in the exact method of scanning, but they all use the same basic system. They use the instruments which give the best information for controlling the aircraft in any given maneuver. They also scan the other instruments to aid in maintaining the important, or primary, instruments at the desired indications.

The primary instrument is always the instrument that gives the most pertinent information for any particular maneuver; it is usually the one that you should hold at a constant indication. The horizon indicator, for example, is always the primary instrument for pitch attitude in level flight, especially in conditions such as thunderstorms where there are exceptionally strong vertical currents. As already explained, you can use any of the pitch instruments to hold a level attitude (or with the proper power setting, reasonably level flight), but none of these instruments except the horizon indicator will give you the exact information desired. The other instruments, which you use to aid you in holding the horizon indicator constant, are referred to as supporting instruments.

There are times when you use a supporting instrument almost as much as the primary instrument. For example, when you are attempting to maintain constant pitch by reference to the horizon indicator, the altimeter and the vertical-speed indicator will show you whether you are succeeding and will show you the direction (up and down) of any variation from the desired pitch. Scanning can thus be a real help because the sooner you determine the need for a correction, the smaller the corrective action you need.

Trim

Proper trim techniques are essential to smooth and accurate instrument flying. Use trim to relieve control pressures and not to initiate attitude changes. Sometimes, when the control pressures have apparently been relieved by trimming, there may be very small pressures which you can't feel.

Figure 8–8. Indications of attitude by airspeed indicator

Therefore, release the controls slowly and observe the instruments to determine if the aircraft will maintain the desired attitude. If it will not, apply pressures to the controls again to attain the desired attitude, and retrim the aircraft. Repeat this procedure until the aircraft will maintain the desired attitude without pressure on the controls.

BANK CONTROL TO PRODUCE COORDINATED STRAIGHT FLIGHT

The bank attitude of an aircraft is the angular relation of the lateral axis of the aircraft to the true horizon. To maintain a straight course in visual flight, you must keep the wings of the aircraft level with the true horizon. Assuming that the aircraft is trimmed properly and is in coordinated flight, any deviation from a wings-level attitude produces a turn.

The instruments used for bank control are the horizon indicator, the heading indicator, and the turn-and-bank indicator (Fig. 8-9).

Horizon Indicator

In instrument flight, the miniature airplane and the horizon bar of the horizon indicator are substituted for the real aircraft and the true horizon (Fig. 8-10). The horizon indicator is a direct-reading instrument. The attitude of the aircraft is indicated on its face instantly through the relative position of the miniature aircraft with respect to the horizon bar. For easy interpretation of this instrument, the pilot imagines himself "flying" the miniature aircraft.

The angle of bank is indicated by the pointer on the banking scale at the top of the instrument. On some horizon indicators, you can readily determine small angles of bank (which you may not see while observing the miniature aircraft) by referring to the banking scale pointer.

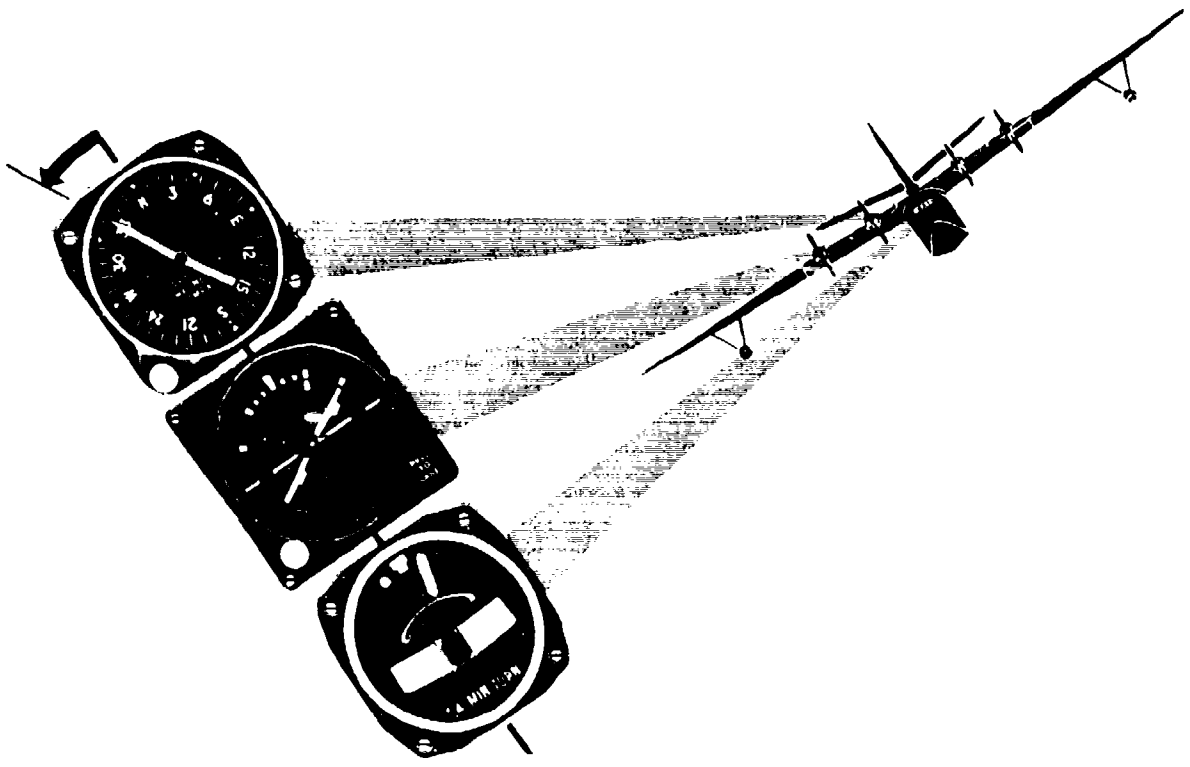

Figure 8-9. Instruments used for bank control

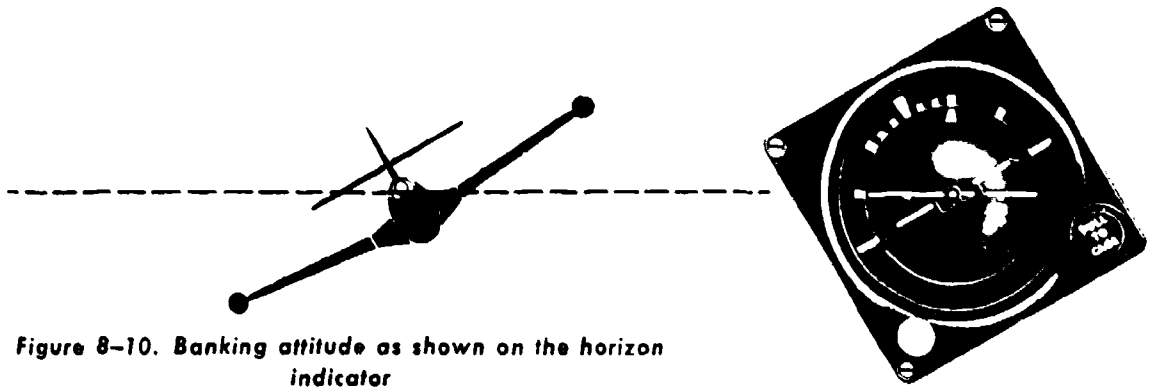

Figure 8-10. Banking attitude as shown on the horizon indicator

You can determine pitch and bank attitude simultaneously on the horizon indicator. Even though the wings of the miniature aircraft are not level with the horizon bar, you can determine pitch attitude by observing the relative position of the nose of the miniature aircraft with respect to the horizon bar.

Uncage the horizon indicator only in straight-and-level attitude, as indicated by the other attitude instruments. Of course, the electrical horizon indicator has no tumble limits; however, you should not rely on the suction-driven horizon indicator after exceeding 100° of bank.

Both the electrical horizon indicator and the suction-driven horizon indicator may show small misrepresentations of the bank attitude during maneuvers which involve turns. You can detect this precession immediately by closely scanning the other bank instruments during these maneuvers. Even though the gyro of the horizon indicator may precess during certain maneuvers, you can still use this instrument as an aid in controlling the bank attitude of the aircraft.

You will normally notice precession when you roll out of a turn. If, on the completion of the turn, the wings of the miniature aircraft are level and the aircraft is still turning, make a small change in the bank attitude to center the turn needle and stop movement of the heading indicator.

Heading Indicator

Some aircraft you fly will have an electric heading indicator, and some will have a suction-driven heading indicator. One or the other of these instruments will be installed, but not both. To cover both, the term "heading indicator" is used here for both electric and suction-driven gyro heading indicators.

The banking attitude of the aircraft is shown indirectly on the heading indicator. A deviation from the desired heading in coordinated flight suggests a bank in the direction that the aircraft is turning. A small angle of bank is indicated by a slow deviation from the desired heading, and a large angle of bank by a rapid change in heading. If you notice a turn, apply coordinated rudder and aileron pressures until the heading indicator indicates a constant heading. When an aircraft is banked, it turns. When the wings are level, it flies straight if in coordinated flight. Therefore, when the heading indicator shows a constant heading the wings are level. Make your correction to the desired heading by using an angle of bank no larger than the number of degrees to be turned. In this correction, do not exceed the angle of bank required for a standard rate turn.

The suction-driven heading indicator has no direction-seeking qualities and should be adjusted while the aircraft is in straight-and-level flight so that its indication coincides with the magnetic heading. Check it frequently against the magnetic indicator for precessional error. The limits of operation of the suction-driven heading indicator are approximately 55° of pitch and/or bank.

Turn-and-Bank Indicator

When the turn needle is exactly centered, the aircraft is in straight flight. When the turn

needle is displaced from center (Fig. 8-12), the aircraft is turning in the direction of the displacement. Thus, in coordinated flight, if the turn needle is to the left of center, the left wing is low; re-centering the turn needle will produce straight flight.

Close observation of the turn needle is necessary to interpret accurately small deviations from the desired position. In turbulent air, the turn needle oscillates from one side to the other, and you must average the fluctuations to determine the banking attitude. When the deflection is greater on one side of center than the other, the aircraft is banking in that direction. To determine whether the turn needle is out of adjustment, place the aircraft in straight flight, as indicated by observing the other banking instruments. If the turn needle indicates a deflection, you should interpret this position as the center position.

Use the ball of the turn-and-bank indicator to determine whether the ailerons and rudder are coordinated. If the wings are level and you have the aircraft properly trimmed, the ball will remain in the center, and the aircraft will maintain straight flight. If the ball is not centered, the aircraft is improperly trimmed.

To trim the aircraft properly, use the aileron pressure required to maintain a wings-level attitude (by reference to all available instruments); then center the ball with rudder pressure. To relieve these individual pressures, adjust the appropriate trim control. Release the controls slowly and observe the instruments to determine whether the aircraft will maintain straight flight. If it does not, again apply pressures to attain the desired attitude and retrim the aircraft. Repeat this procedure until the aircraft will maintain straight flight without pressures on the controls.

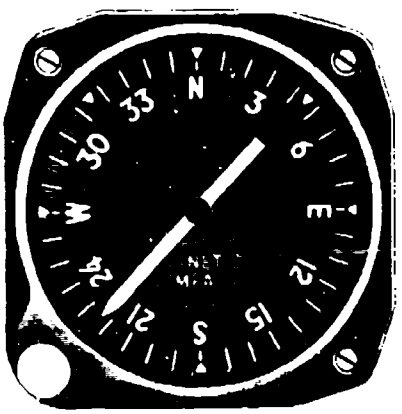

Figure 8-11. Heading indicator

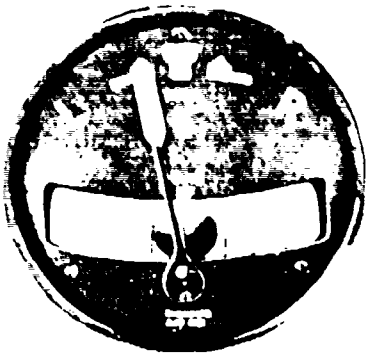

Figure 8-12. Turn-and-bank indicator

Scanning

You should practice the combined use of all available bank-control instruments to produce straight flight. Both the heading indicator and the turn needle indicate when the aircraft is turning. Either the horizon indicator or the ball of the turn-and-bank indicator can show you the cause of the turn. In straight flight, the horizon indicator is the primary instrument for bank control. If it is not available (inoperative, unreliable, etc.), maintain straight flight by reference to the turn needle and the heading indicator.

Throughout your practice of the techniques described in this chapter, remember that control of pitch and bank attitude is of equal importance. Therefore, as you learn the use of each of the bank instruments, you must include it in the sequence of scanning previously used. As the number of instruments you must observe increases, the speed of scanning also must increase.

POWER CONTROL IN STRAIGHT-AND-LEVEL FLIGHT

At any given airspeed, the power setting determines whether the aircraft is in level flight,

in a climb, or in a descent. In other words, power controls altitude. For example, cruising airspeed maintained with cruising power will result in level flight. If you increase the power setting and hold the airspeed constant, the aircraft will climb. Conversely, if you decrease the power and hold the airspeed constant, the aircraft will descend.

If you hold the altitude constant, the power determines the airspeed. For example, at a constant altitude, cruising power results in cruising airspeed. Any deviation from the cruising power setting results in a change in airspeed.

To maintain level flight when you change power and airspeed, you will need considerable elevator pressures in all types of aircraft. You will also need various rudder pressures in propeller-driven aircraft, because of torque changes. When you add power to increase the airspeed, the aircraft tends to assume a nose high attitude and climb without any movement of the elevators or the elevator trim. The opposite effect occurs when you reduce power: the aircraft tends to assume a nose-low attitude and descend. These changes in attitude are caused by the changes in vertical lift, which, in turn, are caused by changes in power. Also, when you increase power, the nose of the aircraft tends to yaw to the left. This yawing effect, which is most pronounced in single-engine, propeller-driven aircraft, and to lesser extent in multi-engine, propeller-driven aircraft, is absent in aircraft with counter-rotating propellers and in jet aircraft. To counteract the tendency of the aircraft to change attitude, retrim the aircraft.

During a change in power, you should make an accurate interpretation of the altimeter. Then counteract any deviation from the desired altitude by appropriate pressure on the elevator control. If the altitude is low and the airspeed is high, or vice versa, a change in pitch alone may return the aircraft to the proper altitude and airspeed. If both airspeed and altitude are low, or if both are high, then a change in both power and pitch is necessary.

To make power control easy when changing airspeed, you should know the approximate power

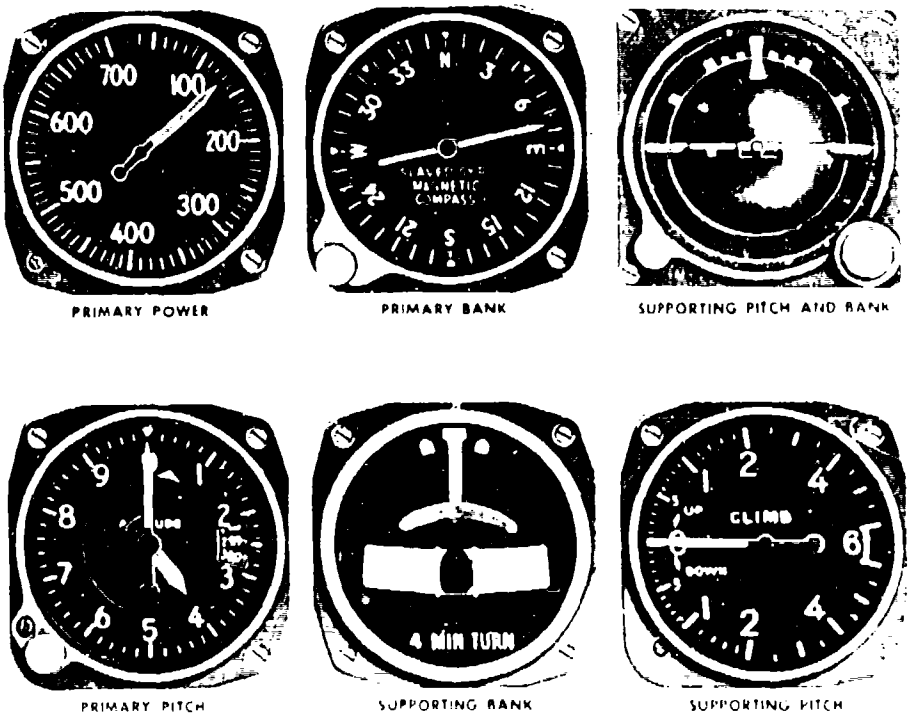

Figure 8-13. Instruments indicating straight - and - level flight

settings for the various airspeeds which will be flown. When you wish to change the airspeed any appreciable amount, adjust the power so that the manifold-pressure gauge shows approximately 3 to 5 inches more change than you anticipate will be required to maintain the new airspeed. This is sometimes called the power differential. As the airspeed changes, you must control the pitch and bank attitudes to maintain a constant altitude and heading. As you approach the desired airspeed, adjust the power to the new cruising power setting. Overpowering and underpowering 3 to 5 inches of manifold-pressure is the normal procedure. This results in a change of airspeed at a moderate rate, which allows ample time to trim the aircraft. In certain types of aircraft these figures will not apply.

In changing airspeed any appreciable amount, use the manifold-pressure gauge to give you the power required for the airspeed you want. When making the change, the manifold-pressure gauge is momentarily the primary power-control instrument. However, as the airspeed approaches the desired speed, the airspeed indicator becomes the primary instrument for power control.

Since power changes effect aircraft attitude, scanning the attitude-indicating instruments is continued during all power transitions.

As you can see, the necessity for power control thus adds the power-control instruments to the pitch and the bank instruments which you must scan to produce straight-and-level flight. With a constant power setting, a normal scan should be satisfactory. When you change the power, however, you must increase the speed of the scan to cover the pitch and bank instruments adequately as well as the power-control instruments. This is necessary to counteract any deviations immediately.

CONSTANT AIRSPEED CLIMBS, DESCENTS AND LEVEL-OFFS

For any power setting and load condition there is only one attitude which will give the most efficient rate of climb. Climb data for the type of aircraft you are flying gives you the best climbing airspeed and power settings for different altitudes. In a climb or a descent at a constant airspeed and

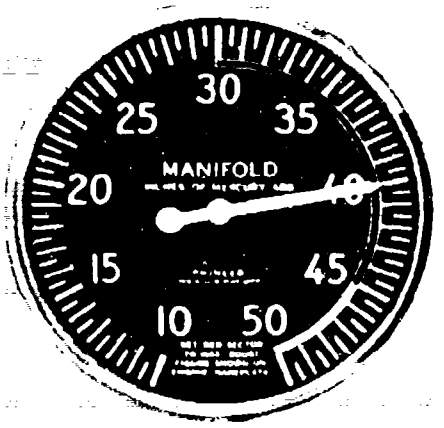

Figure 8-14. Manifold-pressure gauge

power setting, you must accept whatever vertical speed results. The manifold-pressure gauge is the primary instrument for power control.

To enter a climb from cruising airspeed, raise the nose to the approximate climbing attitude; after the airspeed drops to about 5 knots above the desired climbing airspeed, apply climbing power. It takes only a very small amount of back pressure to complete the change from level to climbing attitude. Follow the horizon indicator in accomplishing the change in attitude. It is the primary instrument for pitch. Hold this established rate of climb constant. This causes the airspeed to decrease smoothly. As the desired airspeed is approached, lower the nose slightly to stop and maintain the airspeed on the desired indication.

Although the horizon indicator is the primary instrument for pitch, it is important that you use the vertical-speed indicator as an aid to maintain a constant airspeed. For example, if the vertical speed is 800 fpm (feet per minute) after the entry, you should hold this rate of climb until the airspeed shows a change. If the airspeed decreases 2 knots below that desired, you should adjust the attitude on the horizon indicator to establish a rate of climb of 700 fpm. This should regain the desired airspeed, but if it does not, make another correction. If the initial change were as much as 5 knots, it would be advisable to make a 200 fpm correction on the vertical speed indicator. Main-

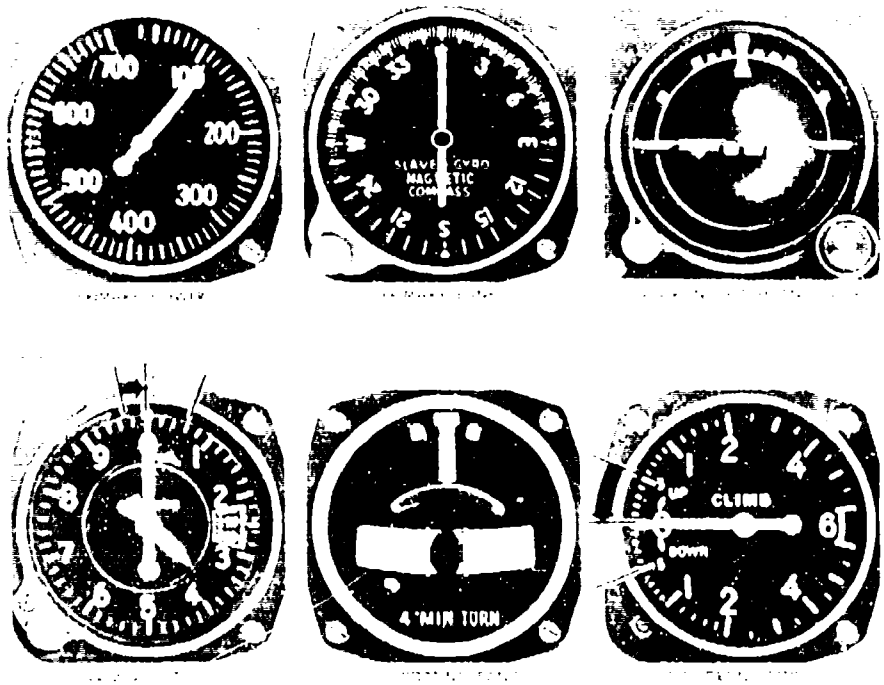

Figure 8-15. Level off from either climb or descent

tain directional control as in straight flight. Be sure to use the proper trim technique throughout the climb.

Entering a climb without the horizon indicator is the same except that you must use the airspeed indicator and the trend of the vertical speed indicator for pitch control. Applying power, will normally bring the nose up and you will not have to apply back pressure to attain the desired vertical speed. Hold this vertical speed until the airspeed approaches the climbing airspeed. From this point the procedure is the same as when all the instruments are available.

Start the level-off from a climb before reaching the desired altitude. Although the necessary amount of lead varies with the aircraft and pilot technique, the most important factor is the vertical speed. Normally, the lead for each 500 fpm rate of climb will be 20 to 30 feet. When you reach the proper altitude for starting the level-off, the altimeter becomes primary for pitch (Fig. 8-15). Adjust the nose attitude to the level-flight attitude for that airspeed. Cross-check the altimeter and vertical speed indicator to determine whether you have attained level flight at the proper altitude. Follow changes in nose attitude with appropriate trim adjustments when necessary.

To enter a climb when already at climbing airspeed (Fig. 8-16), advance the throttle to the climbing power setting and adjust the nose attitude on the horizon indicator to maintain a constant airspeed. As you apply power, the airspeed indicator becomes primary for control of the nose attitude. Then use the relationship between the vertical speed and the airspeed for control of the nose attitude as previously described.

If you want to cruise at climbing airspeed, accomplish the level-off with a coordinated change of power and pitch. When the aircraft reaches the point of level-off, reduce the power smoothly to maintain airspeed and adjust the nose attitude to level off on the desired altitude.

A constant airspeed descent may be performed at any airspeed, but you must determine the airspeed before entry. Regardless of the airspeed, the technique is basically the same.

To descend at an airspeed lower than cruising, reduce power to the descending setting and maintain a constant altitude. When you approach the descending airspeed, adjust the nose attitude to establish a descent at the desired airspeed. Use the horizon indicator as the primary instrument. Then, when the descent is started, cross-check the airspeed indicator. Use the vertical-speed indicator as previously described in a climb.

To enter a descent from descending airspeed, reduce the power and adjust the pitch simultaneously to maintain a constant airspeed. The horizon indicator is the primary pitch instrument throughout the descent. Use the airspeed indicator and the vertical-speed indicator exactly as in a climb to aid in controlling the nose attitude.

To level off at descending airspeed, simultaneously advance the power to the setting necessary to maintain this airspeed in level flight and adjust the nose to level-flight attitude. As in a climb, a lead is necessary to level-off at a desired altitude. This lead is approximately 40 to 60 feet for each fpm rate of descent. When you reach the proper altitude for starting the level off, the horizon indicator becomes the primary instrument for pitch and the airspeed is primary for power.

To level off at an airspeed lower than descending airspeed, use the same lead and primary instruments as just discussed for levelling off at descending airspeed. Here's what you do. When you reach the level-off point, adjust the pitch as necessary to maintain level flight as the airspeed is reduced. As the airspeed approaches the speed desired, adjust the power to maintain that airspeed in level flight. The power used in some

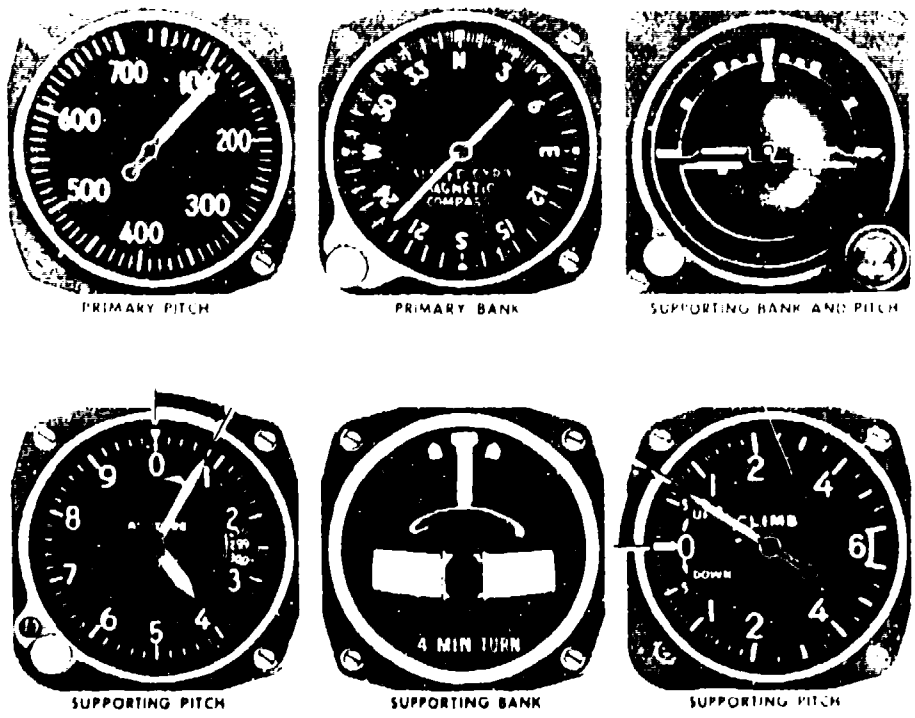

Figure 8–16. Entry into a climb at climbing airspeed

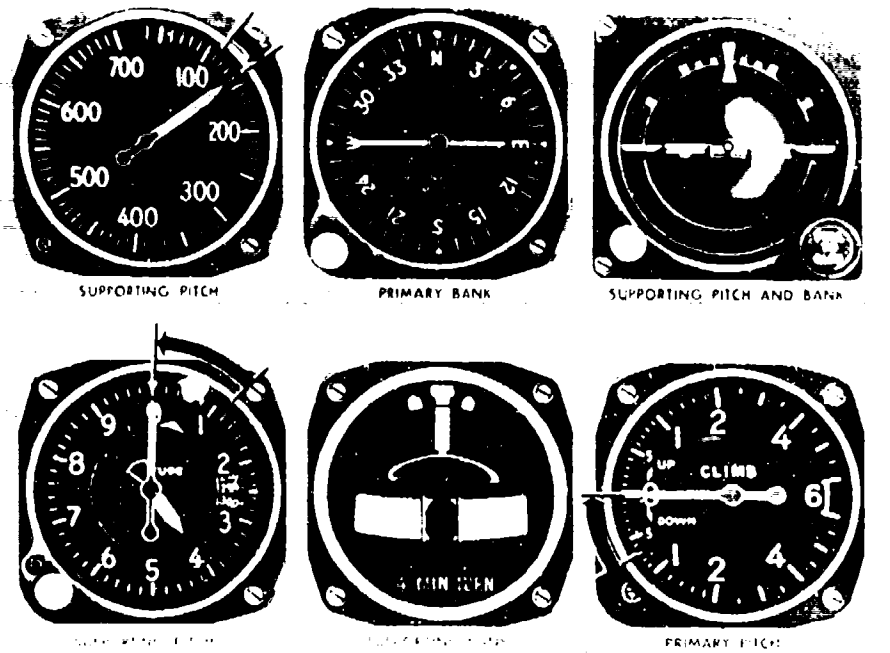

Figure 8-17. Leveling off from a descent at cruising airspeed

descents may be too high to allow the airspeed to change at a normal rate. This may require a reduction in power as you adjust the nose attitude in the level-off.

To level off at an airspeed higher than that used for the descent, you must advance the power before reaching the level-off point. The new power setting should be the one necessary to maintain the desired airspeed in level flight. Add the power at the point that will allow you to attain the desired airspeed at the time you reach the level-flight attitude. This point varies with different types of aircraft, with the amount of change in airspeed, and with the rate of descent. The horizon indicator becomes the primary instrument for pitch as you add the power (Fig. 8-17). Hold this rate of descent constant until you reach the lead point for changing the pitch to the level-flight attitude. At this time the altimeter becomes primary for pitch and the airspeed indicator primary for power.

During straight climbs and descents, the heading indicator is primary for bank control. You must relieve control pressures by use of trim, as in all instrument maneuvers.

RATE CLIMBS AND DESCENTS

Rate climbs and descents are excellent maneuvers for developing and improving precision aircraft control. In addition, rate descents are essential in the accomplishment of a GCA or an ILS landing.

The procedures, scan, and aircraft control for constant-rate climbs and descents are very similar to those just described for climbs and descents at a constant airspeed. The key principle, as stated before, is that the nose attitude controls airspeed and power controls vertical speed, which means altitude. The horizon indicator is primary for pitch control. The heading indicator remains the primary turn control instrument, because the as-

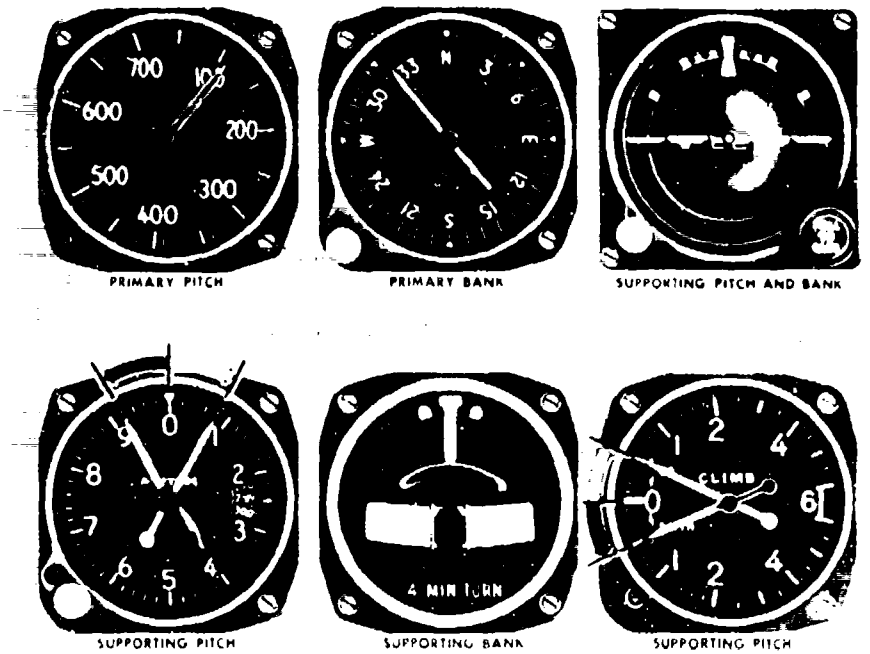

Figure 8-18. Entering into rate climbs and descents

sumption is that, at this point, you are making climbs and descents on a constant heading.

For training purposes, rate climbs or descents are often entered from climbing or descending airspeed. This may not always be possible or desirable in actual instrument conditions. The rate utilized in these maneuvers is one that is practical for the type of aircraft. Normally, in prop aircraft, you make the climbs and descents at 500 fpm.

To enter a climb at a definite rate, increase the power to the approximate setting for the desired rate. At the same time, raise the nose of the aircraft to the climbing attitude for the desired airspeed and rate of climb. As you add the power, the airspeed indictor is primary for pitch control until the vertical speed approaches the desired rate (Fig. 8-18). At this time, the vertical-speed indicator becomes the primary instrument for pitch control. Change the nose attitude of the aircraft as required to maintain the desired indication (Fig. 8-19). However, the vertical-speed indicator may be inaccurate to some extent. Check the change in altitude against the time interval while performing a rate climb or descent. This will determine whether the vertical-speed indicator is properly calibrated. Start by establishing a rate climb or descent. Then check the altimeter every 15 seconds for the proper change in altitude. For example, if you use a 500 fpm rate, the altitude should change 125 feet every 15 seconds. If the change in altitude is more or less, adjust the vertical speed accordingly. Repeat the procedure until you determine what indication will produce the desired rate. If you find any error, take it into account in later rate climbs and descents.

When the vertical-speed indicator becomes primary for pitch control, the airspeed indicator becomes primary for power control. Adjust the power to maintain the desired airspeed. Pitch and power corrections must be closely coordinated.

Thus, for example, if the vertical speed is correct but the airspeed is low, add power. As you increase the power you must lower the nose slightly to avoid increasing the vertical speed. Adjust the nose attitude smoothly to avoid over-controlling. Small power corrections are usually sufficient to bring the airspeed back to the desired indications.

To enter a descent at a definite rate, decrease the power to the approximate setting for the desired rate and aircraft configuration. At the same time, lower the nose to maintain the airspeed. The airspeed indicator is the primary instrument for pitch control until the vertical speed approaches the desired rate. The vertical-speed indicator is then the primary instrument for pitch control. Maintain it at the desired indication. Coordinate power and pitch control as described for climbs, and use an identical scan.

Proper trim technique is essential in climbs and descents at a definite rate, and helps prevent over-controlling the pitch attitude.

Level-offs from climbs and descents at a definite rate are accomplished in the same manner as level-offs from climbs and descents at a constant airspeed.

TURNS: ENTRY, TURNING, AND RECOVERY

A turn made by reference to instruments should be made at a definite rate. Turns described in this section are those which do not exceed a standard rate (3° per second) as indicated in the turn-and-bank indicator. The true airspeed determines the angle of bank necessary to maintain a standard rate turn (single needle width for 3° per second with the two-minute turn needle, or two

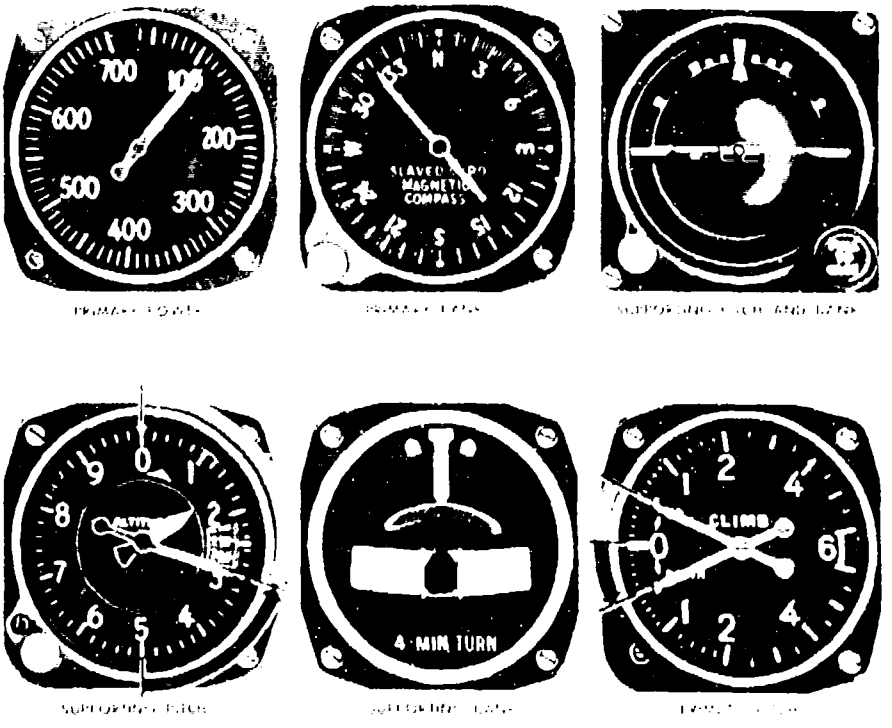

Figure 8-19. Instruments used during rate climbs and descents

needle widths with the four-minute turn needle). At high speeds (above 220 knots true airspeed) a ½ standard rate turn (1½° per second) is desirable to avoid steep banks.

To enter a turn, apply steady, coordinated pressure on the ailerons and rudder in the direction of the desired turn. The horizon indicator is the primary bank instrument, and the turn needle is the secondary instrument. Use the turn needle as an aid in maintaining a constant rate of turn.

In level turns, as in straight-and-level flight, the horizon indicator is the primary pitch instrument and the altimeter is secondary (Fig. 8-20). During the entry into a turn, you must change the nose attitude to compensate for the loss of vertical lift caused by the banking of the aircraft. Therefore, you must observe the pitch instruments while rolling into a turn. Remember, however, that you should not apply corrective action until the flight instruments indicate a deviation from the desired condition of flight. As you raise the nose of the aircraft to hold altitude, add power necessary to maintain the desired airspeed. Proper trim technique is especially valuable at this time since you must vary the control pressures during the turn entry.

When you attain the desired angle of bank, you may have to apply a slight opposite pressure to the ailerons to prevent the bank from increasing beyond the desired amount. It is very important that you maintain the desired angle of bank accurately, since any change in bank changes the vertical component of lift, thus necessitating a change in pitch to maintain level flight.

To return to straight-and-level flight, apply coordinated pressure to the ailerons and rudder in the direction opposite to the turn. The rate of roll-in and roll-out should be the same. To ac-

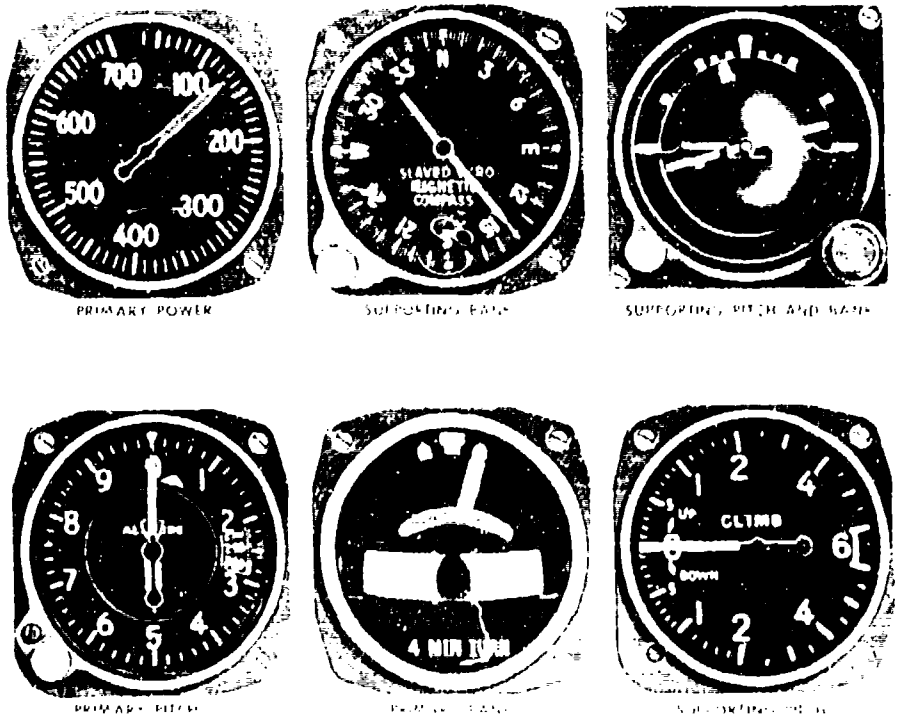

Figure 8-20. Instruments for level turns

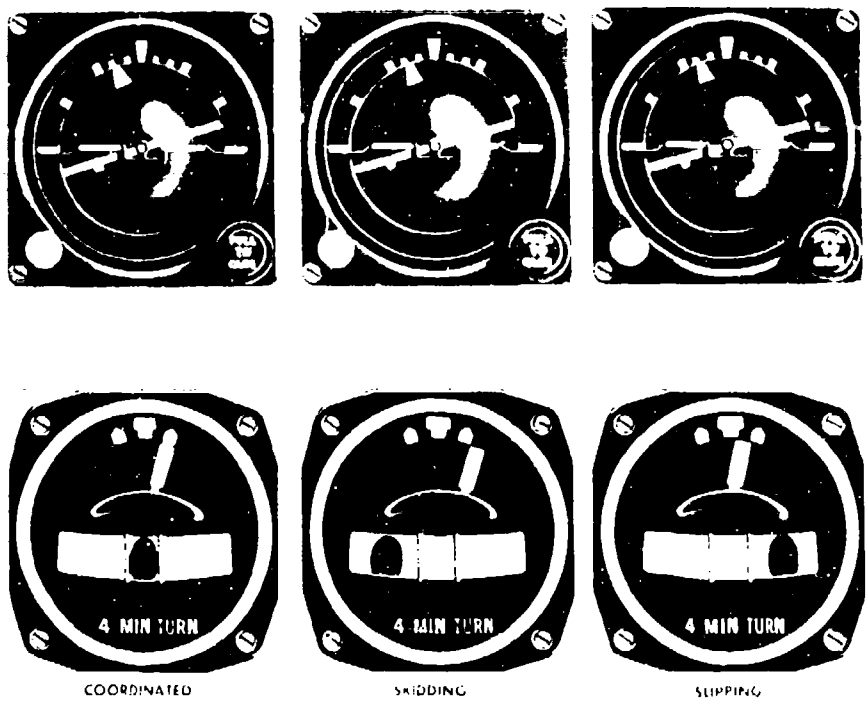

Figure 8-21. Turn indications

complish this, use the rate of roll-in as a guide during the roll-out. As the angle of bank decreases, the vertical lift increases and you must lower the nose of the aircraft to maintain the desired altitude. At the same time, you must make the proper power adjustment to maintain the desired airspeed.

You can enter a turn with rudder alone, but this results in a skid instead of a coordinated entry (Fig. 8-21). You can also enter a turn by use of ailerons alone, but the resulting aileron drag causes a momentary slip (Fig. 8-21). Simultaneous use of the ailerons and rudder will produce a coordinated entry. The ball of the turn-and-bank indicator shows whether the aircraft is in coordinated flight. Observe the ball during your scan throughout the turn, so that you may apply pressures to keep it centered.

To make sure of the calibration of the turn needle in case the horizon indicator fails, calibrate your turn needle on the first turn after take-off. Set your airspeed and, using the horizon indicator, bank the aircraft at the proper angle for a standard rate turn at that airspeed. Time your turn through at least 30° (10 seconds), checking your turn needle to see how far it deflects. You then know how much your turn needle deflects for a standard rate turn—whether it is actually a single needle width or is off somewhat. Then, if you lose your horizon indicator, you know accurately the significance of the turn needle deflection.

Remember that three distinct steps are utilized in executing a turn:

1. *Start* the turn at a normal rate, coordinating aileron and rudder.

2. *Stop* the rotational movement of the wing when the desired angle of bank is achieved when necessary aileron force.

3. *Hold* the desired angle of bank with the necessary aileron force. Remember that the three steps should be coordinated into one continuous movement.

Coordinating ailerons and rudder means that you apply pressures simultaneously to rudder and

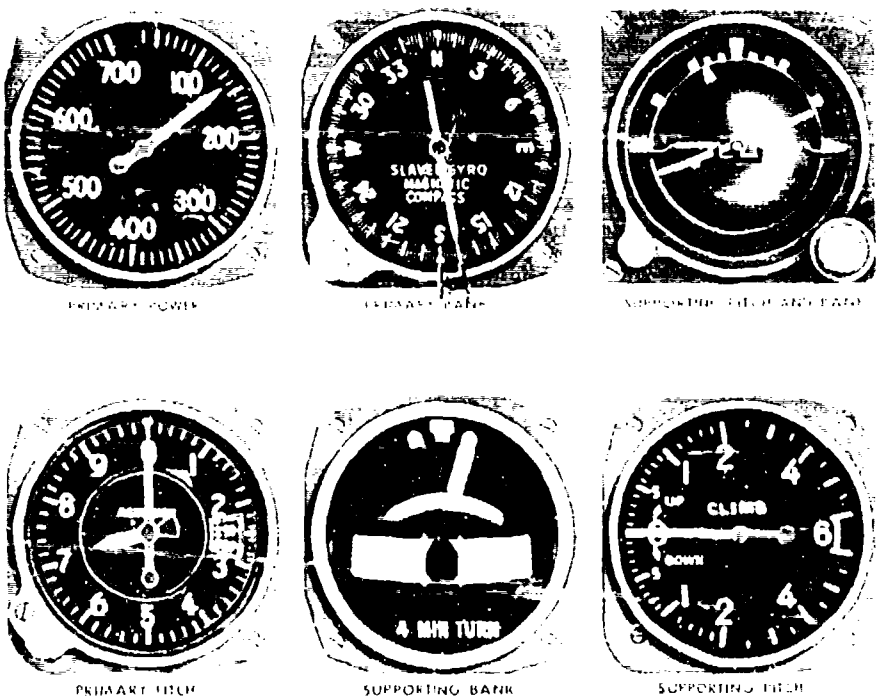

Figure 8-22. Rolling out on a heading

aileron. Good coordination requires that you don't skid or slip the aircraft in executing a turn. By referring to the altimeter and vertical-speed indicator frequently, you can apply immediate corrective action if you observe any tendency for the aircraft to climb or descend. Check the heading indicator frequently during the turn, and start the recovery in sufficient time to stop on the desired heading.

HEADING INDICATOR TURNS

In the section "Bank Control to Produce Coordinated Straight Flight," you learned that turning and banking in coordinated flight are the same. An aircraft will continue to turn as long as the wings are banked; therefore, you must start the recovery from a turn to a heading on the heading indicator before the desired heading has been reached. The amount of this lead varies with the relationship between the rate of turn and the angle of bank and with the individual pilot's rate of recovery. If you analyze the following examples, you will see the reasons for varying the amount of lead necessary to roll out on a given heading.

As a guide, when you recover from a 3° per second rate of turn, use a lead of one-half the angle of bank; when you recover from a 1½° per second rate of turn, use one-third the angle of bank as a lead. As an example, suppose you are turning at a rate of 3° per second, using a 24° bank. Lead your roll-out point by 12°. If you are turning at a rate of 1½° per second, using a 24° bank, lead your roll-out point by 8°. Use these amounts of lead until you are able to determine the exact amount required for your particular aircraft and technique.

To roll out on a given heading (Fig. 8-22), use the same technique as you would during a normal roll-out from any turn, except that you should start the recovery the instant you reach the predetermined lead on the heading indicator. Check the heading indicator after you have the turn

needle centered to determine whether or not you used the proper lead. Any deviation from the desired heading on the heading indicator will then indicate a need for a change in the number of degrees of lead used. For example, if you used 13° of lead to roll out of a 26° angle of bank, and the roll-out was 2° beyond the desired heading, the proper lead would be 15°. The rate of entry and recovery should be the same. During the turn, use the normal scan technique and the primary instruments you use in any turn. To determine when to start the recovery, however, add the heading indicator to the scan as the aircraft approaches the desired heading.

USE OF THE MAGNETIC COMPASS

The direct-reading panel magnetic compass (Fig. 8-23) is the only heading indicator that does not become inoperative with the loss of suction and/or electrical current. Therefore, it is important that you be able to turn your aircraft to a magnetic compass heading and maintain it. To do this, you should understand and remember the following characteristics of the magnetic compass:

1. If the aircraft is on a northerly heading and you start a turn toward the east or west, the indication of the compass lags, or indicates a turn in the opposite direction.

2. If the aircraft is on a southerly heading and you start a turn toward the east or west, the indications of the compass precede the turn and indicate a greater amount of turn than has actually been made.

3. When the aircraft is on an east or west heading, no error is apparent while turning toward north or south.

4. If the aircraft is on an east or a west heading, an increase in airspeed causes the compass to indicate a turn toward the north.

5. If the aircraft is on an east or a west heading, a decrease in airspeed causes the compass to indicate a turn toward the south.

6. If the aircraft is on a north or south heading, no error is apparent while climbing, diving, or changing airspeed.

Obviously, then, it is best to read the compass only when the aircraft is flying straight and level at a constant speed. If you do that, you will reduce errors to the minimum.

When you make turns on the magnetic compass, use an angle of bank that gives a standard-rate turn, but this angle should not exceed 18°. You must hold this angle of bank accurately to be successful in turning to magnetic compass headings. In a turn to north or south, the amount of lead or lag in the indications of the magnetic compass depends on the latitude at which the turn is being made. In fact, it is approximately equal to the latitude. This lead or lag is at the minimum over the equator and increases as the latitude increases, reaching its maximum in the polar regions. Besides this lead or lag, you must consider also the normal lead necessary for the roll-out of a turn. To understand this, consider turns to cardinal headings.

When you turn to a heading of north, the number of degrees of lead necessary is equal to the latitude plus the number of degrees required for the roll-out. For example, during a left turn to a

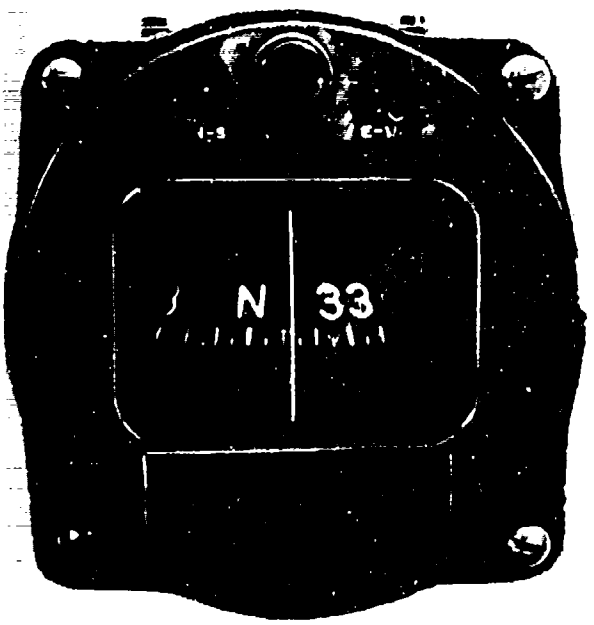

Figure 8-23. Magnetic compass

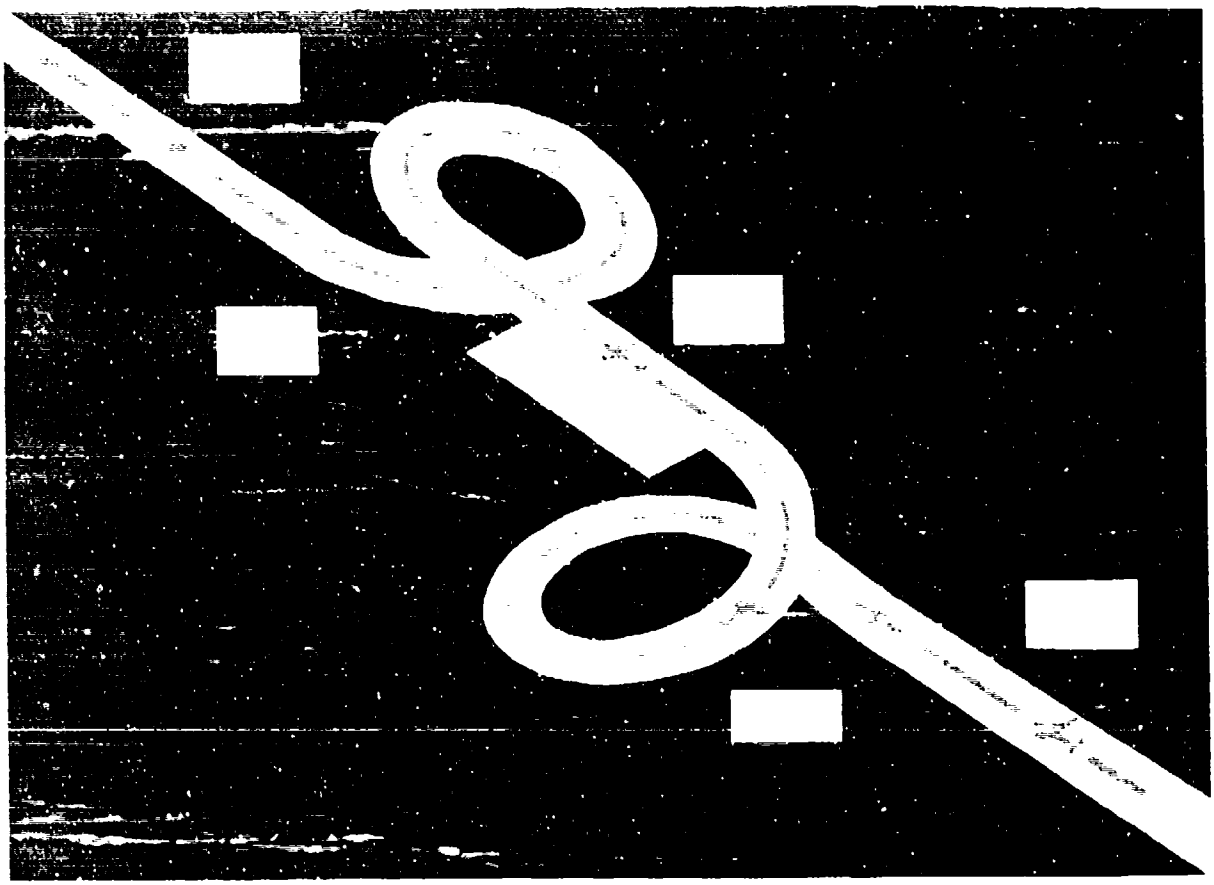

Figure 8-24. Oboe pattern

heading of north, using a 15° angle of bank at a TAS of less than 220 kts. In a locality where the latitude is 30° N, you should start the roll-out when the magnetic compass read 075° (180° plus one-half of 150).

To turn to a heading of south, turn past south the number of degrees equal to the latitude, minus the number of degrees required for the roll-out. For example, when you turn to the right to a heading of south at a TAS of less than 220 kts, start the roll-out when the magnetic compass reads 210° (180° plus 60° minus 30°).

In a turn from north to east or west, the magnetic compass noticeably shows a lag. As the heading approaches the east or west heading, the magnetic compass starts to turn faster than the aircraft is turning. For this reason, you must start the roll-out when the magnetic compass indicates approximately 10° ahead of 90° or 270°. For example, start the roll-out at approximately 80° when turning to east; start 280° when turning to west.

In a turn from south to east or west, the magnetic compass initially shows a lead. As the heading approaches east or west, the rate of turn of the compass card decreases and you must start the roll-out only 5° ahead of 90° or 270°.

ADVANCED PATTERNS

If you examine the advanced patterns in Figures 8-24 and 8-25, you will see that they incorpo-

rate all the fundamental basic airwork into a single pattern, which is performed as a sequence without interruption. These patterns are normally introduced toward the end of the basic airwork. They cover all maneuvers involved in the control of aircraft through instruments, developing a sound sense of timing, precision, and general smoothness required by a good instrument pilot. Obviously, because of their very nature, all pattern flights must be well planned and orderly, and serve to introduce the aviator to exact flight planning during the early stages of instrument training.

WINGOVERS

Wingovers have a practical value as a confidence maneuver in the use of the horizon indicator. They are commenced at fast cruise with wings level. The nose of the aircraft is raised above the horizon and a coordinated climbing turn executed. The wing tip of the miniature aircraft should pivot on the horizon bar, and the bank should vary from 60° to 70°. The airspeed should fall to a value below slow cruise and above the stalling point. When you complete the climbing turn, you allow the nose of the aircraft to fall through the horizon; you start recovery as the opposite wing tip reaches the horizon. This should result in the aircraft flying level and the airspeed assuming its original starting value. You then repeat this cycle in the opposite direction.

STEEP TURNS

Any turn with an angle of bank greater than 30° is considered a steep turn (Fig. 8-26). This type of turn is seldom necessary or advisable in routine instrument flight. However, all-weather jet interceptors employ precise steep turns on instruments as a matter of routine. Therefore, the ability on the part of prop-aircraft pilots to per-

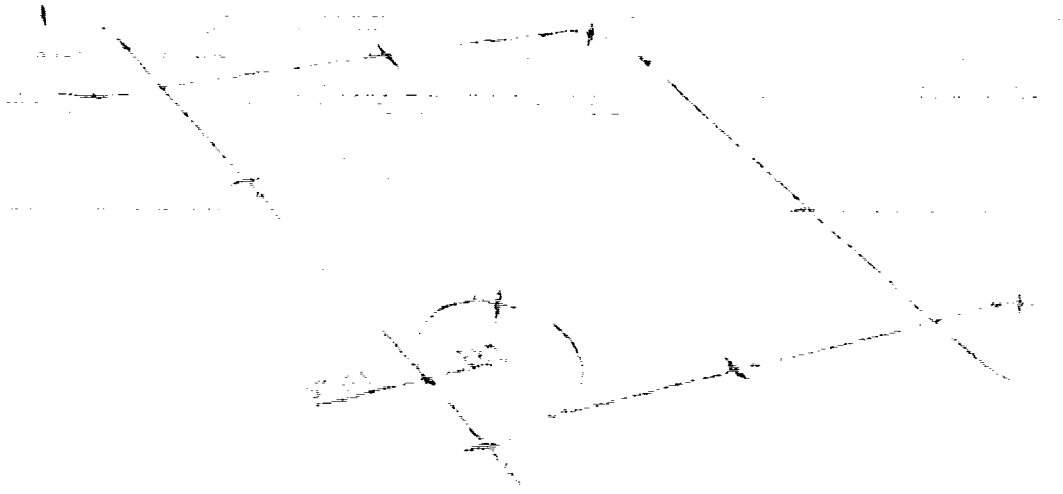

Figure 8-25. Baker pattern

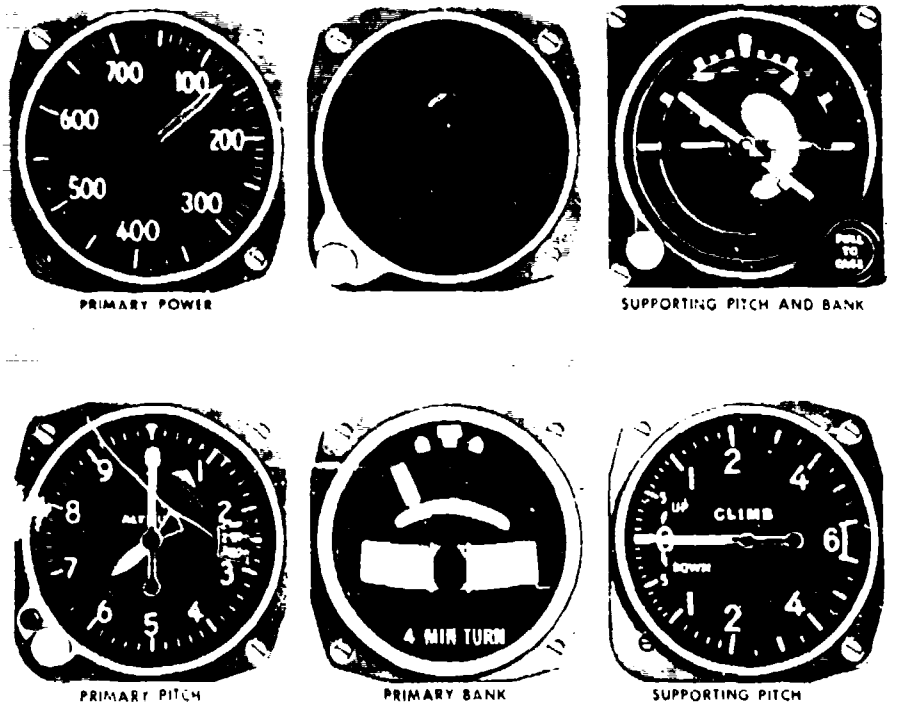

Figure 8-26. Steep turn

form these maneuvers on instruments as evasive action against all-weather jets is very desirable. A steep turn is also a good maneuver to increase your ability to react quickly and smoothly to rapid changes in attitude.

Regardless of the angle of bank, the techniques of entry, control during the turn, and recovery are the same in steep turns as in normal turns. You will find it more difficult to control the pitch attitude, however, because of the greatly reduced vertical lift when you increase the angle of bank. This produces a tendency to lose altitude in steep turns. In addition, with some horizon indicators, precession during the turn makes it more difficult to maintain the desired attitude. Therefore, to maintain a constant altitude, you must take immediate corrective action as soon as the necessity is indicated on the flight instruments. It is important, however, that you do not initiate a correction before the necessity arises. Since this correction involves an increase in the angle of attack, the drag increases and the airspeed decreases. Apply the necessary power to maintain a constant airspeed if this is desired.

When making any corrections, refer to the horizon indicator even though the precession of the instrument is apparent. To accomplish this, note the need for a correction on the vertical-speed indicator or the altimeter; check the attitude indicated on the horizon indicator; and effect the change on the horizon indicator for this indication. After you make this change, again check the altimeter and vertical-speed indicator to determine whether or not the correction was adequate.

If the horizon indicator is not available, note the need for correction on the vertical-speed indicator and altimeter. Initiate the correction action immediately and observe the altimeter and vertical-speed indicator closely to determine whether or not the correction was adequate. Use the turn needle in your scan to maintain a constant rate of turn.

Your recovery should be smooth and with a normal rate of rollout. As you roll the aircraft

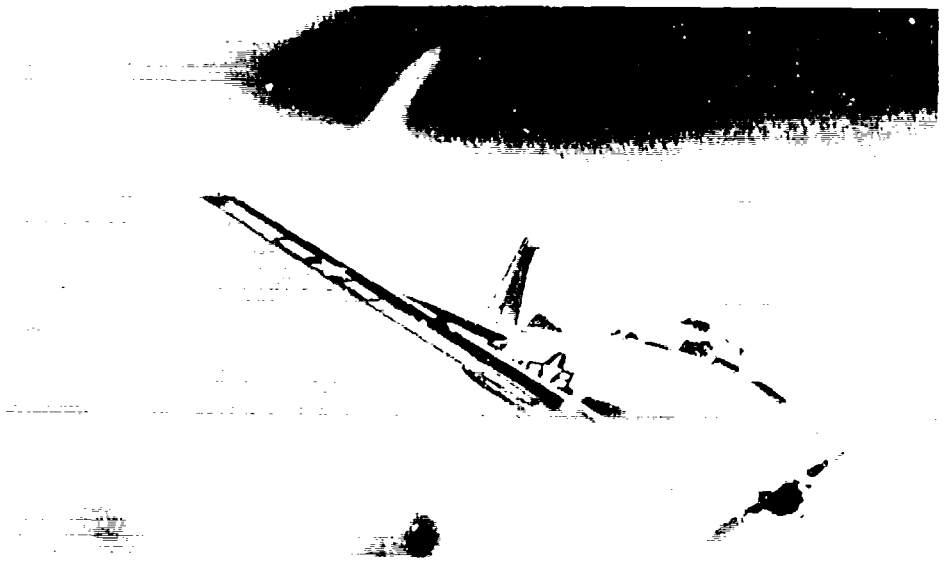

Figure 8-27.
Unusual attitude

out of the turn, the vertical lift will increase and the aircraft will tend to climb if you do not effect the necessary corrections as soon as you note the need on the instruments. Remember to adjust the power to maintain the desired airspeed.

RECOVERIES FROM UNUSUAL ATTITUDES

An unusual attitude is any attitude of the aircraft not required for normal instrument flight. It may result from any one factor or a combination of several factors, such as turbulence, vertigo, instrument failure, confusion of the pilot, or carelessness in scanning the instruments.

If you are flying a conventional aircraft with suction-driven gyro instruments or electric gyros which are not non-tumbling, you make the recovery from any unusual attitude by utilizing the airspeed indicator, the altimeter, the turn needle, and the vertical speed indicator (Fig. 8-28). If you are flying an aircraft with a non-tumbling horizon indicator, use the easier techniques described in Chapter 9 under the heading of Recovery from Unusual Attitudes. Still, it is worthwhile for you to be familiar with the procedure explained here in case you should have an electric failure and get into an unusual attitude.

In any event, recovery must be effected so as to resume straight and level flight with a minimum loss of altitude, yet, at the same time, without exceeding the stress limits of the aircraft.

There are two general procedures for recoveries from unusual attitudes. One of these procedures is used for recoveries from nose-high unusual attitudes; the other is used to recover from nose-low unusual attitudes.

As soon as you detect an unusual attitude, check the airspeed indicator and the altimeter to determine whether the nose of the aircraft is above or below the horizon. Because of the lag in the vertical-speed indicator, disregard it during the initial part of the recovery. If the nose is below the horizon, and the airspeed is high, reduce the power and level the wings by centering the turn needle; then correct the pitch attitude to level flight. Level flight will be indicated when the altimeter is constant on an altitude. If the nose is above the horizon and the airspeed is low, correct the bank to a wings-level attitude; then, as you lower the nose, add power. At the time the airspeed indicator and the altimeter reverse their indications, the nose of the aircraft has passed through the level-flight attitude for the airspeed indicated at that time. Again, level-flight attitude will be indicated when the altimeter is constant on an altitude and the turn needle is centered.

Change all components of control almost simultaneously, with only a slight lead of one over the other; however, this lead should be in the sequence just mentioned. To establish and maintain a level flight attitude, observe the altimeter and turn needle closely as the aircraft approaches level flight. Also, since the control pressures you usually use in recoveries from unusual attitudes are greater than those necessary for normal flight, you should use care to neutralize these pressures as you approach straight-and-level flight.

If the aircraft is equipped with electrical horizon and heading indicators, you may use them as the aircraft approaches level-flight attitude to assist you in the full recovery. Remember, however, that the flight attitude indicated on the horizon indicator may not be the exact aircraft attitude because of gyro precession.

A spin is indicated by a low airspeed, extreme displacement of the needle in the direction of the spin, and a rapid loss of altitude. The ball may be displaced in either direction depending on the spin characteristics of the aircraft. To recover from a spin, use the same mechanical procedures as you use in visual flight to stop the spin. Once you have the spin stopped, make the remainder of the recovery the same as for a nose-low unusual attitude. In general, follow these rules to recover from unusual attitudes:

1. Check the airspeed indicator and altimeter as soon as you detect any unusual attitude in flight.

2. If the aircraft is in a nose-low attitude, simultaneously reduce power and correct the bank, then correct the pitch attitude.

3. If the aircraft is in a nose-high attitude, correct the bank to a wings-level attitude, then simultaneously lower the nose and add power.

Because of the very nature of the occurrence of an unusual attitude, corrective action must be prompt. Speed is essential in the recovery. Excessive loss of altitude is undesirable and may be dangerous. Start a climb or descent back to the original altitude and heading as soon as you attain full control of the aircraft and a safe airspeed.

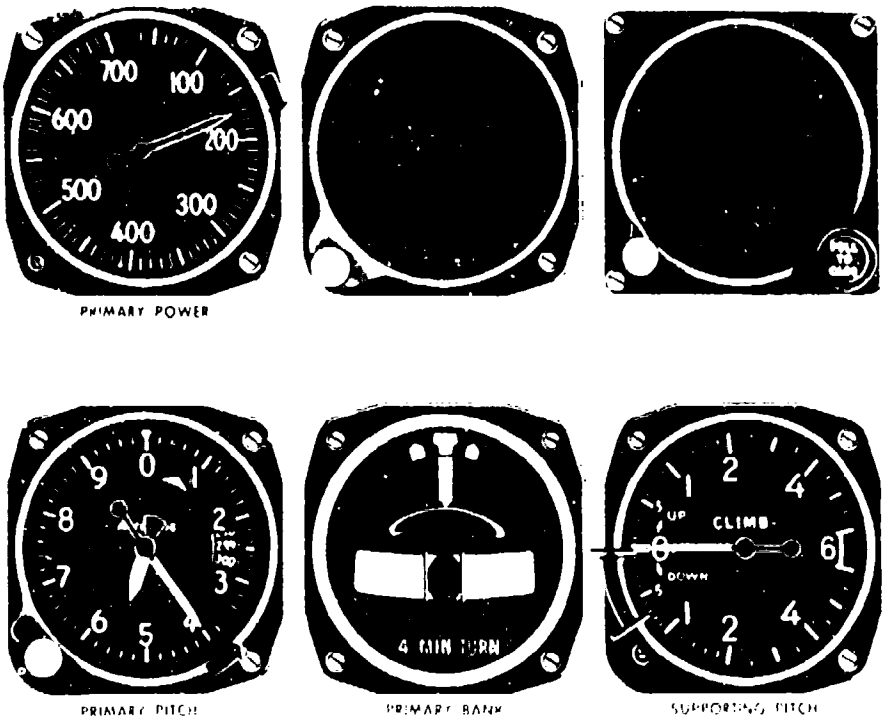

Figure 8-28. Recovery from unusual attitude

CHAPTER 9

BASIC INSTRUMENT FLYING—JET AIRCRAFT

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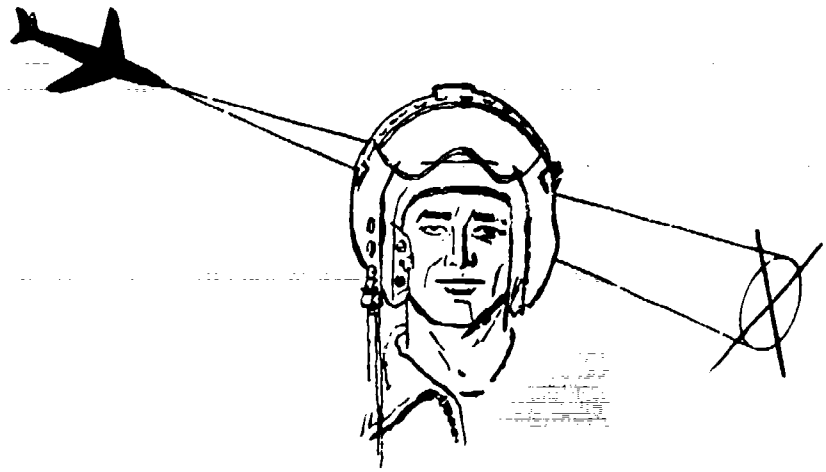


CHAPTER 9

BASIC INSTRUMENT FLYING—JET AIRCRAFT

THE modern high-flying jet aircraft, with its high speed and long range but shorter endurance, requires of the instrument pilot a high degree of proficiency. The performance characteristics of jets have brought about changes in instrument-flying techniques and procedures. These changes have been necessary to make instrument flying in jets effective.

Even with the changes, however, jet instrument flying depends on the same basic considerations and techniques as conventional instrument flying. The techniques and procedures described in this chapter are based on the *attitude instrument system* of aircraft control. Of course, this manual cannot possible cover the operation of all models of jet aircraft. The techniques described here are based on the TV-2 jet instrument trainer and will require suitable adjustment to fit your aircraft. The first topic, for example, is the instrument part of the cockpit check. This procedure must be tailored to your individual aircraft and its instrumentation.

INSTRUMENT COCKPIT CHECK

Normally, the instrument cockpit check is made after you have completed the preflight inspection and started the engine(s). The same procedure is followed in student training, except that the student pilot performs the instrument

cockpit check and reads the items on the check-list to the instructor over the interphone as the instructor taxis the aircraft.

Here are the items which must be checked in all high-speed aircraft:

1. Inverter
2. Loadmeter.
3. Airspeed Indicator.
4. Slaved Gyro.
5. Horizon Indicator.
6. Altimeter.
7. Turn-and-Bank Indicator.
8. Vertical-Speed Indicator.
9. Magnetic Compass.
10. Clock.
11. Engine Instruments.
12. Radio Equipment.
13. Pitot Heat.
14. Throttle.
15. Navigation Publications.

(On training flights, when this check-list is to be given to an instructor pilot, the radio-interphone control should be checked in the INTERPHONE position before making the cockpit check.)

When checking the items listed, use the following procedures.

1. *Inverter.* Check the inverter circuit breaker during the preflight cockpit check. During the instrument cockpit check, actuate the inverter test switch and check the gyro instrument light to determine if both inverters are operating properly.

2. *Loadmeter.* Check the loadmeter to see if the generator is operating properly.

3. *Airspeed Indicator.* If there's not much wind and the aircraft is in the chocks, the reading should be 0. Some later types of airspeed indicators may not register appreciably until the airspeed is up to 60 to 70 knots.

4. *Slaved Gyro.* The slaved gyro or RMI should indicate the proper direction (check with a known direction and the magnetic compass), and should indicate the correct heading at all times.

5. *Horizon Indicator.* If sufficient time has elapsed for gyro warm-up, the horizon indicator should have erected to a wings-level attitude and should indicate the pitch attitude of the aircraft on the ground. You can now set the miniature aircraft level with the 90° marks on the sides of the case which should give approximately level-flight attitude at normal cruising air speed. However, do not set the miniature aircraft on the ground at 100% power as the nose will be down. Instead, set it when the aircraft is in chocks or just before take-off when the power is not on full.

The average erection time is 3 to 4 minutes; but, since the gyro is only slightly pendulous, it may sometimes assume an initial position as much as 40° to 50° from the vertical. When this occurs, it may take as long as 14 minutes to complete the erection cycle, depending on the model.

However, you can erect the gyro much more quickly than that. Apply power to the instrument for 30 seconds, cage the instrument until it hits the stop, then release the caging knob quickly. In this way you start the erection electrically and assist it mechanically. If you should erect it mechanically and then apply the power, you might damage the gimbals.

The erection and turn compensation mechanism of the gyro is designed to operate with the gyro running at a speed of 23,000 rpm. This does not mean that the gyro has insufficient stability for use at lower rotor speeds, but merely that it shows slight increases in both turn errors and erection rate. However, the gyro accelerates rapidly, and with the quick erection just described, it has sufficient stability for reliable pitch indications by the time you have finished taxiing.

6. *Altimeter.* Set the altimeter setting received from the tower in the Kollsman window and compare the altimeter indication with the field elevation. If there is any deviation, make note of it and apply it when you use the altimeter.

7. *Turn-and-Bank Indicator.* Check the turn needle during taxiing turns to see that it moves in the proper direction and returns to center promptly when the turn is stopped. Also check the ball to see that it moves freely and that the tube is filled with damping fluid.

8. *Vertical-Speed Indicator.* The vertical-speed indicator should read zero. If it does not, tap the panel gently. If it still does not return to zero, make allowance for the error when using the instrument. It is also possible to readjust the position of the needle by turning the screw in the lower left hand corner of the instru-

ment with a small screw driver while gently tapping the instrument panel.

9. *Magnetic Compass.* Check the accuracy of the magnetic compass with a known direction and be certain that it swings freely during turns. Be sure no air bubbles are present in the fluid. Of course, this is only a standby instrument and even a 10° difference between it and the magnetic heading indicator (such as the G-2) is acceptable.

10. *Clock.* Check the clock to see that it is running and that it indicates the correct time.

11. *Engine Instruments.* Check all engine instruments for proper indications. (This does not replace the final check to be made just before take-off.)

12. *Radio Equipment.* Check all radio equipment in the aircraft. The normal UHF calls can be considered as an adequate check for the UHF set. Also check the radio compass and the other radio navigational equipment. Tune the radio compass to a radio aid in a known direction and check it for calibration of the tuning dial, correct indication of relative bearing on COMP position, reception of audible signals in all positions, and satisfactory operation of the CW-VOICE and Left-Right (L-R) switches.

13. *Pilot Heat.* At over 40 percent rpm, turning on the pitot-heater switch should cause the loadmeter to indicate a slight increase, which is a fairly reliable check on the operation of the pitot heater.

14. *Throttle.* Check throttle friction to make sure that the throttle will move easily by hand but is not so loose that it will move as a result of vibration.

15. *Navigation Publications.* Before you leave the line, check to see that all radio-navigation and let-down manuals are in the aircraft and are in usable condition.

INSTRUMENT TAKE-OFF

The instrument takeoff is becoming more and more important as the day of all-weather flying approaches. Rain on the windshield, ceilings that are lower than reported, or vertigo at night may make it necessary for you to go on instruments during the take-off run or shortly after leaving the ground on a normal take-off. Practice the instrument take-off frequently.

First, of course, make a complete cockpit check, including all items necessary for visual flying. In addition, pay special attention to the gyro instruments and trim tabs; any irregularity in them may have a disastrous effect. After being cleared for take-off, align the aircraft with the center of the runway, allowing it to roll straight for a short distance before stopping to be sure that the nose wheel is straight. Hold the brakes firmly to prevent creeping. If your aircraft is equipped with a slaved gyro, rotate it until the needle is properly aligned. This may or may not be the exact heading of the runway but in any case, it should be close to the exact heading. Recheck the horizon indicator to insure that the miniature aircraft is properly aligned with the 90° indices on either side of the instrument.

While continuing to hold the brakes rigidly, increase the power to approximately 90 percent rpm and check the engine instruments and generator output. Release the brakes and advance the throttle(s) to take-off power to get as rapid an acceleration as possible. Since the rudder is ineffective at slow speeds, you must immediately counteract any deviation in heading as indicated on the heading indicator by applying sufficient brake pressure to return to the desired heading. Some pilots tap the brakes on the same side as the deviation. However, use the brakes only when necessary since the unnecessary riding of brakes

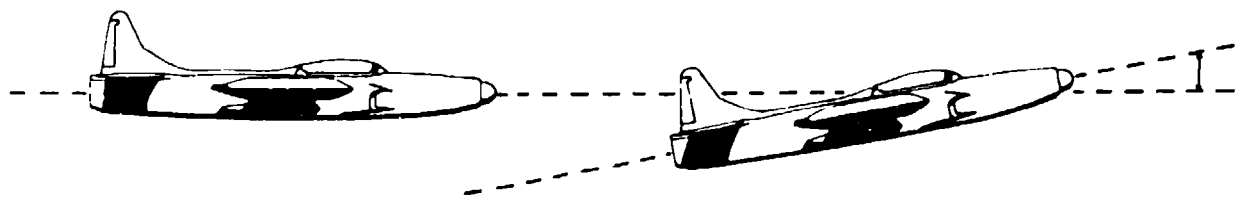


Figure 9-1. Pitch attitude

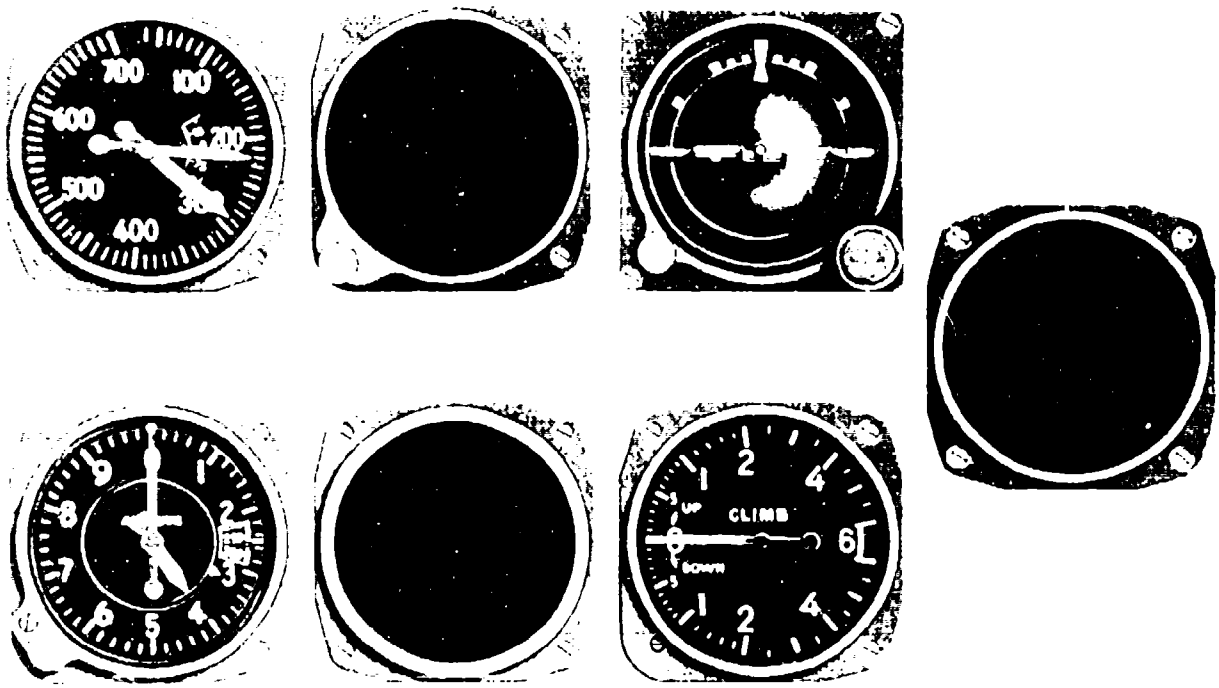


Figure 9–2. Pitch instruments

lengthens the take-off roll considerably. After the airspeed reaches the point where the rudder becomes effective (about 50 knots), use the rudder exclusively for directional control. After applying rudder to correct the heading of the aircraft, you may have to continue to hold pressure on the rudder to maintain the heading.

In most aircraft, when the airspeed reaches 20 to 30 knots below the take-off airspeed (approximately 90 knots for the TV-2), you should apply sufficient back pressure to the controls to raise the nose wheel off the runway and to establish a climbing attitude on the horizon indicator. If this attitude is maintained, the aircraft will fly off the ground well above stalling airspeed. In aircraft with swept-back wings, wait until you attain flying speed before rotating the aircraft.

As the aircraft leaves the ground (about 120 knots), attitude is of paramount importance because a small variation in pitch at this time may cause the aircraft to settle to the runway or stall. It is essential to have a definite but smoothly executed transition to a climbing attitude which will result in a rate of climb of approximately 500–700 fpm. The altimeter should show a definite increase in altitude (about 100 feet) and the vertical-speed indicator a steady indication of a climb (500–700 fpm) before you retract the landing gear. Raise the wing flaps only after a safe airspeed and altitude have been attained (about 150 knots and 350 feet). Keep your eyes on the instruments and maintain a safe climbing attitude while the gear and flaps are being retracted to prevent leveling off, entering a descent, or allowing the vertical speed to increase excessively. Since the climbing speed of jet aircraft is relatively high, maintain a vertical speed of from 500 to 1,200 fpm rate of climb until the airspeed approaches the desired climbing airspeed. You may use trim as desired after take-off, but don't use it to pull the aircraft off the ground; by doing so, you may cause an excessive nose-high condition as gear and flaps are retracted and the airspeed increases.

The horizon indicator is primary for pitch and bank from the time the aircraft leaves the deck until it establishes a good climbing attitude and reaches a safe altitude (about 200 feet). After that you resume your normal scan.

PITCH CONTROL FOR LEVEL FLIGHT

In flight, the nose attitude required to maintain any desired condition (climb, descent, or level flight) is the result of the simultaneous effect of three variable factors—airspeed, altitude, and load condition. As the airspeed is changed, the angle of attack or nose attitude must be changed to maintain a constant altitude. In comparison with normal cruising speed, the nose must be raised to maintain level flight at lower airspeeds and lowered to maintain level flight at higher airspeeds. At high altitudes, the aircraft will fly with nose slightly higher at a given indicated airspeed than at low altitudes. This is caused by the fact that the equivalent airspeed is less than the reading of the airspeed indicator because of compressibility and calibration errors.

The load condition (gross weight) of the aircraft has a definite effect on nose attitude. At high gross weights, the aircraft flies with nose higher than at low gross weights to maintain altitude at the same airspeed. This effect is more noticeable at low speeds than at high speeds.

Most high-speed aircraft are particularly sensitive in the pitching plane and can be easily over-controlled, especially at high altitudes. The instruments used for pitch control are the altimeter, horizon indicator, vertical-speed indicator, and to a lesser degree in high-speed aircraft, the airspeed indicator. (See Fig. 9-2.)

The Altimeter

The altimeter, in conjunction with the vertical-speed indicator, is the primary instrument for pitch control in level flight. The altitude should remain constant, and any deviation from the desired altitude shows the necessity for a change in pitch. (See Fig. 9-3.) Although there is a very slight lag in the indications of the altimeter, at low altitudes it may be considered to give an immediate indication of a change, or the necessity for a change, in nose attitude. At high altitudes, the altimeter may appear to lag occasionally, and you must cross-check the other pitch instruments carefully to control the nose attitude properly.

In aircraft with a flush static source, there may be a reversal of the altimeter indications when you overcontrol. If you raise or lower the nose abruptly in the TV-2, for example, the altimeter will momentarily indicate a change of altitude in the opposite direction. This will not occur if you use the proper control technique.

The Vertical-Speed Indicator

The correct use of the vertical-speed indicator is essential for precision control of nose attitude

LEVEL FLIGHT (CONSTANT POWER)

Figure 9-3. Indications of attitude by altimeter

in high-speed aircraft. Although it gives an indirect indication of the nose attitude rather than a positive indication, when smooth control technique is used it will positively indicate any change from the desired nose attitude. When light control pressures are used, the initial movement indicates the trend of the vertical movement of the aircraft.

The vertical-speed indicator is always used in conjunction with the altimeter for level flight. Any movement of the needle from the zero position indicates the need for an immediate change in nose attitude. If you detect this movement immediately and apply corrective pressure to return the needle to zero, the altimeter will usually indicate that there has been no change it altitude.

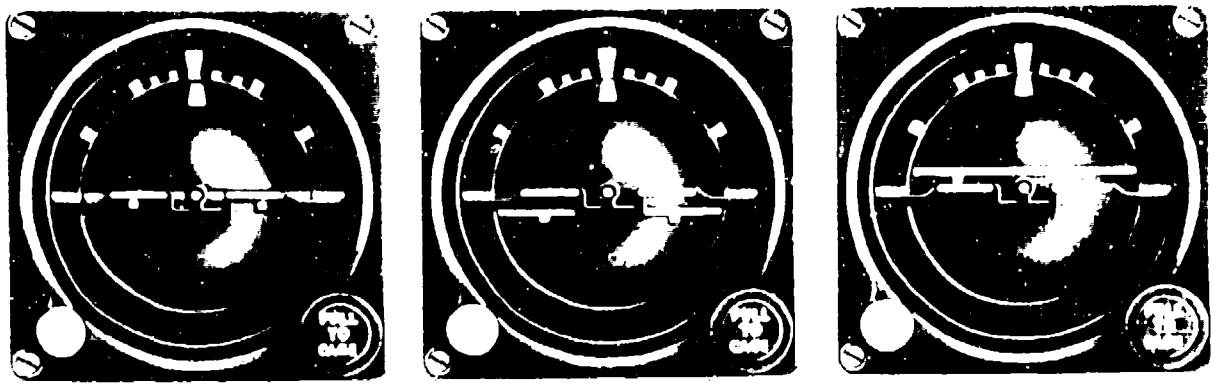
The amount that the altimeter has moved from the desired altitude governs the rate at which the aircraft should be returned to that altitude. If the deviation is 100 feet or less, the rate of return should be no more than 100-200 fpm. A higher vertical speed will require too much attention to avoid overshooting the desired altitude, thus sacrificing the scan of the bank and power instruments. If the deviation from the desired altitude is over 100 feet, the rate of return may be doubled (200-400 fpm).

The vertical-speed indicator is a sensitive instrument. Like the altimeter, it indicates a reversal error in some types of aircraft when the nose attitude is changed abruptly. In addition, because of the weight and inertia of the actuating mechanism, several seconds are required for the instrument to indicate the exact rate of change of altitude when a large pitch correction is made. For example, if the nose is lowered abruptly from a level flight attitude to an attitude that will give a 500 fpm rate of descent, the initial vertical-speed indication will be a climb and there will be a noticeable lag before the needle indicates 500 fpm descent. To overcome the tendency to "chase the needle," always make corrections by reference to the horizon indicator and hold any correction you make long enough to allow the needle to reach a stabilized indication. You can make a further correction at that time if it is required.

The Electric Horizon Indicator

In visual flight, any required nose attitude is reached and maintained by raising and lowering the nose of the aircraft in relation to the true horizon. In instrument flight, the horizon indicator replaces the true horizon and you follow exactly the same procedures by raising or lowering the miniature aircraft in relation to the horizon bar. By using the horizon indicator to adjust nose attitude, you can quickly place the nose of the aircraft in approximately the correct position for any desired condition of flight. After doing this, check the other pitch instruments to determine whether the nose attitude is correct, for the horizon indicator is subject to error as a result of precession.

Figure 9-4. Indications of attitude by horizon indicator



LEVEL FLIGHT CLIMB DESCENT

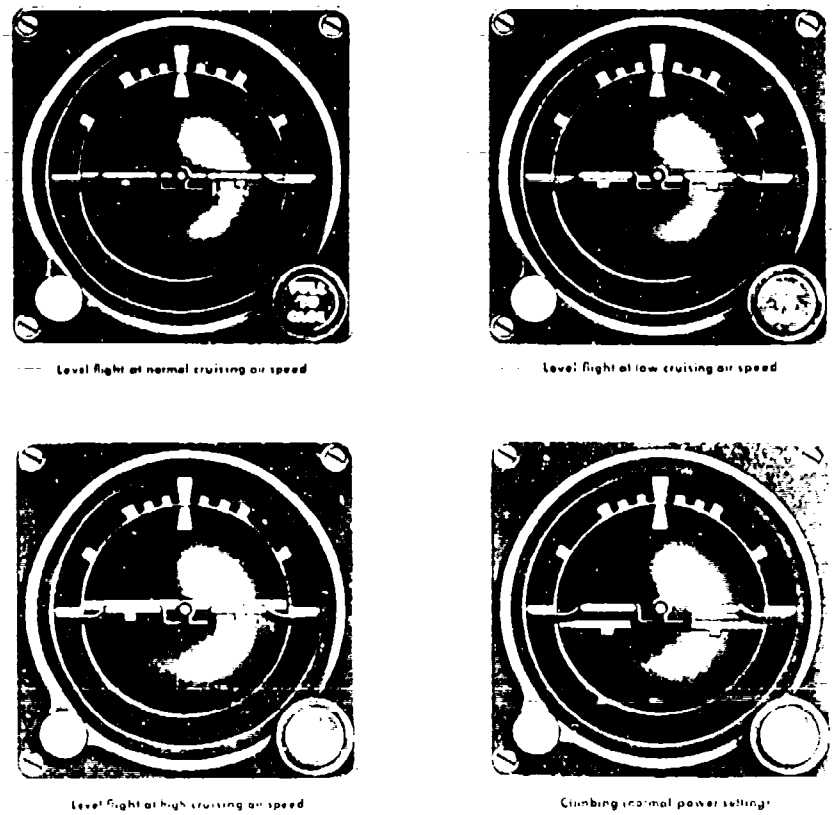


Figure 9–5. Pitch attitudes for various conditions

Adjust the miniature aircraft so that it is level with the 90° index lines on the sides of the instrument while still on the ground or align it any other way you prefer. Then, if the miniature aircraft is not level with the horizon bar at cruising airspeed and you want to readjust it, adjust it to show level flight, making sure, of course, that the aircraft is in level flight and the horizon bar is not precessing at the time of adjustment. Most experienced instrument pilots, however, prefer not to adjust the miniature aircraft continually in flight.

When using the horizon indicator to make pitch corrections, use light control pressures but make positive corrections. Use the vertical-speed indicator to determine when the nose attitude is being overcontrolled. As the true airspeed increases, pitch corrections must be smaller to prevent overcontrolling.

The Airspeed Indicator

The airspeed indicator gives an indirect indication of the nose attitude of the aircraft. For any power setting there is one nose attitude that will hold the altitude and airspeed constant. Therefore, if the airspeed increases, you know the nose is low and should be raised; if the airspeed decreases, the nose is high and should be lowered.

The importance of proper trim in high-speed flight cannot be over-emphasized. Because of the control sensitivity of high-speed aircraft, any out-of-trim condition makes it very difficult to maintain the desired flight condition. The trim-tab controls are convenient and easy to use; however, don't try to fly the aircraft with trim tabs alone. Put the aircraft in the desired nose attitude and relieve all pressure on the controls with the trim tabs. Trying to trim the aircraft to a new nose attitude usually results in over-trimming.

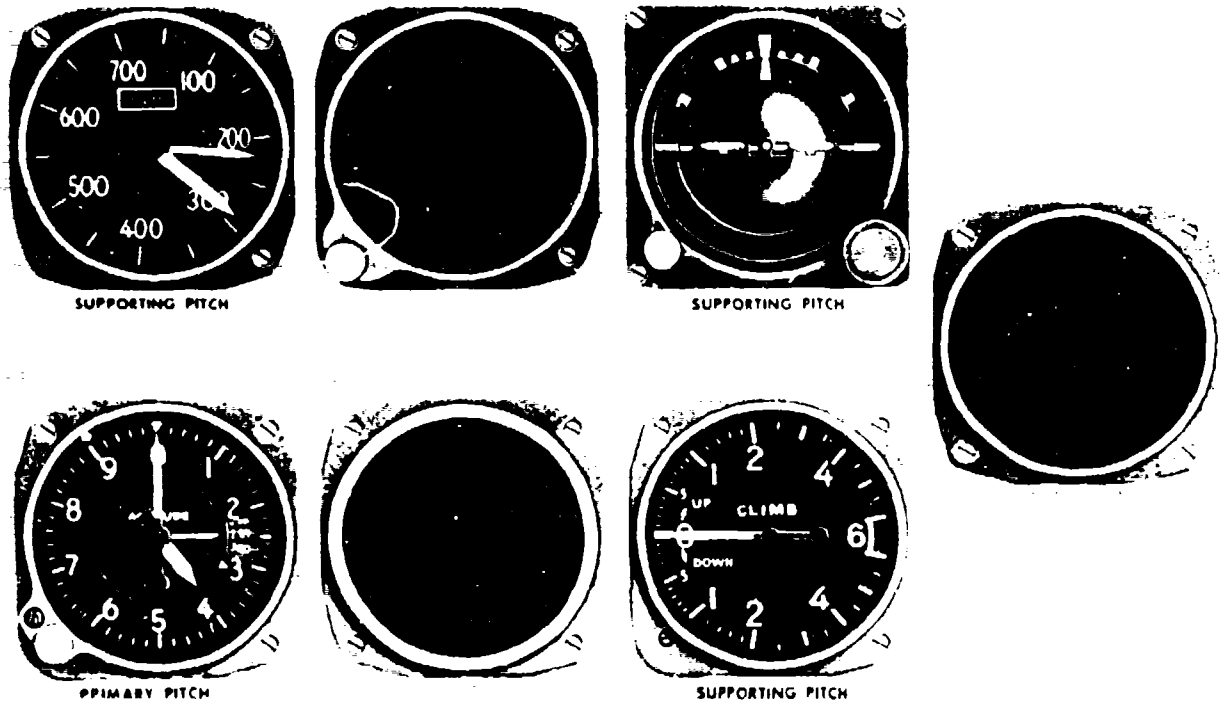


Figure 9–6. Primary and supporting pitch instruments for level flight

In jet-propelled aircraft, changing power has little effect on the pitch trim. Changing airspeed has a decided effect, and you must be careful to keep the aircraft properly trimmed during airspeed changes.

When flying an aircraft equipped with electric trim tabs, always be aware of the danger of trim buttons sticking in the actuating position and applying full trim. To prevent this, move the trim button in the direction you want, then move it back to the neutral position even though the button is spring loaded. This will prevent an extreme out-of-trim condition and possibly avoid an unusual attitude while in flight.

Scanning

The techniques for interpreting each of the individual pitch instruments has already been discussed. However, proper interpretation of individual instruments is not enough. You must use the combined indications of all available pitch instruments to gain precision control of the aircraft. This process is known as scanning and is one of the most important skills in instrument flying.

Of course, not all pilots scan the instruments in the same specific sequence. They do, however, follow definite rules concerning the instrument(s) to be observed closely during any particular maneuver. For each maneuver or flight condition there are certain instruments that give the best and most reliable information concerning the desired condition of flight and is usually the one that should be held at a constant indication. Thus the altimeter is always the primary pitch instrument in level flight, except in thunderstorms where strong vertical air currents and pressure changes tend to make the altimeter unreliable. As already explained in this section, any of the pitch instruments can be used to hold a level attitude or, with the proper power setting, a reasonably constant altitude. None of these instruments except the altimeter will give the exact information desired: whether the aircraft is on and maintaining a constant altitude. Therefore, the altimeter is the primary pitch instrument for level flight; the other pitch instruments which are used to aid in holding

the altimeter constant and to check its indications are referred to as supporting instruments. (See Fig. 9-6.)

There are times when a supporting instrument may be observed as often, if not more often, than the primary instrument. In level flight, for example, you use the horizon indicator to hold a constant attitude and to make any pitch corrections if the need for a change is indicated by the altimeter. You may note errors on a supporting instrument before you observe them on the primary instrument. If so, you make a correction immediately and quickly check the primary instrument to determine if you made the proper correction. Thus, the altimeter may indicate that the nose attitude is satisfactory, but while scanning the other instruments, you may see a deviation from zero on the vertical-speed indicator. You should apply an immediate correction by reference to the horizon-indicator and check the altimeter as soon as possible to see if the correction was effective. Regardless of which instrument shows the deviation, apply a correction in pitch and continue the scan to see how effective the correction is in maintaining the desired condition of flight. Always remember that the sooner a deviation is noticed and a correction applied, the smaller the required corrective action will be.

BANK CONTROL FOR STRAIGHT FLIGHT

To maintain a straight course, the wings of the aircraft must be kept level with the natural horizon. Assuming that the aircraft is in coordinated flight, any deviation from a wings-level attitude will result in a turn. The instruments used for bank control are the horizon indicator, the turn-and-bank indicator, and heading indicator. (See Fig. 9-7.)

Heading Indicator

The heading indicator gives an immediate indication that the wings have moved from the level position by deviating from the desired heading. If you want to fly straight, take corrective action as soon as you notice a deviation in heading; use the horizon indicator in conjunction with the turn needle.

Figure 9-8 shows the RMI or ID-250-type of magnetic heading indicator. This instrument always shows the magnetic heading at the index at

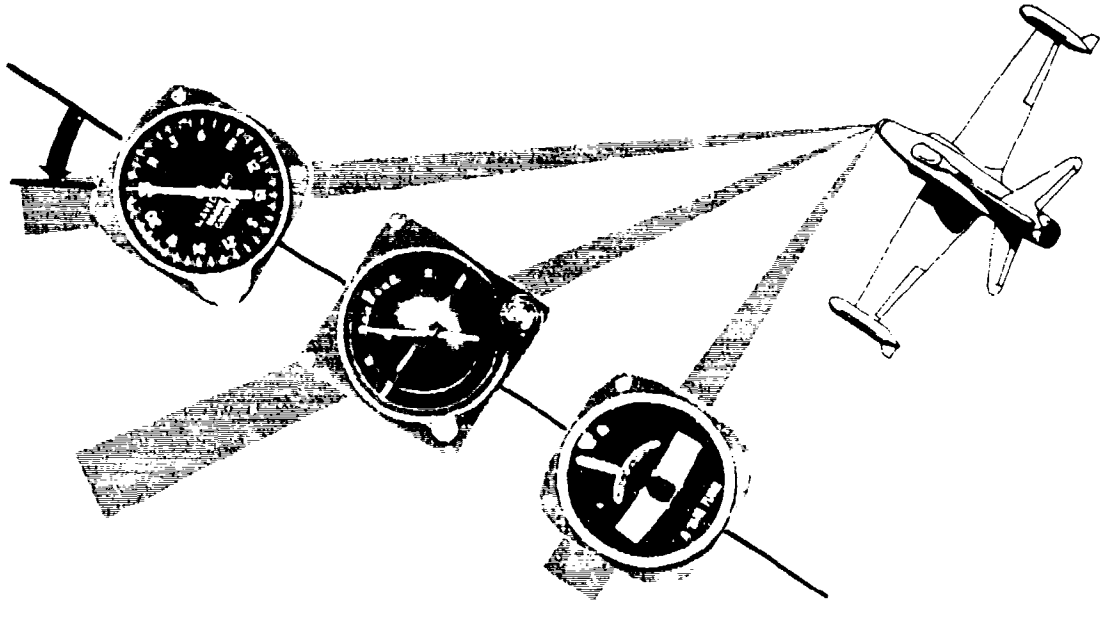


Figure 9-7. Instruments used for bank control

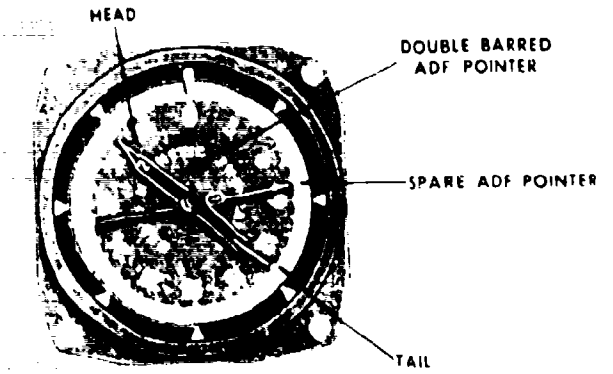


Figure 9–8. Radio magnetic indicator (RMI)

the top of the dial. Its presentation is easiest for instrument work because you can visualize the top of the dial as the nose of the plane. Most types of heading indicators allow you to select free or slaved gyro operation; some do not. In such cases, you must know whether your indicator is a gyro-driven instrument and therefore subject to precession and drift, or whether it is slaved to a magnetic compass transmitter system. You should know, in fact, which of the various models it is and its limitations, as explained in Chapter 4. If the indicator has a settable dial, instrument work, especially GCA or ILS work, will probably be easier if you set the heading at the top of the indicator dial.

Horizon Indicator

The horizon indicator gives a direct indication of the bank attitude of the aircraft. (See Fig. 9-9.) In coordinated flight, the aircraft starts to turn when the wings are moved from the level position; you can stop the turn by levelling the wings of the miniature aircraft on the horizon bar. Always do this by coordinated use of aileron and rudder. Of course, in high-speed aircraft at high true airspeeds, very little rudder is necessary. If you exert gentle pressures on the ailerons, you can almost disregard rudder pressure. When you change the bank rapidly, considerable aileron drag is created and you must use rudder in the direction of movement to overcome it.

You can determine the bank attitude of the aircraft in two ways on the horizon indicator—by the position of the wings on the horizon bar or by the position of the bank index or pointer in relation to the zero mark on the banking scale. In a turn, the latter is more likely to be accurate.

Turn-and-Bank Indicator

The turn-and-bank instrument operates the same in jet aircraft as in conventional aircraft. As we have noted in Chapter 8, this instrument operates as follows:

1. When the turn needle is exactly centered, the aircraft is in straight flight.

2. When the turn needle is displaced from center, the aircraft is turning in the direction of the displacement.

3. In coordinated flight, recentering the needle from its displaced position will produce straight flight.

4. When the ball is centered, the aircraft is in coordinated flight.

5. When the ball is displaced, it is centered by applying rudder in the direction in which the ball is displaced.

Trim

If the aircraft is properly trimmed, it tends to maintain a wings-level attitude and fly straight in smooth air. If the aileron trim is incorrectly adjusted, the aircraft tends to bank, and a turn results unless the aileron and rudder trim tabs neutralize each other to produce a *slip* on a constant heading. Excessive pressure on one of the rudders (with the wings level) results in a skid. Skidding and slipping are especially undesirable in high-speed aircraft as they cause a loss of aerodynamic efficiency and a large reduction in airspeed. Don't try to stop a turn by use of rudder alone, except in the case of a yawing turn caused by loss of an engine in a multi-engine aircraft.

Scanning

Practice the combined use of all available bank instruments to produce straight flight. (Fig. 9-10.) The heading indicator and the turn needle indicate when the aircraft is turning. The horizon indicator and the turn needle show the cause of the turn. In straight flight, you maintain the heading primarily by reference to the heading

indicator which indicates any deviation from the desired heading. You use the horizon indicator to hold a constant wings-level attitude or to make any changes in bank required by the indications of the heading indicator. If the heading indicator fails, you maintain straight flight by using the turn needle as the primary bank instrument.

If the heading indicator indicates that the aircraft has deviated from the desired heading, bank the aircraft to return to the desired heading. The angle of bank depends on the number of degrees the aircraft should be turned. A rule of thumb is that the degree of bank should never exceed the number of degrees to be turned with a maximum angle of bank of 30°. For example, if the aircraft is 5° off the desired heading, use a maximum of 5° angle of bank on the horizon indicator to correct this error.

POWER CONTROL IN STRAIGHT-AND-LEVEL FLIGHT

At any given airspeed, the power setting determines whether the aircraft is in level flight, in a climb, or in a descent. If you hold the altitude constant, the power setting determines the airspeed. To maintain constant altitude and airspeed in level flight, you must coordinate pitch and power control. The relationship between altitude and airspeed determines the need for a change in power and or pitch. If the altitude is constant and you see that the airspeed is high or low, change the power to obtain the desired airspeed. (See Fig. 9-11.) While changing power, correct any deviation from the desired altitude by appropriate pressure on the elevator control.

In jet-powered aircraft, changes in power have no effect on the bank attitude as there is no torque. Power changes also have very little immediate effect on the pitch attitude of jet aircraft. As the airspeed changes, however, you must constantly change the nose attitude to avoid deviating from the desired altitude. This will require careful trimming to avoid using heavy control pressures. You should know the approximate power settings as well as the approximate nose attitudes for high, low, and normal cruising airspeeds.

Increasing airspeed while maintaining straight-and-level flight is easily accomplished if the proper techniques are used. Increase the power to 100%. (In a training situation, it may be desirable to use 98%.) There will be no reaction in control pressure until the airspeed increases and causes the lift to increase and the aircraft to gain altitude. At this time you must observe instruments closely. The vertical-speed indicator in particular will be of value in noting the tendency to climb. To counteract the tendency to climb, apply forward control pressure. Then use elevator trim to relieve the pressure. This is extremely important in high-speed aircraft as control pressures must be kept light for precision flying. As the airspeed increases, lower the miniature aircraft in relation to the horizon bar on the horizon indicator. Use the horizon indicator to make all pitch corrections and to hold a constant attitude while the other instruments indicate a deviation. As you approach the desired airspeed, adjust the

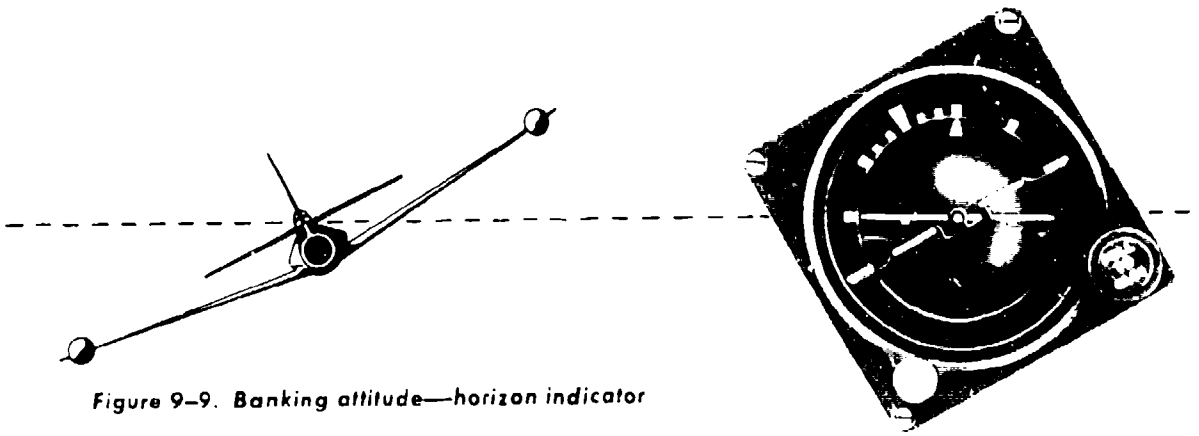


Figure 9-9. Banking attitude—horizon indicator

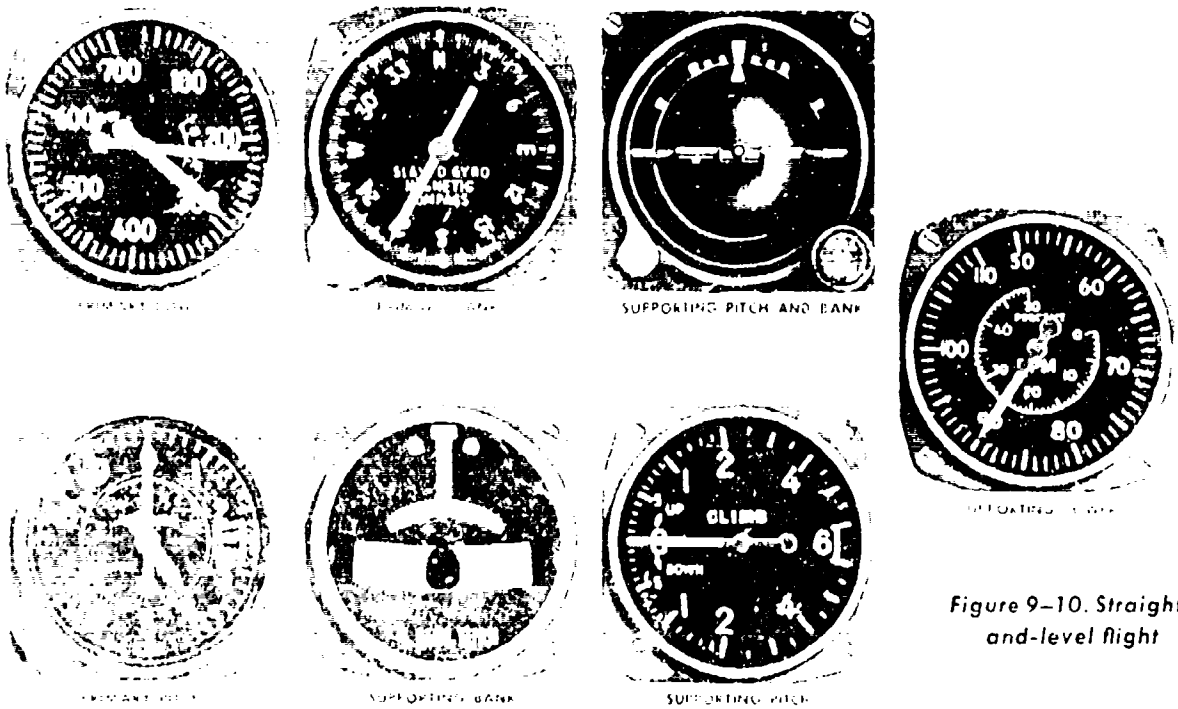


Figure 9–10. Straight-and-level flight

power to maintain this airspeed. Make the initial power setting as close as possible to the desired setting without interrupting the normal cross-check. After trimming the aircraft, check the airspeed indicator and the tachometer to determine whether the power setting is correct. If not, make a final adjustment to produce the desired airspeed.

In some types of aircraft, reducing airspeed while maintaining straight and level flight presents a greater problem than does increasing airspeed. First, you reduce power to the setting that will maintain the desired airspeed. This reduction in power is not sufficient to reduce the airspeed rapidly; therefore, you use dive brakes when the airspeed is to be reduced more than 20 kts.

The reduction in power will have very little effect on control pressures. In some aircraft, extending the dive brakes will result in a sudden nose-up tendency. To maintain level flight, you must be prepared for this effect and take corrective action when the dive brakes are extended. Compensate for the nose-up tendency by maintaining a constant attitude on the horizon indicator. This will require considerable forward control pressure which may be relieved by trim. You scan the pitch and bank instruments as previously described to maintain straight and level flight, and you check the tachometer to determine whether the change in power setting is correct. As the airspeed decreases, the nose tends to drop. Apply back pressure to raise the nose and use trim to relieve this pressure.

As the desired airspeed is approached, retract the dive brakes. The nose of the aircraft will then tend to drop, but you must maintain a constant attitude by reference to the horizon indicator. After retracting the dive brakes, retrim the aircraft and, if necessary, make a final power adjustment to produce the desired airspeed.

CLIMBS AND DESCENTS

For any given power setting and load condition, there is only one attitude that will give the most efficient rate of climb. Climb data for the

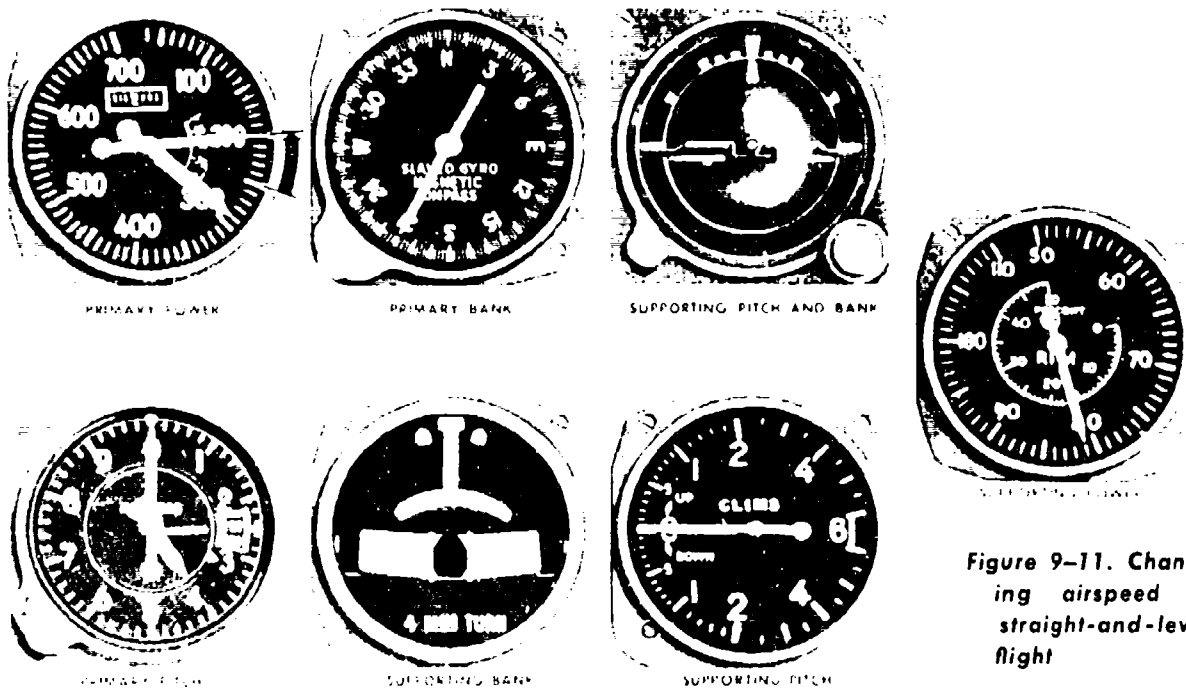


Figure 9–11. Changing airspeed in straight-and-level flight

type of aircraft you are flying gives you the best climbing airspeed for different altitudes. Follow the climb schedule printed in the aircraft handbook or on the REST computer. In a climb or a descent at a constant indicated airspeed, the vertical speed that results from the power setting used is accepted. You use the tachometer to control the power and maintain it at the desired setting throughout the climb or descent.

Constant Mach-meter reading climbs are used to reach cruising altitudes, and constant indicated airspeed descents are used during the instrument let-down procedures. Again, follow the schedule for your aircraft.

This section deals with climbs and descents made during straight flight. The heading indicator is primary for bank control unless it is inoperative, in which case the turn needle is primary for bank control.

A climb may be entered while cruising at climbing airspeed. Here are the procedures to be followed in each case.

Entering a Climb

To enter a climb while cruising at a climbing airspeed, increase the power to 100% power and raise the nose to approximately the required attitude on the horizon indicator. Then you can use the airspeed indicator or Mach meter as the primary instrument for pitch (following the climb schedule).

Leveling Off From a Climb

To level off from a climb at a predetermined altitude, you must start the level-off before reaching this altitude. This is necessary to prevent overshooting the altitude, since the aircraft continues to climb for a few seconds after pressures have been applied to level off. High rates of climb require that the point where the level-off is begun be further in advance than with lower rates of climb. Another factor governing the amount of lead required is the technique used in the level-off. Practice and observation will help you determine the amount of lead required for level-offs under all conditions. A generally accepted rule

of thumb is to use a lead equal to 10% of the rate of climb in feet.

When you reach the lead point, exert smooth forward control pressure to lower the nose to the level-flight attitude. When you attain cruising airspeed reduce the power to the setting which will maintain the airspeed in level flight. The altimeter becomes the primary pitch instrument as soon as the level-off is begun, but the horizon indicator would be used to make the change to level-flight nose attitude.

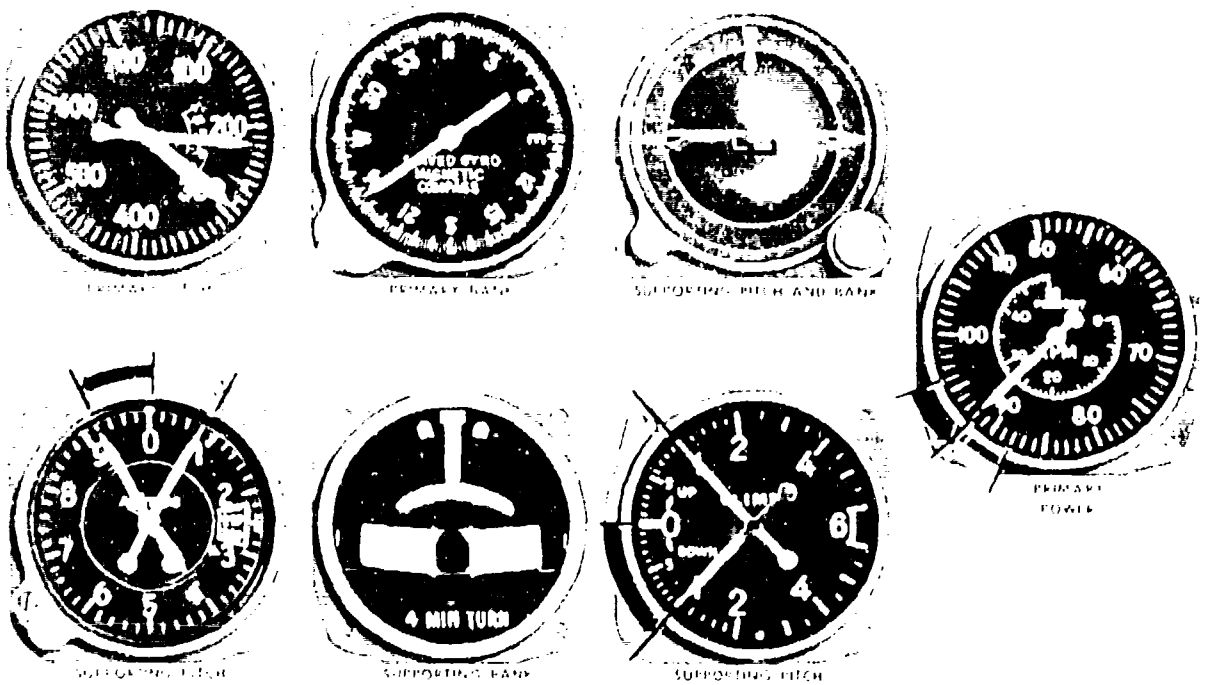
An alternate procedure preferred by some pilots is to level off about 300 feet above cruising altitude, then descend to cruising altitude at climbing power. The speed builds up in this short descent more quickly than in levelling off right at cruising altitude. If they reach this airspeed before getting back to cruising altitude, they reduce power to maintain the speed.

Descents

To enter a descent from descent airspeed, reduce the power to the proper setting and, at the same time, lower the nose to an attitude that will maintain the airspeed. If the dive brakes are to be used, lower them after the power reduction is completed. When you lower the dive brakes, you have to use considerable forward pressure to hold the proper nose attitude. Use the horizon indicator to make this initial pitch change, and remove all control pressure with the trim as soon as practicable. The airspeed indicator is the primary pitch instrument as soon as the power reduction is started. However, as in a climb, you use the vertical-speed indicator and horizon indicator to aid in holding the airspeed constant. Throughout the descent, you must hold the vertical speed constant until the airspeed indicates the necessity for a change.

To enter a descent from an airspeed higher than descent airspeed, adjust the power and lower the dive brakes if they are to be used. Maintain the attitude until the airspeed approaches the descending airspeed, then lower the nose to the attitude that will maintain the airspeed.

Figure 9–12. Entering a climb or descent at a definite rate



Leveling Off From a Descent

The level-off from a descent must be started before you reach the desired altitude. The amount of lead used is governed by the rate of descent and the control technique used by the pilot. In leveling off from a descent, more lead is required than in leveling off from a climb at the same vertical speed. To level off from a descent, you must adjust pitch and power at the same time. When the proper lead point has been reached, advance the power to the setting required to maintain level flight at that airspeed, and raise the nose to the level-flight attitude at the same time. As soon as the level off is started, the altimeter becomes the primary pitch instrument, and you regulate power and control pressure so that you bring the aircraft to level flight at the same instant that you reach the desired altitude. If you used dive brakes during the descent, retract them when the power application is begun. As soon as the aircraft is in level flight, the airspeed indicator becomes primary for power control and you use the normal level-flight cross-check.

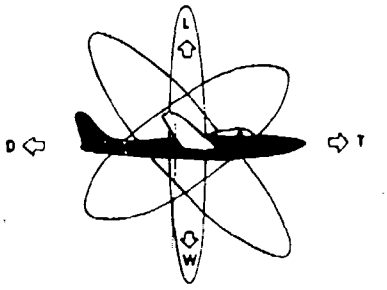
Climbing and Descending Turns

Climbs and descents in turns combine the techniques used in straight climbs and descents with those used in level turns. You start the climb or descent and the turn simultaneously. On entering the turn, use the horizon indicator as the primary instrument. After you are in the turn, use the turn needle as the primary instrument for bank.

STRAIGHT CLIMBS AND DESCENTS AT A DEFINITE RATE

Proficiency in performing climbs and descents at a definite vertical speed is very important in actual instrument flight. The vertical speed must be controlled accurately during a GCA, an ILS, or an instrument take off. In high-speed aircraft, because of critical fuel conditions, it is usually imperative that you make a landing on the first approach.

The procedures, scan, and aircraft control for climbs and descents at a definite rate are very similar to those used for constant airspeed climbs and descents. Since the desired condition is a constant vertical-speed indication, the vertical-speed indicator is primary for pitch control. The heading indicator remains the primary bank-control instrument.



Climbing at a Definite Rate

To enter a claim at a definite rate, increase the power to the approximate setting for the desired rate and simultaneously raise the nose of the aircraft to the climbing attitude for the desired airspeed and rate of climb. As the power is increased, the airspeed indicator is primary for pitch control until the vertical speed approaches the desired value. (See Fig. 9-12.) At this time the vertical-speed indicator becomes primary for pitch control, and you change the nose attitude of the aircraft as required to maintain the desired indication. At the same time, the airspeed indicator becomes primary for power control, and you adjust the power to maintain the desired airspeed. (See Fig. 9-13.)

Pitch and power corrections must be closely coordinated. If the vertical speed is correct, for example, but the airspeed is low, power should be added. As the power is increased, the nose must be lowered slightly to avoid increasing the vertical speed. The nose attitade must be adjusted smoothly to avoid overcontrolling. Small power corrections are usually sufficient to bring the airspeed back to the desired location.

Descending at a Definite Rate

To enter a descent at a definite rate, decrease the power to the approximate setting for the desired rate and aircraft configuration; at the same time, lower the nose to maintain the airspeed. The airspeed indicator is the primary instrument for pitch control until the vertical speed approaches

the desired rate. The vertical-speed indicator then becomes the primary instrument for pitch control, and you maintain it at the desired indication. You coordinate power and pitch control as described for climbs and use the same cross-check. Proper trim technique is essential in climbs and descents at a definite rate and will help prevent over-controlling the nose attitude.

TURNS—ENTRY, TURNING, AND RECOVERY

The turns described in this section are those which do not exceed a standard rate (3° per second) as indicated on the turn-and-bank indicator or a 30° angle of bank as indicated on the horizon indicator. At high true airspeeds where more than a 30° angle of bank is required for a standard-rate turn, make a one-half standard-rate turn (1½° per second or 1-needle-width deflection on the 4-minute turn indicator) to avoid steep banks.

To enter a turn, apply steady, coordinated pressures on the ailerons and rudder in the direction of the desired turn. As soon as you apply pressure, the horizon indicator becomes the primary bank instrument until the approximate desired angle of bank has been established. At this time, the turn needle becomes primary for bank. In a level turn, as in straight-and-level flight, the altimeter is used in conjunction with the vertical-speed indicator to maintain the desired pitch. (See Fig. 9-14.) When you bank the aircraft, of course, vertical lift is decreased, and you must raise the nose to maintain altitude. As you raise the nose of the aircraft to hold the altitude, add power as necessary to maintain the desired airspeed. Proper trim technique is especially valuable at this time, because the control pressures must be varied during the turn entry.

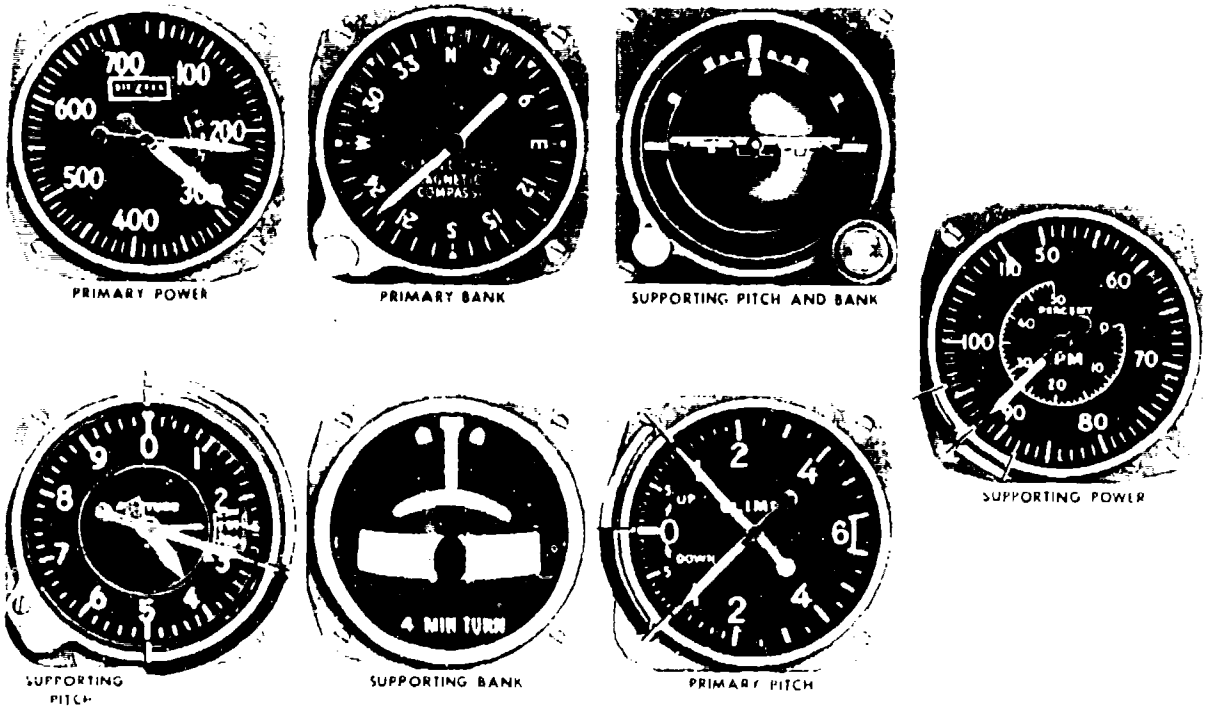


Figure 9-13. Climbs and descents at a definite rate

To recover to straight-and-level flight, apply coordinated pressures on the ailerons and rudder in the direction opposite to the turn. The rate of roll-in and roll-out should be the same. When you apply pressures to recover, the horizon indicator becomes the primary bank instrument. As the angle of bank is decreased, the vertical lift increases and you must lower the nose of the aircraft to maintain the desired altitude. At the same time, you must adjust the power to maintain the desired airspeed. As the horizon indicator indicates the wings are approaching a level attitude, use the heading indicator as the primary bank instrument and the turn needle for cross-checking.

A turn can be entered with rudder alone, but this is definitely undesirable. It results in a skid instead of a coordinated entry. In some aircraft with tip tanks installed, it results in a turn to the opposite direction. A turn can also be entered by use of ailerons alone, but this results in aileron drag, and, consequently, a momentary slip. Simultaneous use of the ailerons and rudder will produce a coordinated entry. The ball of the turn-and-bank indicator shows whether the aircraft is in coordinated flight. Observe it throughout the turn so that you may apply pressures to keep it centered.

TURNS TO HEADING INDICATOR

An aircraft will continue to turn as long as the wings are banked; therefore, the recovery from a turn to a desired heading must be started before the desired heading is reached. The amount of this lead varies with the relationship between the rate of turn, the angle of bank, and the individual pilot's rate of recovery.

The number of degrees to be turned to a given heading and the TAS govern the rate of turn to be

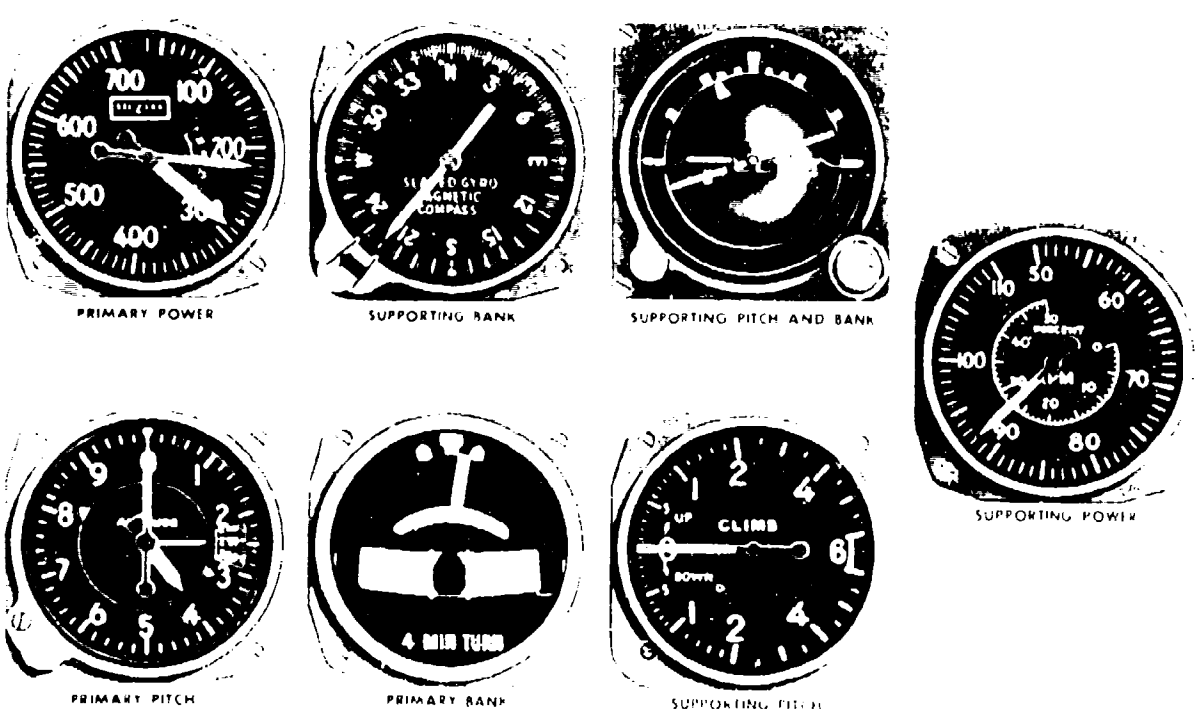


Figure 9-14. Level turns

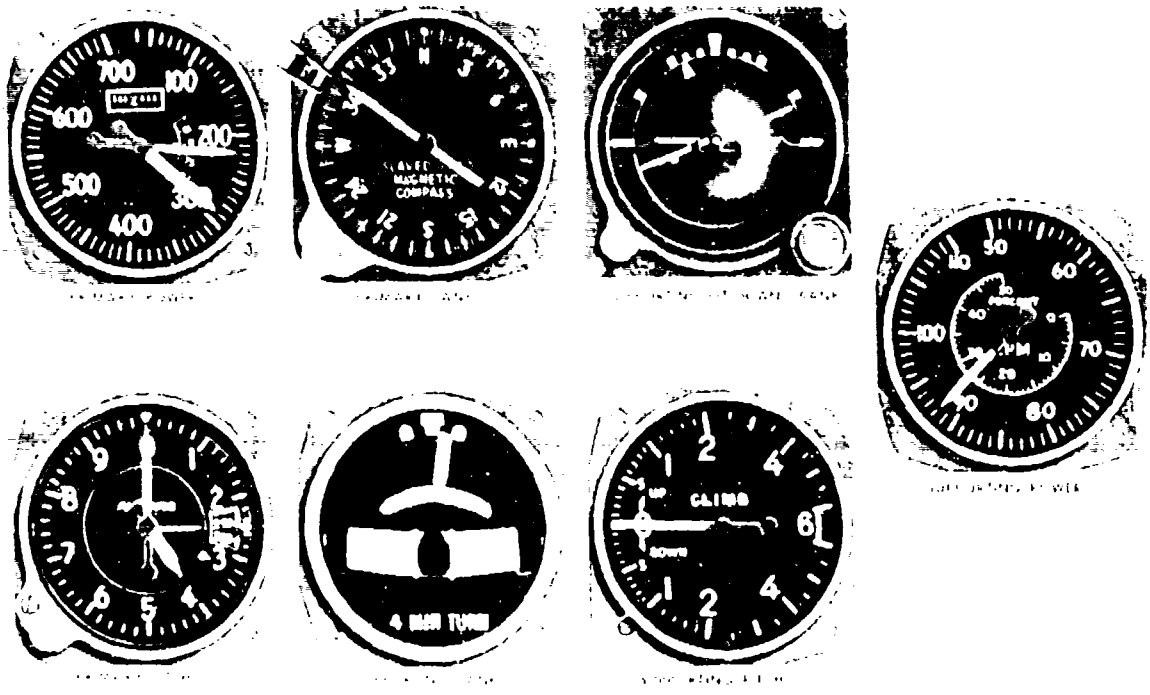


Figure 9–15. Preparing to start roll-out on a heading-indicator heading

used. Normally, at true airspeeds of 220 kts or higher, use a rate of turn of 1½° per second unless the angle of bank required for this rate of turn exceeds the number of degrees to be turned. In any case, do not have the angle of bank exceed the number of degrees to be turned.

The roll-out on a given heading is executed in the same way as a normal roll-out from any turn except that the recovery is started the instant the predetermined lead on the heading indicator has been reached. (See Figure 9–15.) Check the heading indicator after the turn needle is centered to determine whether you used the proper lead. Any deviation from the desired heading will indicate a need for a change in the number of degrees of turn to be used in a future turn.

CHANGE OF AIRSPEED IN TURNS

Changing airspeed in turns is taught in order to improve the scan and to develop greater accuracy of control techniques. This maneuver involves changing all components of control. The pitch and power control techniques are the same as those used when changing airspeed in straight flight.

It has been shown that the angle of bank necessary for a given rate of turn is proportional to the true airspeed. Therefore, a change of airspeed must be accompanied by a change in the angle of bank in order to maintain the desired rate of turn. This means that during a reduction of airspeed in a turn, the angle of bank must be decreased to maintain the desired rate of turn. The nose attitude also varies continuously until the new airspeed is reached. The altimeter is the primary instrument for pitch control, although the vertical-speed indicator is used in conjunction with it. The turn needle is primary for bank control. While the airspeed is being changed, the primary instrument for power is the tachometer. Once the airspeed is stabilized at the new indica-

tion, however, the airspeed indicator becomes primary for power control. (See Fig. 9-16.)

Two methods of changing airspeed in turns should be practiced. In the first method, the power is changed after the turn has been established. In the second method, the power is changed at the same time control pressure is applied to enter the turn. In either case, if you are decreasing the airspeed and using dive brakes, extend them as you make the power change. During the power change, observe the altimeter and vertical-speed indicator closely and make changes of pitch promptly when necessary. If you use dive brakes, use the same technique for the control of pitch at the time they are actuated as you do when decreasing airspeed in straight flight. The scan of the bank instruments is equally important; if the turn needle shows a deviation from the desired deflection, change the bank. Although power changes are less frequent than pitch or bank changes, check the airspeed indicator frequently to establish and maintain the desired air speed. Trim is very important, too. Adjust trim to keep the control pressures neutral.

TIMED TURNS

A timed turn is a turn in which the clock and the turn needle are used in changing the heading of the aircraft a definite number of degrees in a given time.

Calibrate the turn needle as soon as practicable after takeoff to check for any errors. Here's how you do it. Roll into a turn of one-needle-width deflection on the 4-minute turn needle and, as the second hand of the clock passes through a cardinal point (12, 3, 6, 9), check the heading on the heading indicator. Hold the indicated rate of turn exact and, as the second hand of the clock indicates a lapse of 30 seconds, again check the heading for 45° of change. A change in heading of more or less than 45° during the 30-second period indi-

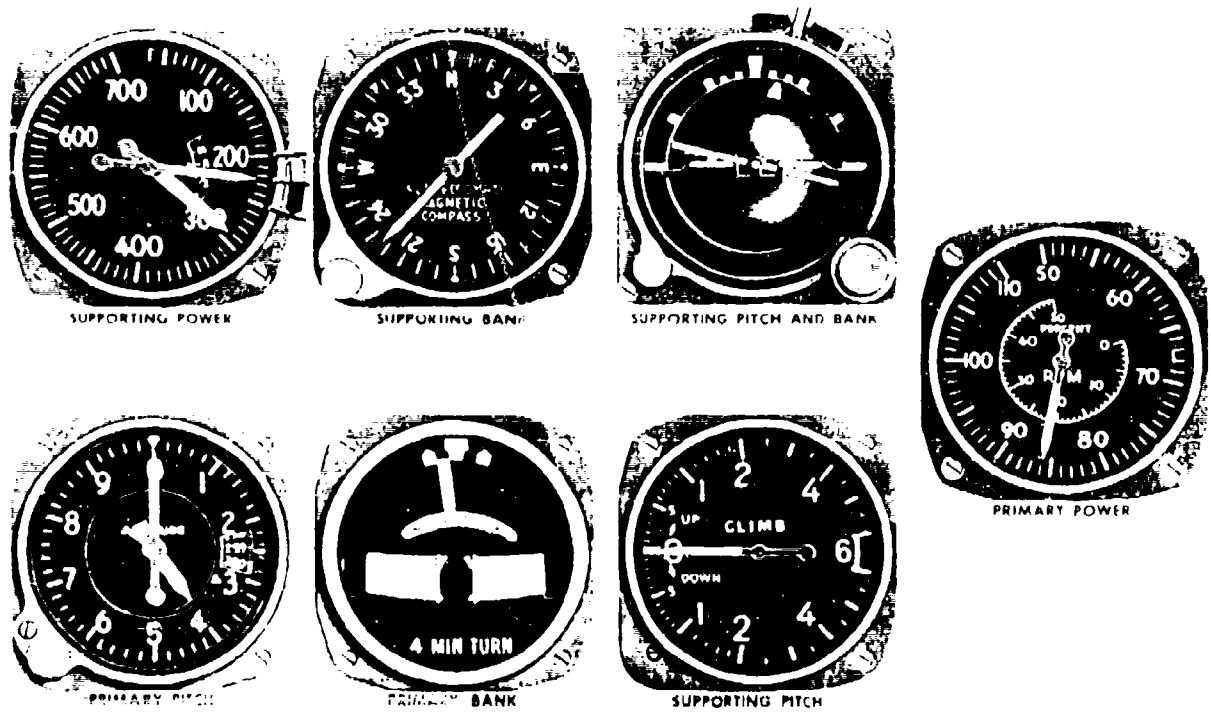


Figure 9-16. Change of airspeed in turns

cates that a larger or smaller deflection of the turn needle is necessary to produce a 1½° per second turn. When you have calibrated the needle properly in each direction, note the exact deflections and use them during all timed turns.

You use the same cross-check and primary instruments in making timed turns as you use in making turns to heading indicator headings, except that you substitute the clock for the heading indicator. The turn needle is primary for bank control, the altimeter is primary for pitch control, and the airspeed indicator is primary for power control. (See Fig. 9-17.)

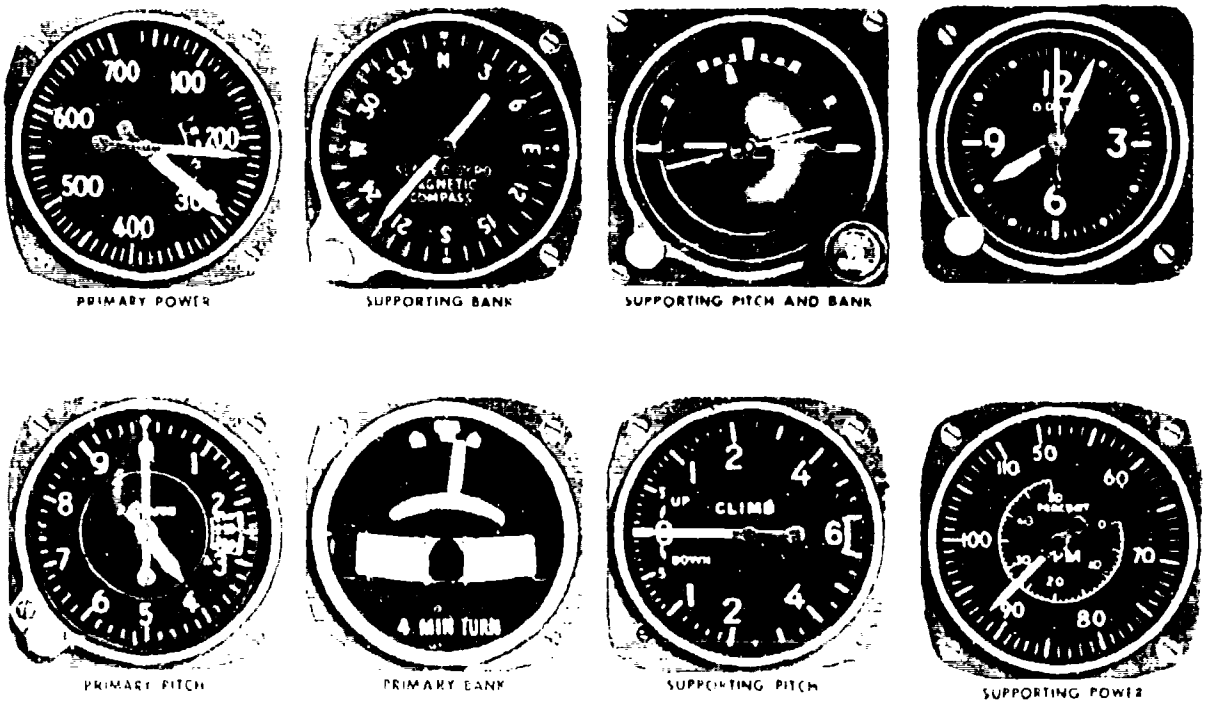
In timed turns to heading where all instruments are available for use, you check the heading indicator against the clock to make sure that the proper rate is being accomplished. Depending on TAS, these turns will be standard rate or one-half standard rate if the change in heading exceeds 30°.

Suppose, for example, that you are flying at a true airspeed of 350 knots (which requires approximately 26° angle of bank to maintain a one-half standard rate turn) and that you want to make a 360° timed turn to the right from a heading of north. To insure the proper lead, watch the clock and, as the second hand approaches the starting time, roll into the turn using approximately a three-second lead. Each 10 seconds should then result in 15° of turn. When you approach the desired heading, roll out of the turn with a lead of 2° to 4°, depending on the rate of roll used.

ADVANCED PATTERNS

After learning the basic airwork of jet instrument flying, you learn patterns, steep turns, aerobatics, and unusual-attitude recoveries. The patterns differ from those for conventional aircraft because of the speeds, stress limits, fuel usage, and turning radius of the jet airplane. The patterns incorporate the fundamental airwork into a sequence in which you are faced with continuous changes of attitude and speed. Such practice maneuvers develop the good timing, the precision,

Figure 9-17. Calibration of the turn needle



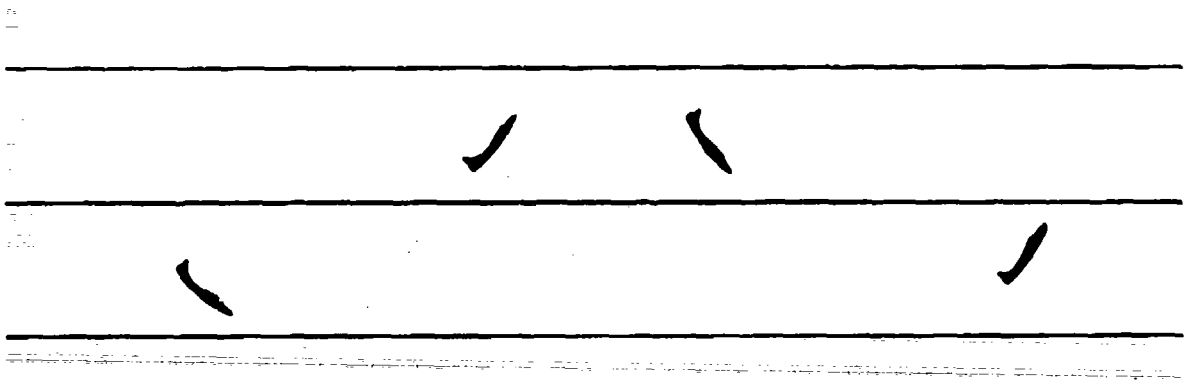


Figure 9-18. Vertical "S-1"

and the smoothness which mark a good pilot.

The vertical "S" is taught in several stages, starting with a simple series of climbs and descents. Its primary purpose is to develop the pilot's proficiency in pitch and power control and to increase the speed of scanning. The "Y" pattern simulates instrument procedure turns and letdown.

Vertical "S-1"

The vertical "S-1" consists of a series of descents and climbs (Fig. 9-18). Throughout the maneuver a constant airspeed and a constant heading are maintained. All climbs and descents are made at a definite rate as shown on the vertical-speed indicator, and the reversal of the vertical direction is made at specified altitudes.

The frequency of reversing the vertical direction depends on the type of aircraft used. Normally, in aircraft with a high rate of climb, the climbs and descents are made at an indicated rate of 1,000 fpm. The maneuver is accomplished by making a series of descents and climbs between two specified altitudes which are normally 1,000 feet apart.

The vertical "S-1" is entered by establishing a definite rate of descent. During the descent, the vertical-speed indicator is the primary instrument for controlling the nose attitude, and the airspeed indicator is the primary instrument for power control. The heading indicator is the primary instrument for bank control throughout the maneuver.

The change from a descent to a climb requires the same amount of lead on the altimeter as a level off from a descent. You must use the power smoothly and adjust it promptly to the approximate setting for the climb. At the same time you change the power, you retract the dive brakes and change the pitch to the approximate climb attitude. At this point, the horizon indicator is the primary pitch instrument until the vertical speed approaches the desired rate of climb. Then the vertical-speed indicator again becomes the primary pitch instrument; the airspeed indicator is the primary power instrument throughout.

The change from a climb to a descent requires the same amount of lead on the altimeter as a level off from a climb. You must retard the power smoothly and promptly to the approximate power setting for a descent. At the same time you change the power, you extend the dive brakes and change the pitch attitude to the approximate descent attitude. At this point, the horizon indicator is the

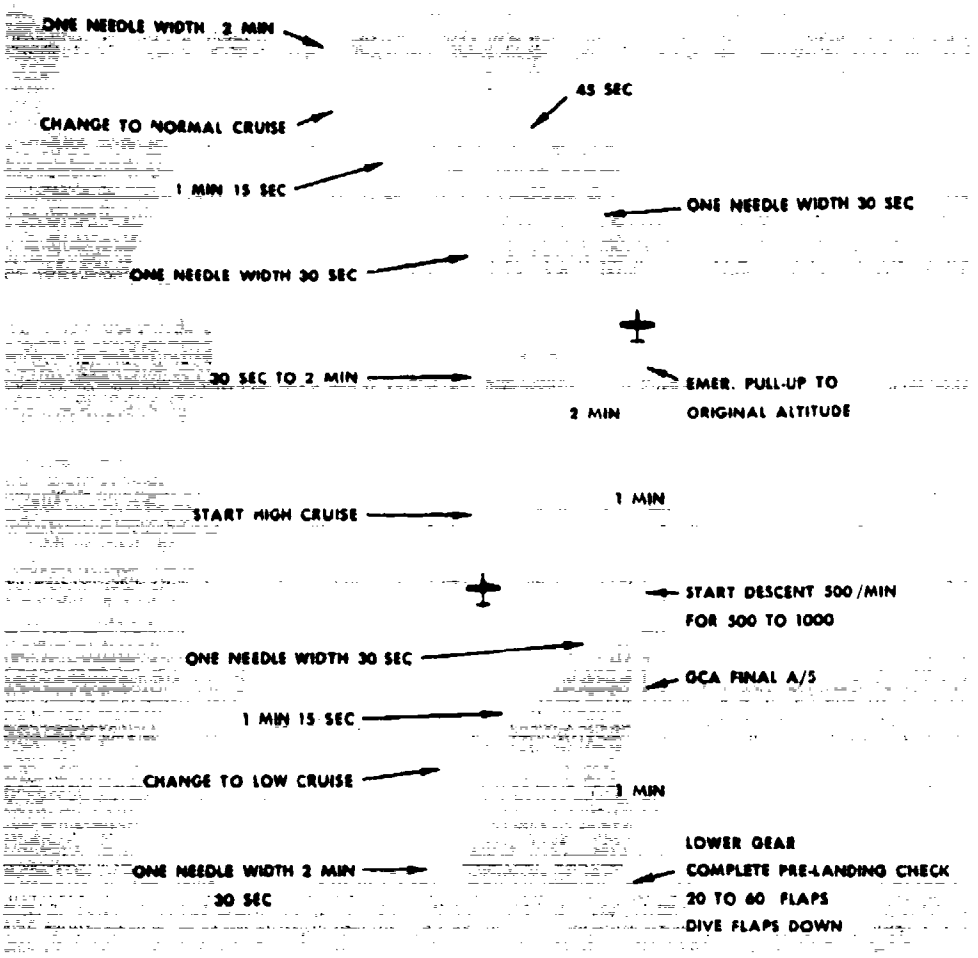


Figure 9–19. Pattern "Y"

primary pitch instrument until the vertical speed approaches the desired rate of descent. Then the vertical-speed indicator again becomes the primary pitch instrument and the airspeed indicator becomes the primary power instrument.

Trim technique is especially important because of the constant changes of attitude and power throughout the maneuver. The frequency of these changes necessitates a rapid scan for accurate control of the aircraft.

Vertical "S–2"

The vertical "S–2" is entered as a descending turn either to the left or right. The direction and rate of turn are maintained throughout the maneuver. Normally, the rate of turn is one-half standard rate (1-needle-width deflection on 4-minute turn needle). The turn indicator is the primary bank instrument throughout the maneuver.

Vertical "S–3"

The vertical "S–3" maneuver is entered in the same way as the vertical "S–2." It combines the vertical "S–1" and a definite rate turn but differs from the vertical "S–2" in that the direction of the turn is reversed at the beginning of each descent.

Vertical "S–4"

The vertical "S–4" maneuver is entered in the same manner as the vertical "S–2." Again, it

is a combination of the vertical "S-1" and a definite rate turn but differs from the vertical "S-2" and "S-3" in that there is a simultaneous change in the direction of the turn with each change of vertical direction.

PATTERN "Y"

Pattern "Y" is designed for practicing the procedures of the advanced phase for combining most of the maneuvers previously performed. It gives invaluable experience in planning, precision timing, maintaining orientation, and computation of procedure turn headings.

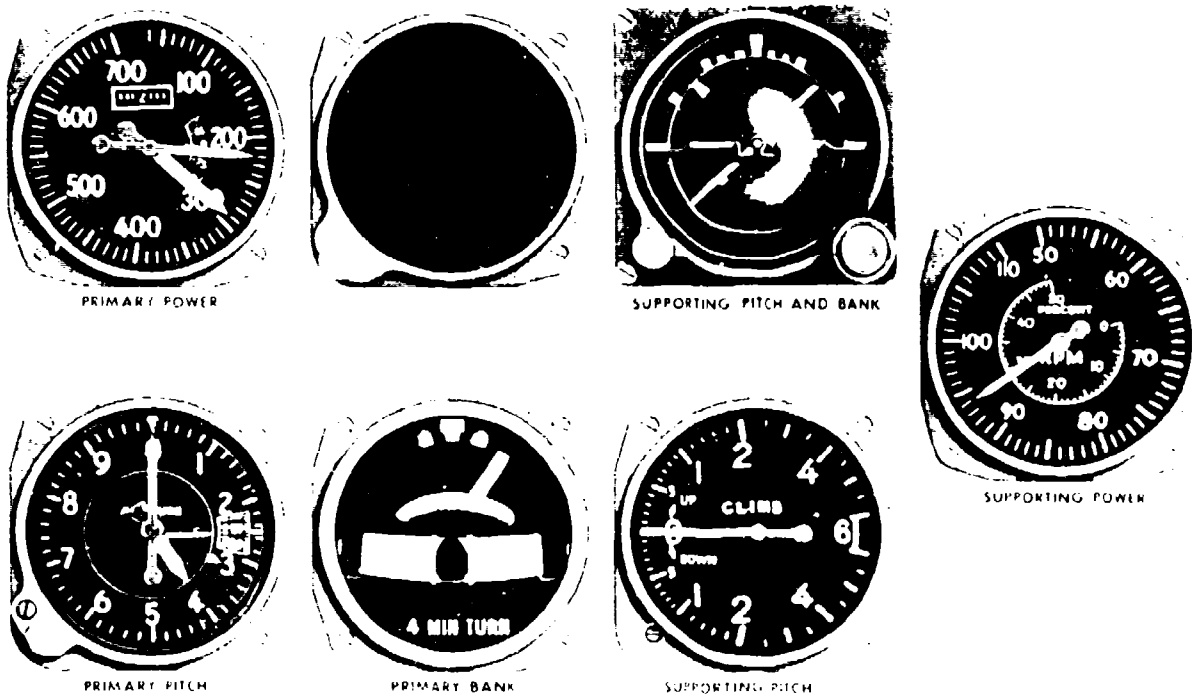
The pattern may be started on any heading, but for simplification, the initial practice should be started on a cardinal heading. The timing should begin when the second hand is on the 12- or 6-o'clock position. All turns are 1½° per-second turns. The timing is consecutive—the time for each leg starts when the time for the previous turn has elapsed regardless of the bank attitude of the aircraft. The airspeed is changed during turns. All available instruments are used throughout the pattern.

STEEP TURNS

Any turn with an angle of bank greater than 30° is considered a steep turn. This type of turn is seldom necessary or advisable in routine instrument flight. However, with the advent of all-weather interceptor aircraft, proficiency in performing steep turns has become a vital necessity. In all-weather interception, steep turns are routine and must be accomplished with precision. A steep turn is also a good maneuver for increasing your ability to react quickly and smoothly to rapid changes in attitude.

Regardless of the angle of bank, the techniques of entry, control during the turn, and recovery are the same in steep turns as in normal turns. However, it is more difficult to control the pitch attitude because the vertical lift decreases when the angle of bank is increased. With some horizon indicators, precession during the turn adds to the difficulty of maintaining the desired attitude.

Figure 9–20. Steep turns



The loss of vertical lift in a steep turn results in a tendency to lose altitude unless you take immediate corrective action as soon as the necessity is indicated on the flight instruments. Apply power as necessary to maintain airspeed. However, start no correction before the necessity arises. Make all corrections on the horizon indicator even though the precession of the instrument is apparent. You do this by noting the need for a correction on the vertical-speed indicator or the altimeter, and then checking the attitude as indicated on the horizon indicator; make the change on the horizon indicator from this indication. After you have made this change, again check the altimeter and the vertical-speed indicator to determine whether or not the correction was adequate.

The recovery should be smooth and at the normal rate of roll-out. As the aircraft is rolled out of the turn, the vertical lift will increase and the aircraft will tend to climb if you don't make the necessary corrections as soon as you note the need on the instruments. Adjust the power to maintain the desired airspeed.

UNUSUAL ATTITUDES

The importance of pilot proficiency in recovering from unusual attitudes cannot be overstressed. The one outstanding cause of instrument flying accidents, as determined by accident investigating boards, is weak pilot technique, or lack of instrument proficiency. *Unusual attitudes from which pilots do not make the proper recoveries occur so frequently that practice and mastery of the procedures for recovering from unusual attitudes are a primary requirement.*

An unusual attitude is any attitude of the aircraft not required for normal instrument flight. It may result from one factor or a combination of several factors, such as turbulence, vertigo, instrument failure, wingmen getting lost from formation, confusion of the pilot, or carelessness in scanning the instruments.

High-speed, high-altitude flight has made the unusual attitude problem especially critical. You must exercise closer vigilance in detection and recovery from an unusual attitude because the degree of error allowable in your recovery is lower. Failure to detect and recover quickly may be fatal. The greater the altitude, the closer your true airspeed will come to the limiting Mach number of your aircraft, while at the same time the greater altitude will reduce the indicated airspeed so that you are even closer to stalling speed. Remember, too, that when you fly at extreme altitudes and are possibly engaged in the violent maneuvers of air combat, you must often refer to your instruments for orientation, since the ground and natural horizon will generally not be visible or may be hard to recognize.

In recent years, manufacturers of aircraft instruments have been trying to produce an instrument presentation which can be interpreted rapidly without being confusing, and which will help the pilot stay within the accepted tolerances for the maneuvers involved. They have finally produced the non-tumbling, electric gyro-horizon, or horizon indicator, which can be used in all attitudes of flight. When properly interpreted, this instrument is your most valuable aid in rough weather or combat maneuvers.

The non-tumbling horizon indicator has been the target of much criticism which it does not deserve. Some instrument flight schools suggest that its presentations are confusing when the aircraft is in an unusual attitude. Some books have stated that it should not be used to recover from unusual attitudes because of its precession. Both statements are wrong. Any other methods set forth for instrument flight recoveries from unus-

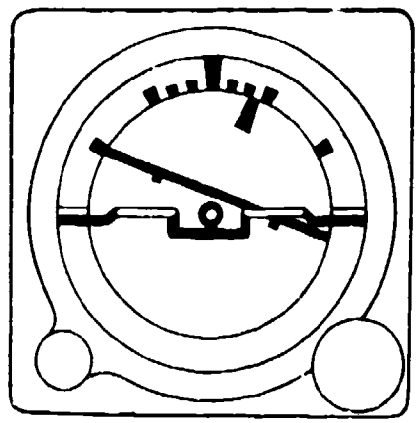


Figure 9-21. Non-tumbling gyro—descending left turn

ual attitudes are too slow and complex. The non-tumbling horizon indicator offers a single instrument to guide you to a quick recovery, with a preliminary airspeed cross-check. The needle-ball partial-panel recovery from unusual positions is just as antiquated as the needle-ball method of level, instrument flight. You can use the same method of instrument scan for recovery from an unusual attitude that you use for straight-and-level flight or for attitude control during maneuvers, such as for a jet penetration.

As an example, consider ordinary jet instrument maneuvers. Changes in attitude are initiated on the horizon indicator (the non-tumbling gyro-horizon), and the amounts of such changes are checked and noted on the rate instruments, specifically the vertical speed or the turn indicator. A cross-check on performance can be made on the airspeed indicator and altimeter. If definite rates are desired in a maneuver, the rate instruments are also considered performance cross-check instruments. The attitude changes, however, are really made on the horizon indicator.

Certainly, when recovering from an unusual attitude, you are not concerned with performance nor are you interested in either rate of turn or rate of climb. You are interested in what your attitude is and how to recover safely. Through use of instrument aerobatic training, sometimes called "confidence maneuvers," it has been shown that pilots can learn to recover from all sorts of unusual positions by using the horizon indicator as the primary instrument. Other instruments (besides an airspeed check) are not used until the recovery is completed and you are once more interested in performance. There is nothing confusing about the horizon indicator in the inverted or other position unless the pilot is unfamiliar with those positions.

Instrument flying, of course, consists of so interpreting your instruments that you visualize your flight condition. If you had a television camera on the nose of the aircraft which showed the earth in a 180° presentation around you, regardless of weather, you would have an ideal instrument flying aid. Having no such instrument, you must translate in your mind the readings of your instruments so that you visualize your aircraft in relation to earth. As the speed of aircraft increases and the allowable stresses on the aircraft become less, this translation process must become more rapid. At present, the non-tumbling horizon indicator is the one instrument which gives you a picture of your aircraft in relation to the earth and which requires the least mental translation, provided you apply a few simple rules. Before considering its use in recoveries from unusual attitudes, however, consider first what it is trying to do and the items of the presentation which it uses to do its job.

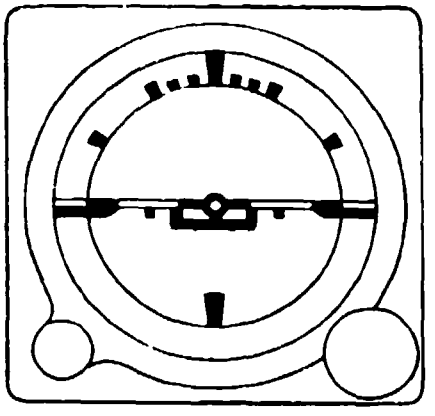


Figure 9-22. Inverted flight

You see two movable elements through the front glass—the bank index and the horizon bar (Fig. 9-21). On the case there are also markings used in coordination with the bank index and horizon bar to measure the amount of your bank. These show 10-20-30-60-90 degrees from each side of the zero point. The bank index always points toward the sky—it tells you which end is up. If the bank index is at the bottom of the case (Fig. 9-22), you are flying upside down just exactly as the gyro indicates. The horizon bar moves across the face of the instrument, *always at 90° to the bank index or "pip."* When you fly in a straight climb, the horizon bar drops down below the miniature aircraft, away from the bank index, toward the bottom of the case (Fig. 9-23). Thus the horizon bar tells you the nose position by the relation of its position as to the miniature aircraft *and* the bank index pip. In this way, the horizon indicator provides valuable information about your wing position, nose position, and sky

position. With this in mind, now look into these four basic considerations applied to use of the horizon indicator in unusual flight positions.

1. AIRSPEED: Check the airspeed quickly before you make any move to recover from an unusual attitude. If it is dangerously low, use caution before making any change in attitude. Add power to 100%, allowing for the slow acceleration of jets. If the speed is dangerously high, execute recovery at once before the speed increases beyond Mach limits, opening dive brakes and cutting power if required. If the airspeed is within safe maneuvering limits, it presents no problem.

2. BANK INDEX PIP: If the movable bank index pip appears on the top half of the case, you are right side up. If it is on the bottom of the case, you are on your back, or upside-down.

3. NOSE POSITION: In normal or inverted flight, when the miniature aircraft is between the horizon bar and bank index, the nose is high. When the miniature aircraft is not between the horizon bar and bank index, the nose is low.

4. WHICH WAY TO ROLL? In an inverted position, when the bank index is on the right side of the case, roll to the right to regain a right side up position. When the bank index is on the left side of the case, roll left. In brief, in an inverted position, roll by pushing the stick toward the bank index and you will always roll in the shortest direction to an upright position.

With respect to precession, remember that when the aircraft is in a vertical climb or vertical dive, the bank index will precess around the *left* side of the gyro case. This is automatic and rapid and presents no problem!

Thus, you have a simple method for recovering from any unusual attitude by using the horizon indicator *if you have one of the non-tumbling types, such as the H-5 or J-8.*

1. Check airspeed; if it is excessive, reduce power and extend dive brakes. If it is low, add 100% power and begin recovery simultaneously and quickly.

2. Execute an aileron roll by putting the stick over to the same side of the aircraft as the bank index is on the face of the horizon indicator. Hold it in roll until the bank index shows that the aircraft is right side up.

There are two cases, however, where an immediate roll-out to level-wing position is not advisable. Both occur when the nose is extremely high. When the aircraft is right side up, but the nose is extremely high, you must correct the nose position first. In this case, the horizon bar is near the bottom of the case and the bank index at the top. In this situation, roll to the 90° position, let the nose drop through to the horizon, and then roll out. If you were to level your wings first, you could not get the nose down fast enough by pushing forward-stick because of the risk of a flame-out due to negative-G. After you roll to the 90° position, the bank index moves in a direction opposite to the direction of roll, and the horizon bar will become more or less centered and vertical to the case. Recovery from this 90° position after the nose comes to or through the horizon and maneuvering airspeed is obtained is the same as from any other unusual position. When the nose is high but you are inverted, you also correct the nose position first. Here it is easiest to apply back pressure on the stick to bring the nose to or through the horizon, insuring that maneuvering airspeed is obtained, then rolling in the shortest direction to an upright position by pushing the stick toward the bank index.

3. Correct the nose attitude by raising or lowering the nose as indicated on the horizon indicator. When you have done this, you are ready to use other instruments to smooth out your attitude.

Notice that, except for one or two airspeed

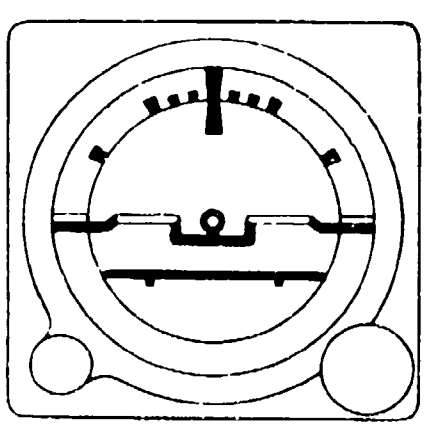


Figure 9-23. Straight climb

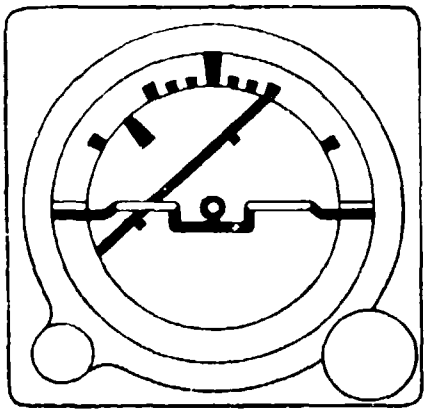


Figure 9-24. Left spin

checks, the non-tumbling horizon indicator is the only instrument you have to use to recover to approximately level flight. You don't have to make a time-consuming check of several instruments until you have recovered from what may be a dangerous attitude.

Of course, the instrument may not read the exact actual attitude at all times through such extreme attitudes. However, you are much more concerned with how to get out of your predicament than you are in knowing your precise attitude. This system gives a quick rule-of-thumb answer to a question for which you want an answer without waiting or analysis. It is also true that when you do recover, the horizon indicator may not be 100% correct, but at least you are right side up and in more or less level flight. In that condition you can easily dress-up your attitude by use of the full panel of pitch and bank instruments.

Recovery from a spin is effected by the same means as in visual flight. A spin is indicated by (1) low airspeed (below stalling), (2) extreme displacement of turn needle and ball, (3) rapid loss of altitude, and (4) one of the indications on the horizon indicator shown in Figure 9-24.

CONFIDENCE MANEUVERS

Confidence maneuvers are an important part of jet instrument flight training; they may also be practiced in conventional aircraft equipped with the non-tumbling, electric horizon indicator. The purpose and result of such training is to develop confidence in a pilot's ability to control attitude under all conditions of flight, including combat conditions, without reference to the visual horizon. These maneuvers are, in fact, instrument aerobatics. They are made possible by the non-tumbling gyro-horizon.

Point Rolls

The first exercise usually consists of point rolls. These are intended for practice in control of wing position (bank control) without much emphasis on nose position. They are essentially aileron rolls which are momentarily halted by hesitation at various points. The 2-point roll involves hesitation in the inverted position. The 4-point roll requires hesitation at each 90° position. The 8-point roll carries the pilot on to hesitations every 45° during the roll. To prevent an excessive loss of altitude, the rate of roll should be slightly increased over the simple aileron roll.

Like all the confidence maneuvers, 2-, 4-, 8-point rolls should be made in balanced flight position (ball in the center), and the hesitations should be very brief. In all confidence maneuvers, avoid pulling negative G's. Keep the posterior in the seat. Keep your feet on the rudders at all times, ready to make necessary adjustments to hold balanced flight. Avoid excessive stress on the airframe, and keep well within the G limits. Observe the rate-of-roll limits, remembering especially the limitations imposed with tip tanks or centerline tanks installed.

The Aileron Roll

The aileron roll must be practiced before point rolls, but emphasis need not be placed on nose position (pitch control) until after point rolls are mastered. After point roll training, aileron rolls may again be practiced in order to master nose position control combined with the wing (bank) control. To enter the aileron roll, lower the nose to no more than 2,000 fpm descent, allowing the airspeed to pick up to the desired levels (for the TV-2, 300 knots). On reaching airspeed, bring the nose up smoothly with wings level until 25° above the horizon. (This places the horizon bar about ¼ inch above the bottom of the horizon indicator dial.) Relax back pres-

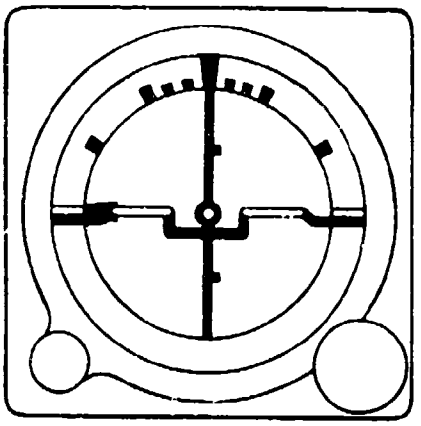


Figure 9-25. 90° position in left wingover

sure momentarily to maintain 25° climb, and then start to roll. Adjust the rate of roll so that the wings will be level in the inverted position at the same time that the nose drops through the horizon; that is, at the time that the horizon bar passes over the center dot of the horizon indicator. Continue the roll, and recover with wings level and nose slightly below the horizon. A TV-2 should be at about 300 knots on recovery. Maintain enough back pressure while rolling to keep in the seat at all times (avoiding negative G). The horizon indicator is primary for pitch and bank throughout. The airspeed indicator serves as a supporting pitch instrument, and the tachometer is primary for power.

The Wingover

A second maneuver to be performed following the point rolls is the wingover. This consists of a steep climbing turn, in which the nose drops through the horizon as speed drops off. As the nose drops below the horizon, roll the wings to level position, and the aircraft will recover in a straight, but not steep, descent approximately 180° opposite to the heading at the time of entry. As a confidence maneuver, it emphasizes nose and wing position control rather than recovery on a certain heading. Smooth, coordinated flight is the aim.

To enter a wingover in a jet aircraft on instruments, use about 90% power in descending flight (1,000 to 1,500 fpm) to pick up suitable speed (for the TV-2, 300 knots). Bring the nose up and begin a climbing turn, increasing the bank as the airspeed drops. Roll to the 90° position, being careful the airspeed doesn't get too low (for the TV-2, not below 150 knots). When the aircraft first reaches the 90° position, the nose should be high enough that the horizon bar will be at the "bottom" side of the dial, as in Figure 9-32. When you hold the 90° position, the nose drops through the horizon until the horizon bar is about ¼ inch from the "top" side. (The word "top" here means up near the bank index pip which is always "up" toward the sky; the word "bottom" means down and away from the pip which is toward the ground. However, in a 90° bank "top" and "bottom" are at the side of the dial.) At this time you should relax the back pressure necessary to hold the aircraft in a steep turn, and start the rollout to recover. The rate of roll on recovery should be the same as on entry. This is a maneuver in which everything should be smooth; to some extent, the aircraft will almost seem to be cooperating in the way the speed diminishes and then increases as the nose falls through at the 90° position.

The Split S

The loop, split-S, Immelmann, and half Cuban eight conclude the confidence maneuvers. In executing the split-S raise the nose 25° and execute an aileron roll to the inverted position. Reduce the power to idle, extend speed brakes, and raise the nose as in aileron roll. When the IAS is 210K, roll to the inverted position. The nose will drop. Maintain the wings level, and pull 3 or 4 G's as you apply back pressure to recover from the resulting dive, until you are back in level flight. The horizon indicator remains primary for pitch and bank throughout.

The Loop

Completing the loop requires greater power and speed. Apply 100% power, lower the nose to reach 4,000 fpm descent, and hold it until adequate airspeed is indicated (for the TV-2, 380 knots). Pull the nose up and through the horizon with about 4-G pullout. The wings must be level at this stage of the loop, for there will be little opportunity to check the wing position again before in-

verted flight is obtained. During the vertical stage, the horizon indicator will precess, the bank index moving around the left side of the dial. When inverted, recheck to make sure that the wings are level as the nose drops through the horizon; reduce power to idle and extend the speed brakes as the nose drops through. As the speed increases, maintain 4-G pull-out until recovery is made in level flight. During the vertical down stage, the gyro will again precess around the left side of the dial. Should the aircraft shudder at low speeds, release back pressure to prevent a high-speed stall. Be careful not to pull too may G's, nor to stall at the top. Pull the nose through and reduce power promptly at the top of the loop. The horizon indicator, as in all of these maneuvers, is primary for pitch and bank throughout. The tachometer is primary for power.

The Immelmann

The Immelmann should be a natural after you have mastered the aileron roll and loop. Start a loop, as described, being sure the speed is adequate. Shortly before reaching a level inverted position, while the nose is still somewhat above the horizon, start the roll. This should bring you out at level flight. If you must err in the point of starting the roll, it is better late than early, because if you roll out too early you may come out in a nose-high stall. Again, the horizon indicator is primary for pitch and bank.

Half Cuban Eight

The technique for executing the half Cuban eight is very similar to that of the Immelmann except that the nose of the aircraft is brought from 25° to 30° below the horizon prior to rolling right side up.

Before practicing these confidence maneuvers, you should be familiar with the procedures for recovery from unusual attitudes. Practice in recovery from the more extreme attitudes, however, should wait until you have mastered the confidence maneuvers and are familiar with most of the unusual indications of the horizon indicator during aerobatic flight.

By the time you have learned the confidence maneuvers, which are really aerobatics on instruments, and have learned to recover from any sort of unusual attitude, you are ready to control the aircraft at all times and under all conditions of weather or combat. The remaining part of instrument flight training concerns flight planning, use of the airways and ground facilities, and weather analysis. Anything involving control of the aircraft by interpretation of the instruments will already be known to you and you will be ready to apply your flying ability in cross-country work in all weather.

CHAPTER 10

COMPUTERS

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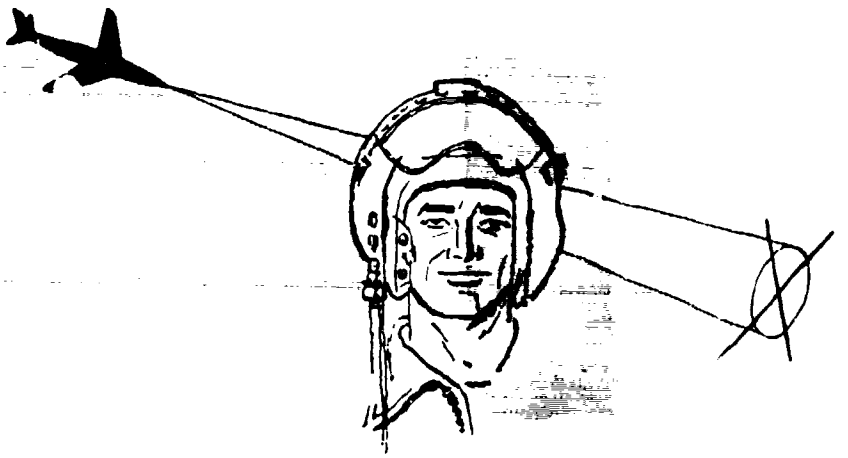


CHAPTER 10

COMPUTERS

THIS chapter concerns the computers you use both in flight planning and in the actual conduct of the flight. The subject divides neatly into two topics—navigational computers and performance calculations.

The only navigational computer discussed here is the E6D (AN-5834-1B). None of the several plotting boards are discussed here because much of the discussion about the E6D applies as well to the plotting boards; besides you probably know the Mk. III or MK. V board well from cadet days, and newer plotting boards are used the same way, differing mostly in size, material, and speed ranges.

So far as performance calculations are concerned, this chapter discusses weight and balance and how to compute the take-off C. G. It also covers the purposes and use of the climb and descent tabulators and the REST computers used to plan jet flights. This involves a discussion of the principles of cruise control.

NAVIGATION COMPUTERS

The E6D (AN-5834-1B, also called the E-10) is really a combination of two devices. One side is a specially designed scale for the solution of wind problems; this side is known as the wind face. The other side, known as the slide rule face, is a circular slide rule for the solution of mathematical problems.

Slide Rule Face

A slide rule is a standard device for the mechanical solution of various mathematical problems. It consists of several scales, fixed and movable, which may be positioned with respect to each other so as to give the result of mathematical operations. Slide rules operate on the basis of logarithms, but you don't have to know logarithms to use a slide rule. Slide rules are either straight or circular; the one on the computer is of the circular type.

In the case of the computer, the slide rule consists of two circular scales—one a stationary scale (often called the "miles" scale), the other a rotating scale (often called the "minutes" scale). Each scale has a reference mark, the 10, called the "Index." The rotation scale also has a black arrowhead at the 60-minute or 1-hour point; this is known as the Speed Index. Graduations of both scales are identical. The graduations are numbered from 10 to 100, and the unit intervals decrease in size as the numbers increase in size. Not all unit intervals are numbered, however, and the first element of skill in using the computer is a sure knowledge of how to read the numbers.

The unit intervals which are numbered present no difficulty. The whole problem lies in giving the correct values to the many small lines which come between numbered intervals. There are no numbers between 25 and 30, for example, but it is obvious that the larger intermediate divisions are 26, 27, 28, and 29. Between 25 and (unnumbered) 26 there are five smaller divisions; each of these is therefore 0.2 of the larger unit. For a number such as 278, first find the 27 (for 270), then the 28 (for 280), and then, since the divisions here are of two units each, find the fourth of the intermediate divisions (for 278).

Of course, there are unit divisions only for numbers made up of relatively few integers. For a number such as 27812, you would use the point already chosen for 278. In this connection, remember that the position of the decimal point will not matter in picking the point on the scale which represents the number. Thus, you would use the same point for 27.8, 2.78, and so on. Each point on the scale therefore represents many numbers.

In addition to the "miles" and "minutes" scales, the slide rule face of the computer contains two special scales. One is marked "For Air Speed Computations" and is used for applying air temperature and pressure altitude to correct the airspeed meter reading. The other is marked "For Altitude Computations" and is used for applying air temperature and pressure altitude to correct the altimeter reading. There are additional scales to compute for density altitude; determine true airspeed from Mach number, and to solve for wind correction factors in constant heading flight technique.

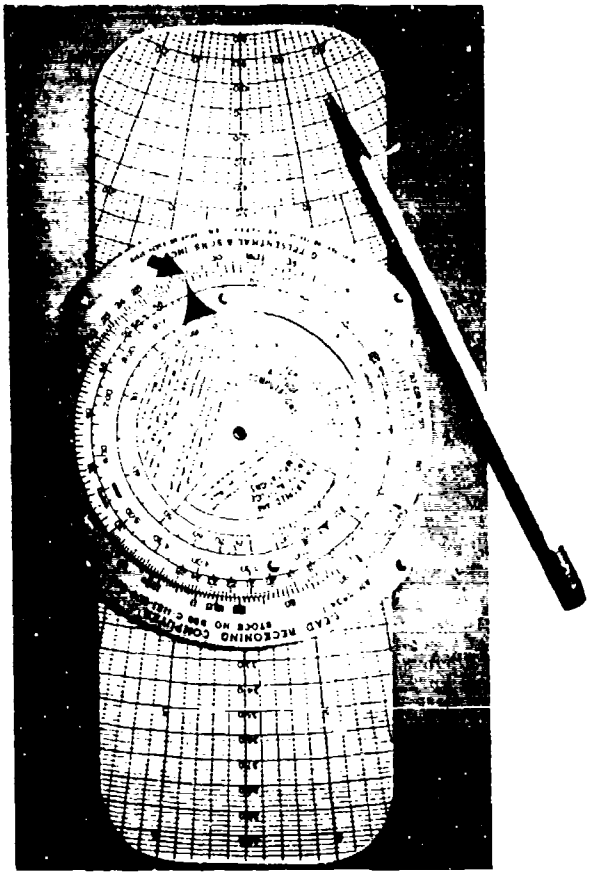


Figure 10-1. Finding 278 on the scale

PROBLEMS ON THE SLIDE RULE FACE

The slide rule face of the computer is so constructed that any relationship between two numbers, one on the stationary scale and one on the

movable scale, will hold true for all other numbers on the two scales. Thus, if you put the two 10's opposite each other, all other numbers will be identical around the whole circle. If you put 20 on the inner scale opposite 10 on the outer scale, all numbers on the inner scale will be double those on the outer scale. If you set 12 on the outer scale opposite 16 on the inner scale, all numbers on the outer scale will be in a 3-to-4 relationship to all numbers on the inner scale.

Time, Speed, and Distance Problems

Most calculations for time, speed and distance required for navigation are set up on the computer as proportions. If you consider the figures on the outer (miles) scale and inner (minutes) scale as the upper and lower parts of a simple proportion, you can set the known values on the computer, and the unknown values will automatically be given by the computer scale.

For example, suppose a plane traveled 80 miles in 14 minutes. How many minutes will it take to fly 120 miles? You can solve the problem in a simple proportion—80 is to 14 as 120 is to the time required. Mathematically you can put it in this form:

$$\frac{80}{14}=\frac{120}{?}$$

In this form, you can set the problem on the computer exactly as it appears.

1. *Opposite the 80 on the outer "miles" scale place the 14 on the inner "minutes" scale.*

2. *Opposite 120 on the outer scale read the answer, 21, on the inner scale. Note that the "arrowhead" or rate arrow now indicates the speed at which you are traveling (343). This is the basis of all time-speed-distance computations.*

You can solve for *distance* in a similar manner. Suppose, for example, that a plane flies at a speed of 174 knots for 40 minutes. How far does it fly?

1. *Place the rate arrow on the inner scale opposite the ground speed of 174 knots on the outer scale.*

2. *Opposite the time of 40 minutes on the inner scale read the distance flown on the outer scale (116 nm).*

You can determine the *time* required to fly a given distance at a given speed in the same way. For example, how long will it take to fly 730 nautical miles at a speed of 350 knots?

1. *Place the rate arrow on the inner scale opposite the ground speed of 350 knots on the outer scale.*

2. *Opposite the distance of 730 nautical miles on the outer scale, read the time on the inner scale (2 hours, 05 minutes, or 125 min.)*

Figuring out the *speed* required to fly a given distance in a given time is just as easy. How fast will you have to fly, for example to go 266 nautical miles in one hour and 25 minutes?

1. *Place the time (1.25) on the inner scale opposite the distance (266 nm) on the outer scale.*

2. *Opposite the rate arrow read the ground speed (188 kts).*

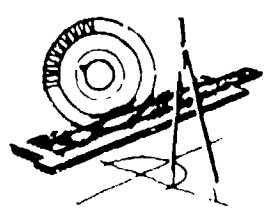
Notice that the hours scale, directly under the minutes scale, ends at ten hours. This makes computations for more than ten hours more difficult. The scale of the computer remains the same, but you must convert the time read on the minutes scale into hours and minutes.

Conversion of Distance Units

The distance units you deal with on the computer are statute miles, nautical miles, and kilometers. A statute mile is 5,280 feet, a nautical mile is 6,080 feet (or 1′ of latitude), and a kilometer is 3,280 feet (about ⅝ of a mile). There is a conversion marker for each of these units on the outer scale: nautical miles, statute miles, and kilometers.

To convert from one unit to another, place the known unit on the inner scale under the respective unit arrow on the outer scale. Read the equivalent distance under the desired unit arrow. For example, to find the nautical mile and kilometer equivalent of 130 statute miles:

1. *Place the known unit (130 Stat. M.) under the statute mile arrow.* (See Fig. 10-2.)



2. *Under the nautical mile arrow read the conversion to nautical miles (113) on the inner scale.*

3. *Under the kilometer arrow read the kilometers (208) on the inner scale.*

Multiplication and Division

When you use the computer for multiplication or division, you use it in the same way as an ordinary slide rule. That is, you use the "10" index instead of the rate arrow. In multiplying, you set the "10" index on the inner scale opposite either of the numbers to be multiplied on the outer scale. Then you read the answer on the outer scale. It is the number on the outer scale opposite the other number to be multiplied on the inner scale.

Multiplying 14 by 46, for example, you proceed as follows:

1. *Place the "10" index on the inner scale opposite either of the two numbers to be multiplied (46) on the outer scale.*

2. *Opposite the other number to be multiplied (14) on the inner scale, read the product (644) on the outer scale.*

When you set up a division problem on the computer, it appears exactly the same as it does when given as a fraction. That makes it easy to visualize and remember. In dividing 180 by 15, for example, think of it as

$$\frac{180}{15}$$

and set it up on the computer as follows:

1. *Opposite the dividend (180) on the outer scale, place the divisor (15) on the inner scale.*

2. *Opposite the "10" index on the inner scale, read the quotient on outer scale (12).*

In general, when multiplying or dividing with the computer, remember the following points.

1. The computer does not show decimal points. Be careful to place the decimal point properly in your answer. Making a common-sense mental check of the problem will prevent many errors.

2. When you work with numbers having three or more digits, you may not be able to get the exact answer. However, the error will be relatively insignificant, not enough to concern you in normal navigation problems.

3. Finally, remember that the computer can be no more accurate than you are and the more you practice using it, the more proficient you will become.

Fuel Consumption Problems

Fuel consumption problems are solved on the computer as proportions in exactly the same way as time-speed-distance problems. For fuel problems, you use the outer scale for gallons instead of miles and the rate arrow for rate of fuel consumption instead of rate of speed. As an example, find the *rate of fuel consumption* when 140 gallons are consumed in 40 minutes.

1. *Place the time flown (40 minutes) on the inner scale opposite the fuel consumed (140 gallons) on the outer scale.*

2. *Opposite the rate arrow read the rate of fuel consumption (gph) on the outer scale (210 gph).*

As an example of finding the amount of fuel required, take a case where the rate of consumption is 320 gallons per hour and the time is 7½ hours.

1. *Place the rate arrow opposite the rate of fuel consumption (320 gph) on the outer scale.*

2. *Opposite the time (7:30) on the inner scale, read the total fuel required for the flight on the outer scale (2,400 gallons).*

To determine the *hours* of fuel available, you follow a similar procedure. Suppose, for example, the rate of fuel consumption is 185 gph and the amount of fuel available is 400 gallons. Find the remaining flight time.

1. *Place the rate arrow opposite the rate of fuel consumption (185 gph) on the outer scale.*

2. *Opposite the amount of fuel available (400 gallons) on the outer scale, read the remaining flying time (2:10) on the inner scale.*

If fuel quantities are available in pounds instead of gallons, you solve the problems in exactly the same manner by substituting pounds for gallons in the computations.

Off-Course Corrections

If an aircraft is one nautical mile off course in sixty nautical miles of flight, it will be approximately one degree off course. You can set up this "rule of thumb" as a proportion on the computer to solve off-course corrections. If, for example,

you have flown 130 nautical miles and you're off course 15 nautical miles to the right with 225 nautical miles more to fly, what correction must you make to return to your desired course. To find the answer, set up your computer as follows:

1. *Place the miles flown (130) on the inner scale opposite the miles off course (15) on the outer scale.*

2. *Opposite the rate arrow, read the degrees off course (7°) on the outer scale. This amount of correction toward true course will parallel course only. You need an additional correction to get you back to course.*

3. *To find the additional correction necessary to get back to your course in the distance remaining, set the miles to be flown in returning to course (225) on the inner scale opposite miles off course (15) on the outer scale.*

4. *Opposite the rate arrow read the additional correction to return to course (4°).*

5. *Add the 7° left correction to parallel course to the 4° left correction to return to course, and you get a total of 11° left correction to return to course in the remaining 225 nautical miles.*

FINDING TRUE AIRSPEED

Before considering the solution of problems of airspeed on the computer, it might be well to review the following definitions:

INDICATED AIRSPEED (IAS)—The airspeed which is read directly from the airspeed indicator.

CALIBRATED AIRSPEED (CAS)—The indicated airspeed corrected for instrument and installation error.

EQUIVALENT AIRSPEED (EAS)—The calibrated airspeed corrected for the compressibility factor.

TRUE AIRSPEED (TAS)—The equivalent airspeed corrected for temperature and pressure conditions.

GROUNDSPEED (GS)—The true airspeed corrected for wind conditions, or the speed the aircraft is actually traveling over the ground.

When solving for true airspeed, set the "10" indices on the outer and inner scale opposite each other. The scale of the computer will now be visible in the window marked "For Airspeed Computations." Then set the flight level free air temperature opposite the pressure altitude and read the true airspeed on the outer scale opposite the equivalent airspeed on the inner scale.

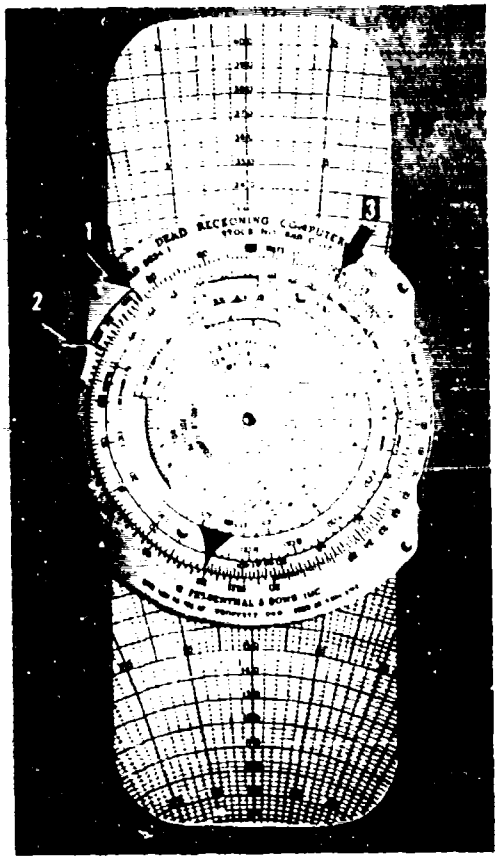


Figure 10–2. Conversion of distance units. (1) Statute miles (2) Nautical miles (3) Kilometers

For example, suppose the flight level free air temperature is −5° C, the pressure altitude is 10,000 feet, and the equivalent airspeed is 250 kts. Find the true airspeed.

1. *Set the flight level free air temperature in centigrade (−5° C) opposite the pressure altitude (10,000 ft.) in the window marked, "For Airspeed Computations."*

2. *Opposite the equivalent airspeed (250 kts) on the inner scale, read the true airspeed (290 kts) on the outer scale.*

The most accurate method of solving for true

airspeed is by use of pressure altitude, as in the example just given. You can find the pressure altitude by setting the altimeter at 29.92" and reading the indicated altitude. However, you can use indicated or calibrated altitude without introducing too great an error in most instances.

In flights at low altitudes and low airspeeds (below approximately 10,000 feet and 250 kts) the compressibility factor is very small. In this case, you can compute true airspeed from calibrated airspeed instead of equivalent airspeed without inducing an appreciable error. At higher altitudes and airspeeds, however, you must correct the calibrated airspeed for compressibility.

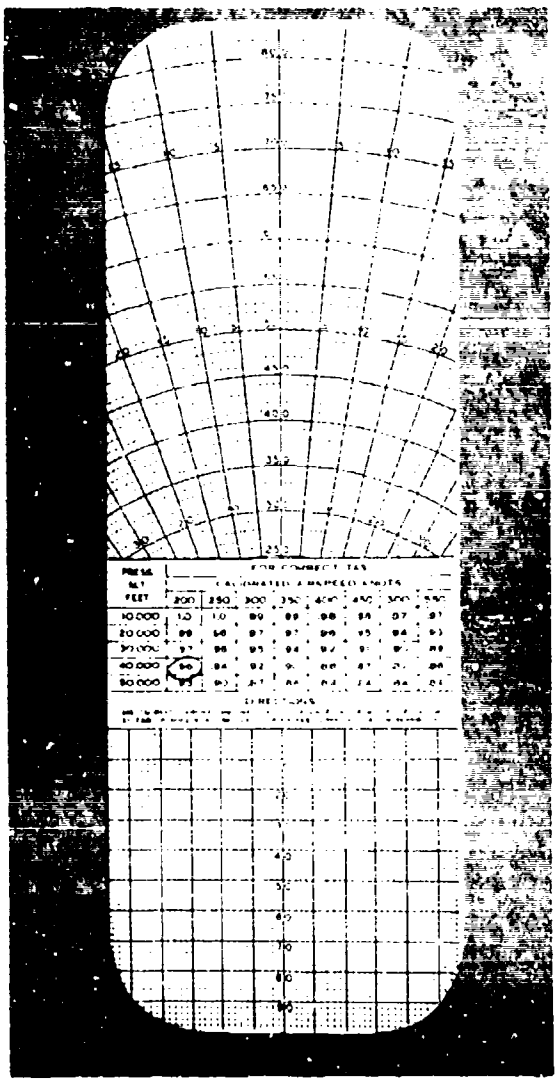


Figure 10–3. Finding correction factor for compressibility

Solving for Correct True Airspeed

If you found the true airspeed on the computer by using calibrated airspeed and want to correct for compressibility error, you can use the chart on the sliding scale. The compressibility error is the same for all aircraft and increases with an increase in speed and altitude. On the chart, it is computed for knots and is not accurate in miles per hour.

For example, if you want to find the true airspeed when the calibrated airspeed is 200 kts, the free air temperature is −60° C, and the pressure altitude is 40,000 feet, proceed as follows:

1. *On the slide rule side of the computer, using the temperature of −60° C, pressure altitude of 40,000 feet, and calibrated airspeed of 200 kts, find the true airspeed (400 kts) uncorrected for compressibility.* (Refer to the section "Finding True Airspeed" to compute this phase of the problem.)

2. *Using the chart titled, "For Correct TAS" on the sliding scale of the computer, find the intersection of the two columns nearest the pressure altitude (40,000) and calibrated airspeed (200), and get the correction factor (0.96).* (See Figure 10-3.)

3. *Multiply the true airspeed (400 kts) computed from calibrated airspeed, by the correction factor of 0.96. You now have the correct true airspeed (384 kts).*

Finding True Airspeed From the Mach Number

The E6B computer has a scale to determine the true airspeed in knots from the Mach number and to determine the Mach number from the true airspeed. You use the arrow marked, "Mach No. Index" which is visible in the window marked, "For Airspeed and Density Altitude Computations" when you set 16 on the inner scale opposite the "1.0" index on the outer scale. For example, if the free air temperature is −45° C and the Mach number is 0.7, find the true airspeed (knots) as follows:

1. *Set 16 on the inner scale opposite the "16" index on the outer scale. The arrow marked "Mach No. Index" will now be visible in the window marked "For Airspeed and Density Altitude Computations."*

2. *Set the flight level free air temperature in centigrade (−45°) opposite the "Mach No. Index" arrow.*

3. *Opposite the Mach number (0.7) on the inner scale, read the true airspeed on the outer scale (410 kts).*

FINDING TRUE ALTITUDE

Here, again, before considering the solution of altitude problems on the computer, it might be well to review the following definitions.

INDICATED ALTITUDE — The altitude read from the altimeter with the correct altimeter setting in the Kollsman window.

CALIBRATED ALTITUDE — The indicated altitude corrected for instrument error.

PRESSURE ALTITUDE—The calibrated altitude corrected for variations in pressure conditions. You determine this by setting the altimeter to 29.92 and applying calibration to resultant indication. This gives you the weight above the standard datum plane (the theoretical point where the pressure is 29.92 inches of mercury and the temperature 15° C).

DENSITY ALTITUDE—Pressure altitude corrected for variations of temperature.

TRUE ALTITUDE — Calibrated altitude corrected for temperature variations from standard temperature.

The altimeter is constructed to record the correct altitude under standard conditions of temperature and pressure. Since atmospheric conditions are seldom if ever standard, the altimeter reading must be corrected for these variable conditions to find true altitude. Suppose, for example, that the pressure altitude is 20,000 feet, the indicated altitude is 19,800 feet, and the free air temperature is −10° C. To find the true altitude, proceed as follows.

1. *In the window marked "For Altitude Computations" place the free air temperature in centigrade (−10°) opposite the flight level pressure altitude (20,000).*

2. Opposite the calibrated or indicated altitude (19,800) on the inner scale read true altitude on the outer scale (21,000 feet).

This is the most accurate method of computing true altitude on the computer. Another method is to use indicated altitude instead of pressure altitude; however, this induces a small error in the solution.

Density Altitude

To determine density altitude, use the scale for that purpose. If, for example, the pressure altitude is 40,000 feet and the true air temperature is −65° C, you find the density altitude as follows:

1. *In the window marked "For Airspeed and Density Altitude Computations" (the same window you use for true airspeed computations), set the free air temperature (−65°) opposite the pressure altitude (40,000).*

2. *Opposite the arrow in the small outer window marked "Density Altitude" read the density altitude (39,000 feet).*

THE WIND FACE

Problems involving wind depend on the solution of the wind vector triangle. Six factors or quantities are involved: wind direction, wind velocity, true course (track), ground speed, true heading, and true airspeed. If any four of these factors are known, the other two can be found either by graphic computations or by use of the computer.

In solving a wind-vector problem on the computer, you plot the wind vector on the surface of the transparent disk. The rest of the vector triangle is already drawn on the computer to complete the problem. There are several methods of solving wind-vector problems on the computer, but—no matter which method is followed—the final answer is the same if the correct procedures are used.

Definitions

As a quick refresher on the meaning of terms used in the wind-vector triangle, refer to Figure 10-4. This is a map showing a flight starting out from San Francisco to Honolulu at 0800. The

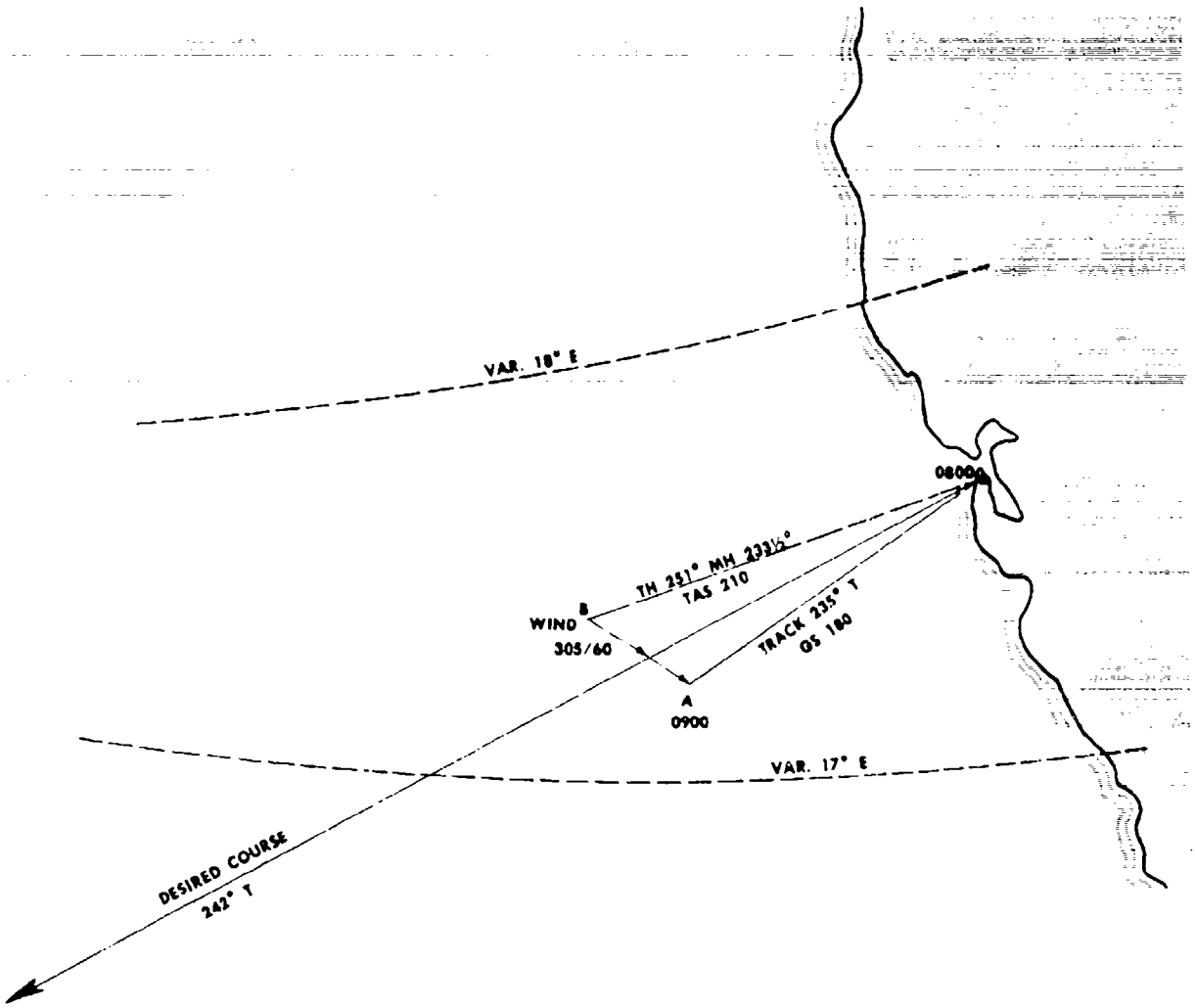


Figure 10-4. Definition of track, course, heading, ground speed, true airspeed, wind direction and speed on a map

desired course for this flight (the long line) was 242° T, and the pilot chose a heading based on forecast wind to make good this course. His actual heading and true airspeed made good is plotted on the map as a dotted line, ending at Point B. If there were no wind, he would be at B. Thus, B is his no-wind position. However, his 0900 fix showed him south of the desired course at Point A. The wind, 60 knots from 305° T, blew the plane to Point A. The solid line ending at A is his track—that is, the course he actually took. These three lines—wind, heading, and track—form a triangle, known as the wind vector triangle. The computer shows this same triangle in values of one hour's flying.

Course is the desired path over the ground. It may be measured in terms of "true" direction or "magnetic direction." In continental flight, magnetic is used; in navigation over water, true is used. The word course is often used loosely, interchangeably with "track."

Track is the actual path or course made good. It also may be measured in terms of true or magnetic.

Ground speed is the speed over the ground which is desired or actually made good. Naval aircraft always measure it in knots (nautical miles per hour).

Heading is the direction in which the nose of the aircraft is pointed in flight. Wind is the factor which makes heading differ from course or track. Heading may be measured in true, magnetic, or compass. *True heading* is the heading measured relative to True North. *Magnetic heading* is the heading measured relative to Magnetic North; it differs from true heading by the amount of variation in that area. *Compass heading* is the heading read off the compass; it differs from magnetic heading by the amount of deviation shown on the Compass Calibration Card. In modern aircraft, deviation is seldom a factor because most compasses, except the direct-reading panel compass, have no deviation. You can determine whether there is a deviation factor by referring to the calibration card near the compass you are using.

True airspeed has already been defined. It determines the length of the heading line in the wind vector triangle.

Wind direction and velocity cause the aircraft to be blown off the heading to the track, and cause the actual speed made good to be the ground speed rather than airspeed being flown. If there were no wind, heading and track (course) would be the same, and airspeed and ground speed would be the same. If the heading and course are plotted in magnetic directions on the wind face of the computer, wind must also be in magnetic terms. Wind velocity, airspeed, and ground speed must all be in knots for naval aircraft navigation.

Drift is the angle to which the aircraft is made to drift right or left of heading by the wind--that is, the angle between heading and track (course) measured from the heading.

Use of the Wind Face

There are four different ways of plotting the wind vector triangle on the computer, and the difference in the methods used often causes confusion. The differences are based on the way wind is plotted on the wind face:

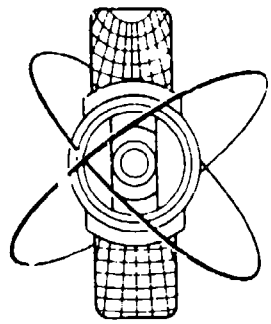
1. Wind plotted *down* from the grommet (center point of wind face in terms of true direction).

2. Wind plotted *up* from the grommet in terms of true direction.

3. Wind plotted *down* from the grommet in terms of magnetic direction.

4. Wind plotted *up* from the grommet in terms of magnetic direction.

Each method has its followers, but only the method listed as 1 was anticipated in the design of the computer; that is the one used here. Remember, though, that all methods give correct results if followed without error. It is true, too, that pilots who fly primarily over the Continental U. S. may prefer to use method 3 in such flights, because that method is much more convenient for that purpose. Thus, if you could use method 1 when outside the U. S. and method 3 when using



the U. S. radio range and airways system without getting confused, such use might be desirable. The advantages and disadvantages of each are tabulated in Figure 10-5. Whatever system you use, remember that wind blows from heading to track, and drift is measured *from* heading *to* track (course).

The vector triangle on the computer is similar no matter which of the four systems is used. The lines along the length of the plastic slide represent the long lines (heading TAS and Course or Track G. S.) of the vector triangle. To reduce the size of the slide, the lower end of the triangle is cut off, as shown in Figure 10-6.

The computer slide has two sides. One side

Figure 10-5. Comparison of Methods of Using Computer Wind Face

Method	Advantages	Disadvantages
1. Standard (USN). Plot Wind *Down*. True Values on transparent disk. Heading (TH) and TAS on centerline.	A. Heading on center line permits drift and variation scale at top to be used properly. B. Drift shows directly. C. Use of variation scale prevents errors likely in C-D-M-V-T or other formulae variation gimmicks. D. Wind used as given by meteorgy (True). E. Computer directions may be drawn on chart directly.	A. Problem of "Finding Heading," when TH, TAS, Wind DV are all known, is difficult and time consuming (juggling to determine heading to make good a certain course).
2. USAF. Plot Wind *Up*. True value on transparent disk. Course or Track and G. S. on centerline.	A. Course (Track) on centerline is easy to determine by direct reading. B. Heading to make good a course is easily determined without juggling. C. Same as "D" and "E" for Method 1.	A. Have to reset computer to use variation scale, or don't use scale but rely on C-D-M-V-T or other formulae. B. Wind correction angle in lieu of drift. Drift scale at top of computer useless. C. Confusion because computer designed for Method 1.
3. Magnetic. #3 is the same as #1, and #4 is the same as #2, except all directions (including wind) are magnetic instead of true.	A. On airways permits use of magnetic courses, bearing, etc. from charts without correction for variation. B. Some of the same advantages as for #1 or #2 are applicable.	A. Wind must be converted to magnetic wind by applying variation to direction. Often forgotten. B. Computer directions can't be drawn on chart without conversion to true. C. Confusion caused because computer designed for Method 1.

is for faster speeds and one is for slower speeds. The fast-speed side also has a rectangular grid which is used for Air Plot, Bombsight Calculations, and Relative Motion. Only the last of these uses is discussed here, as it is the only one Navy pilots are likely to use.

Now consider the solution by Method 1 of four typical problems which you are likely to meet in flight.

1. Finding track and ground speed, other factors being known.

2. Finding heading to make good desired track and determining ground speed, other factors being known.

3. Finding wind D-V, following determination of track and ground speed by a fix or other means after flying a certain heading and airspeed.

4. Finding wind velocity and ground speed after flying a heading and airspeed, and observing wind direction and drift angle.

Solution for Track and Ground Speed

The triangle most easily set up on the computer is the one in which track and ground speed are unknown. Practically, this solution is useful in the air when you know the wind, your true heading (the compass reading corrected for variation and deviation), your true airspeed (the airspeed indicator reading corrected for temperature and pressure), but have no means of visual reference to determine your ground speed or track. With this data, you would solve the problem by the following steps.

Assume, for example, that the wind direction is 320°, the wind speed 30 knots, the true heading 175°, and the true airspeed 180 knots. Find the track and ground speed as follows. (See Figure 10-7.)

1. *Set the wind direction (320°) under the True Index.*

2. *Draw the wind vector down from the center of the disk. Read the length of the vector (30 knots) between the speed circles along the center line. You may use any two speed lines, but it is usually easiest to set one of the heavy lines under the grommet and read down.*

3. *Rotate the compass rose until the true heading (175) is under the True Index.*

4. *Move the slide up or down until you get the true airspeed (180 knots) under the center of*

the disk. Be sure to complete this step—it is the one most frequently overlooked.

5. Read the drift angle (5° left) on the radial line at the head of the wind vector. The number of degrees between the center line and the head of the vector (wind arrow) is drift. When the vector is left, drift is left; when the vector is right, drift is right.

6. On the scale at the top of the computer read the value opposite your drift, which was 5° left in this case, and you find your track, 170°. (Of course, you keep the dial set with T. H. at the True Index.) Notice that this technique, which is not possible by Method 2, eliminates the error likely to result from forgetting to subtract left drift from heading or adding right drift to the heading. A mistake is much less likely.

7. Read the ground speed (206 knots) on the speed circle which passes through the wind point.

Incidentally, some pilots like to draw a dot, encircled, for the wind point, but others draw a cross. It is often wise for purposes of observing weather trends to leave a previous wind showing after determining a new wind, but if you do, designate it by a number. Do not draw a line from the grommet to the wind point. It is unnecessary and makes for a dirty computer face when erasure is needed.

Solution for Heading and Ground Speed

The problem of finding heading and ground speed is the one which led to development of Method 2 of using the computer. Method 1 requires juggling the computer face to find a heading which, with drift, will give a desired course. This solution is often performed on the ground to determine data for the flight plan and a heading for the first leg of a flight. If this were the only use ever made of the wind face, Method 2 would be the most desirable. However, since that is not often the case, use Method 1 and simply learn this solution. After practice, it causes no confusion and no loss of time.

As an example of how to solve for heading and ground speed, assume that the desired course (true) is 195°, the TAS is 180 knots, and the variation is 4° W. To find the heading (true and magnetic) and the ground speed, proceed as follows. The wind is 240° at 30 knots:

1. Set the wind direction (240° T.) under the True Index.

2. Draw in the wind point at a point 30 knots down from the grommet.

3. Move the slide until the TAS (180 knots) is under the grommet.

4. Rotate the disk until the desired course (195° T.) is under the True Index.

5. Observe the drift which would be obtained if you used the course as a heading (7½° or 8° L.). Since it is not zero, you must expect to use a heading which will give approximately that much left drift.

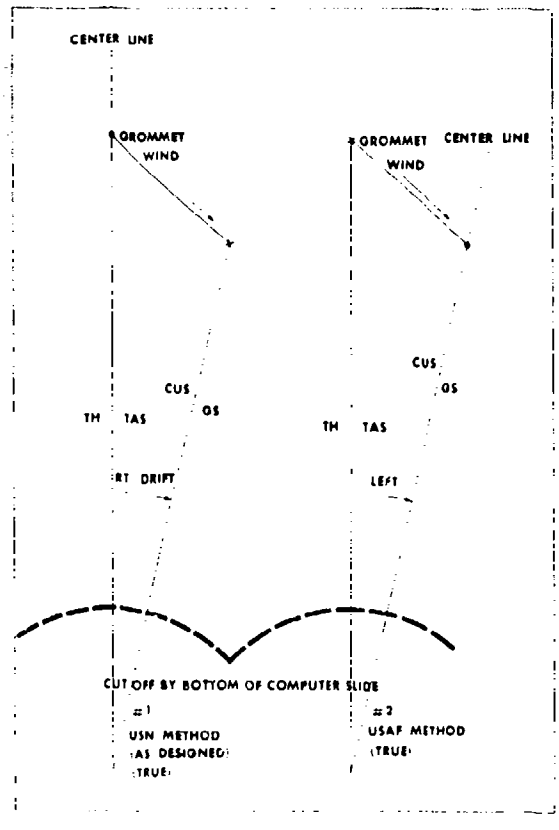


Figure 10-6. Wind vector triangles (by two methods) as they would appear on the E6D or E6B computers

6. Turn the disk until the desired course is opposite 7° or 8° left drift, and again read the drift shown by the wind vector. Juggle the disk until the course (195° T.) is opposite the same drift value at the top of the computer as that on which the wind point is located on the slide. In this case, if you set 8° L. as the first try, you find 6½° L. would result; so you try 7° L. and the two drift values are then equal. Now the True Index shows a TH (202° T.) which will result in flight on the desired course of 195° T. with a wind which causes 7° left drift. (See Figure 10-8.)

7. Read the GS 157 kts. under the wind point.

8. Opposite the variation taken from your area chart (in this case 4° W.), read the magnetic heading 206° M. Apply the deviation from the compass calibration card, if any, and you are ready to fly. (If you want, you can put in the deviation correction also by using the top scale on the computer and applying the deviation correction to MH.)

To avoid errors, which can sometimes be dangerous, be careful not to plot variation as plus instead of minus or vice versa. Such an error would take the pilot in Figure 10-6 nearer to Alaska than Honolulu if he made no fixes en route. In 1943 the pilot of a B-24 did just that. Using the

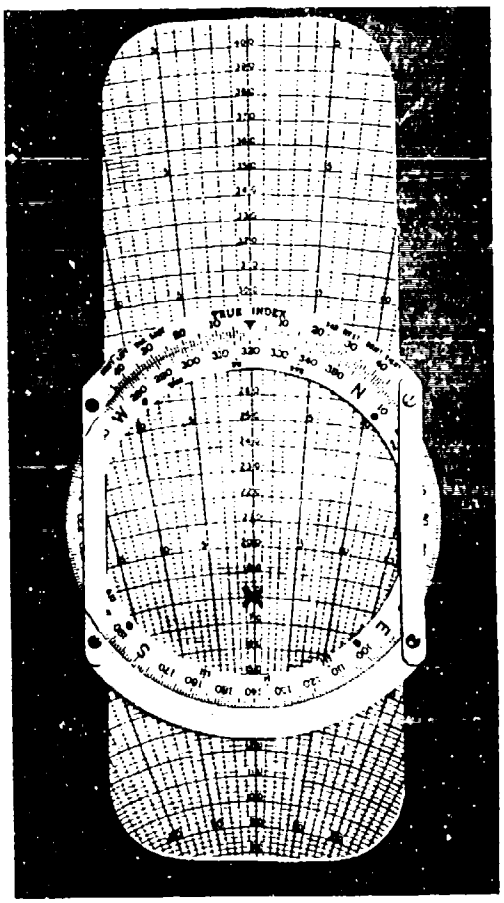


Figure 10-7. Solution for track and ground speed (steps 1 and 2)

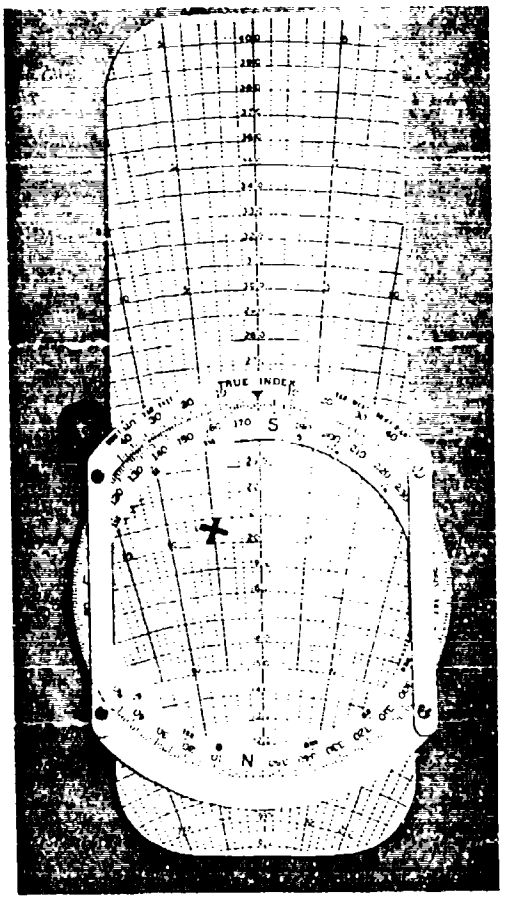


Figure 10-7A. Solution for track and ground speed (steps 3, 4, 5, 6, and 7)

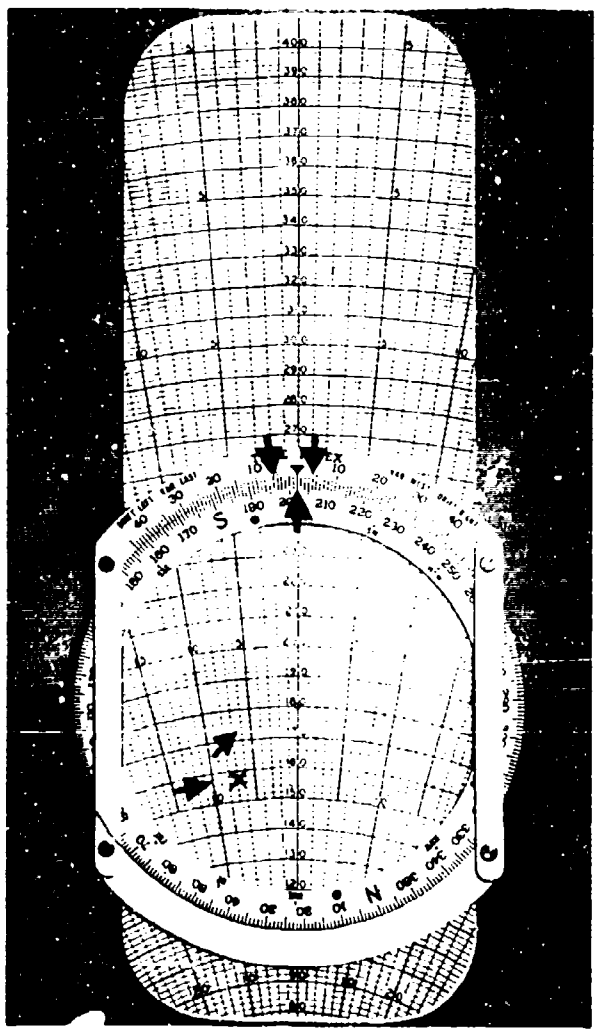


Figure 10–8. Solving for heading and ground speed

variation scale on the computer to change MH to TH or vice versa will eliminate 99% of such errors and will allow you to forget the "Can Dead Men Vote Twice" rule or any plus/minus rules you may have previously struggled with. This is another major advantage in using the computer by Method 1 instead of 2.

Solution for Wind Direction and Speed

The solutions discussed up to now presuppose that you know the wind and could use it preflight or flight calculations. But in many cases, perhaps in most cases, you will not know the wind direction and speed. You must find them from information obtained in flight. If you can determine your position, you will know your track and ground speed. With true heading (compass reading corrected for variation and deviation) and true airspeed (airspeed reading corrected for temperature and pressure), you will have the four elements needed for a wind-vector solution.

As an example, consider a case where you know that the true heading is 118°, the true airspeed is 160 knots, the track is 122° T., and the ground speed is 154 knots. Find the wind direction and speed.

1. *Set the true heading (118°) under the True Index.*

2. *Move the slide until the true airspeed (160) is under the center of the disk.* (See Figure 10-9.)

3. *Without turning the disk, read the drift opposite the track (122° T.). Notice that 122° is opposite 4° Right Drift.*

4. *Locate the track line 4° to the right of the center.*

5. *Along this line, locate the speed circle for 154 knots. Place a mark at the intersection of the track line and the ground speed circle. This is the wind point.*

6. *Rotate the compass rose until the wind vector points* down *along the center line. Read wind direction (58°) at the True Index and wind speed (13 knots) as the length of wind vector.*

SOLUTION FOR WIND SPEED AND GROUND SPEED

Often, in aircraft equipped with a drift sight or bomb sight, you can observe drift angle, and can observe or estimate wind direction. Wind direction is observed on the surface from smoke, waves, or a wind T at some airport en route. If you are within 1,000 feet of the surface, it is safe to apply that as your wind direction, but if you are higher, use a rule of thumb, adding 10° to the direction for each 1,000 feet above the terrain, or adding an amount suggested by upper air charts before takeoff for the route.

Suppose, then, that you have estimated the

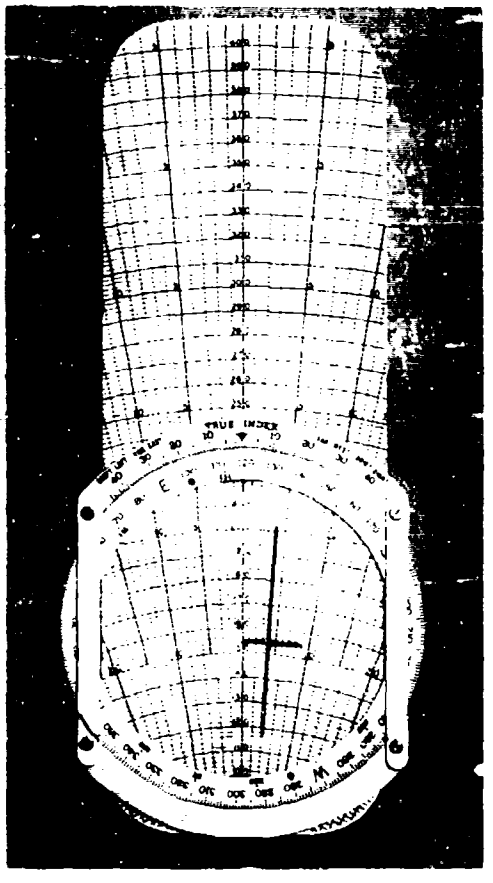


Figure 10–9. Solving for wind direction and speed

wind direction for your altitude as 340°T. and you know that your drift is 5° L., your heading is 260° magnetic, the variation is 5° W., and your true airspeed is 225 kts. Find the wind speed and ground speed as follows:

1. *Rotate the disk to 340° and draw a line down from the grommet for wind direction.*

2. *Set the MH 260° opposite the variation scale at 5° W. (Read TH 255°.)*

3. *Set the TAS, 225, under the grommet.* (See Figure 10–10.)

4. *Draw a short line at drift (5°L.) where it crosses the wind line. Read the track, 250° T. at* ∧ *left on top drift scale. Read the ground speed (224 kts.) where the drift and wind lines intersect.*

5. *Rotate the disk back to the wind direction, 340° T., and read the wind speed 20 kts.*

Another solution for wind, when you know the TAS and headings, is to fly a wind star. The easiest wind star is to turn 60° right or left and hold your heading until you read drift, then turn back 120° in the opposite direction for the same period of time, observing drift again, and then resume your original heading and take drift again on your original heading. Set up each of the three headings on the computer and draw a line for the drift (setting TAS under the grommet, of course). The three drift lines will intersect or form a small triangle. (See Figure 10–11.) The intersection or center of the triangle is the wind point. If the triangle is large, an error has been made. After flying a wind star, add to the ETA the amount of time flown on the first right or left leg. Retard your position on your chart by the distance at original track and ground speed for such time. You have flown two sides of an approximately equilateral triangle, and the extra distance is about equal to the third side of the triangle, as you can see from Figure 10–11. Usually three minutes on each leg is enough.

Use of Method 2

Some pilots prefer to plot wind *up* from the grommet. This requires the use of the center line of the computer for course and ground speed, and the track lines at each side for heading and airspeed. The angle between them is called the wind correction angle. It is the same as drift except that the left and right are interchanged. This method is best for problems in which you have to find a heading and ground speed, so Method 2 is used here for that purpose. The problem is the same one that was solved before by Method 1 so that you can see Method 2 at its best advantage.

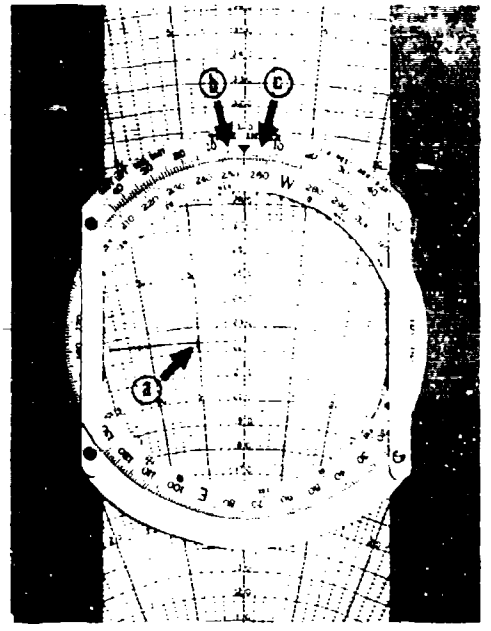
The wind is 240°/30, the course is 195° T., the TAS is 180 kts, and the variation is 4° W. Find the heading, true and magnetic, and the ground speed.

1. *Rotate the disk to wind direction and plot the wind up from the grommet.* (See Figure 10–12.)

2. *Rotate the disk to set the course (195°) at True Index.*

3. *Move the slide until the TAS (180) is under the wind point. Read the wind correction angle, 7° R., which is the same as drift 7° L., at the*

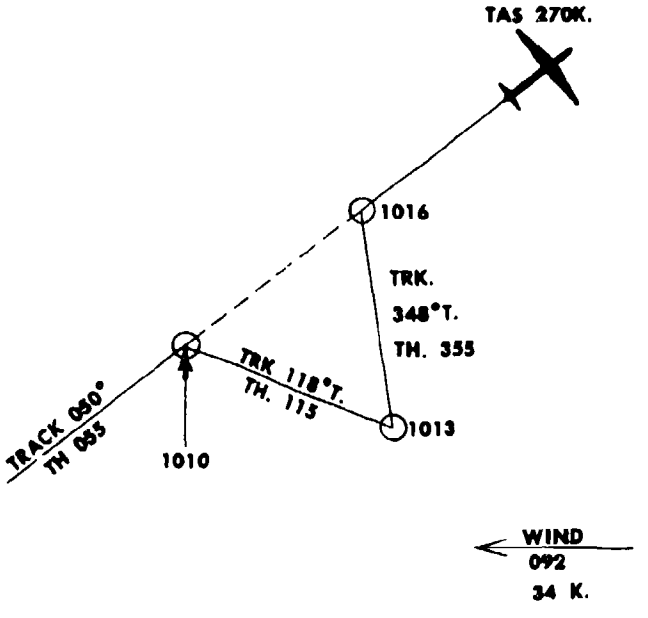
Figure 10-10. Solving for wind speed and ground speed. (A) GS = 224K (B) Track = 250° (C) MH = 260°



wind point. Read the ground speed, 151 knots, at the grommet. Using the drift scale at the top, opposite the wind correction angle of 7° R., find the T. H., 202.

4. *For M. H., either apply the C-D-M-V-T (add West going from True to Magnetic) correction to the T. H. or rotate the disk until the T. H. of 202 is at the true index and read M. H. opposite the variation of 4° W. Either way you get 206° M. H.*

Notice that by Method 2 you reduced the steps because you didn't have to juggle and match drifts in order to find a suitable heading. However, by Method 2, you can't read M. H. directly



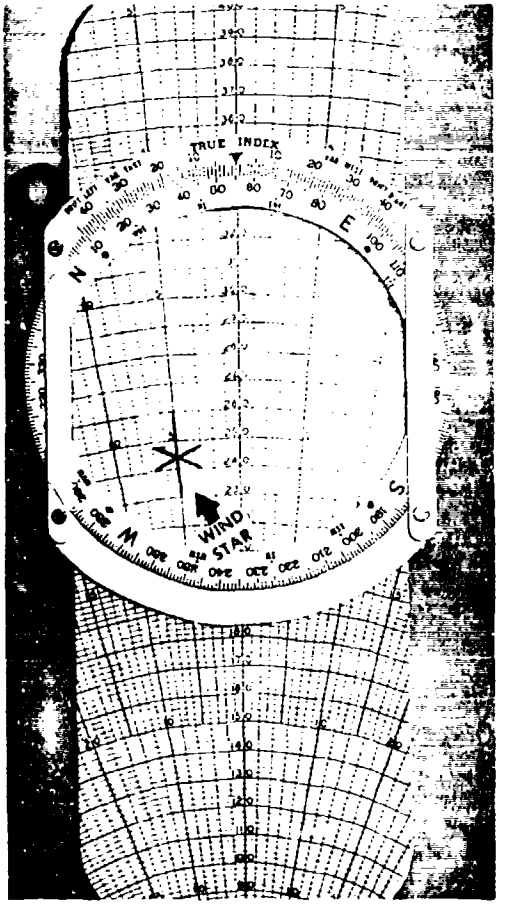


Figure 10-11. Flying the wind star (left). Wind star as it appears on the E6D

without rotating the disk and without using the formulae for variation. Method 2 also introduces the wind-correction angle which may cause confusion.

Use of Method 3

Method 3 is the same as the basic, standard Method 1, except that all directions are plotted in magnetic. This is mainly useful in Continental North America where charts and radio facilities are indicated in magnetic. The only conversion is wind direction. Method 4 is the same as 3, except that the wind is plotted *up* and other features are as in Method 2, but the directions are all magnetic.

To repeat the previous problem, but using Method 3, assume again that:

Wind: 240° T./30 kts.
Desired Course: 199° *Magnetic.*
T. A. S.: 180 kts.
Variation: 4° W.

Find the magnetic heading and ground speed.

1. *Set the true wind direction opposite the True Index and read the magnetic wind (244) on the variation scale at 4° W.*

2. *Rotate the disk slightly to put the magnetic wind, 244, at the True Index. Plot the wind* down *30 kts. from the grommet and mark the wind point.*

3. *Set the slide so that the TAS, 180, is under the grommet.*

4. *Rotate the disk to put the magnetic course (199) under the True Index and observe the approximate drift, 7½° L.*

5. *Rotate the disk to put the magnetic course (199) under the approximate drift on the top drift scale, and check the actual drift that results. Juggle the disk until the drift at the top opposite M. C. (199) is the same as the drift shown by the wind point. Then read the M. H. at the True Index, 206, and the ground speed, 157, at the wind point.*

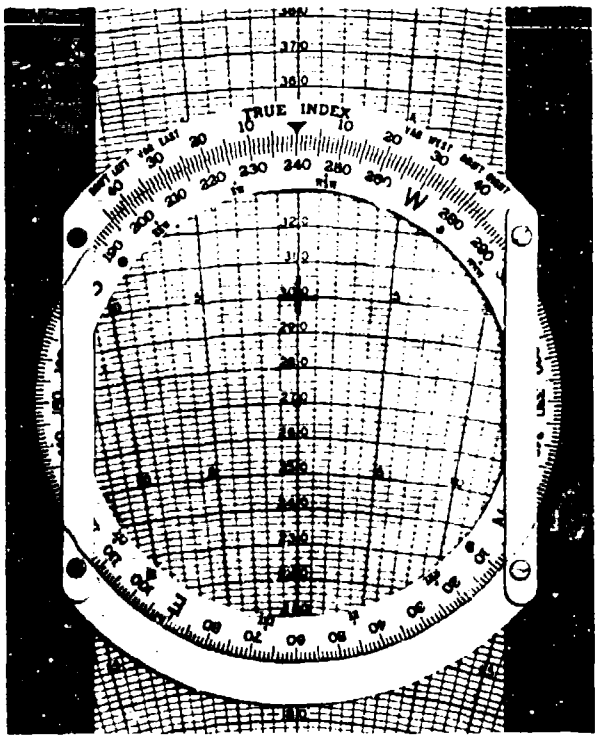


Figure 10–12. Solving for heading and ground speed by Method 2 (steps 1 and 2)

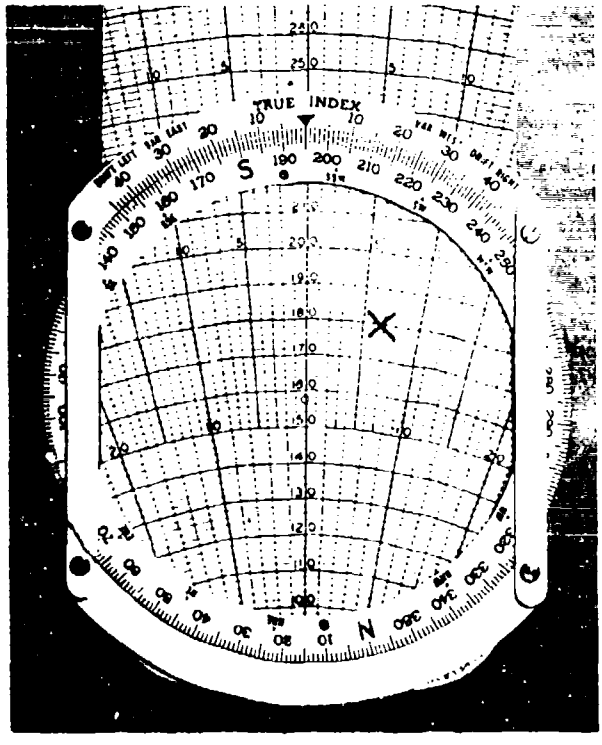


Figure 10–12A. Solving for heading and ground speed by Method 2 (steps 2 and 3)

Notice that the same problem was solved by Methods 1, 2, and 3, and the same answers resulted: M. H. 206°, G. S. 157 kts., Drift 7° L. If Method 4 were used, the same answers would be obtained.

SOLVING RADIUS OF ACTION

Radius of action is the greatest distance an aircraft can fly along a certain course, under given conditions of wind, true airspeed, and fuel consumption, and return to the same base. The solution of this type of problem, requiring the use of both sides of the computer, is broken down into two steps:

1. *Wind-vector solution*, which computes the true heading and ground speed outbound and inbound; and

2. *Radius-of-action proportion*, which computes time to turn and the radius-of-action distance.

As an example, consider a situation in which you know the following:

True course out: 45°.
True airspeed: 360 kts.
Fuel supply: 3 hrs., plus reserve.
Wind direction: 345°.
Wind velocity: 50 kts.
Variation: 10° E.

You then have to find:

Heading and ground speed outbound.
Head and ground speed inbound.
Time to turn.
Radius of action distance.

1. *Place the wind direction (345°) on the rotating scale opposite the True Index.*

2. *Measure the wind velocity (50 kts.) on the sliding scale down from the grommet.*

3. *Place the true course (45°) on the rotating scale opposite the True Index.*

4. *Set the TAS (360 kts.) under the grommet. Note the drift which would result if the course were your heading (7° plus, to the right).*

5. *Set the desired course (45°) at 7° R. drift on the scale at the top and compare the actual drift. Since the drift to make good that course and the drift resulting on that heading are both 7° R., you may now read T. H. outbound (38°) at the True Index and read ground speed (332 knots) at the wind point.*

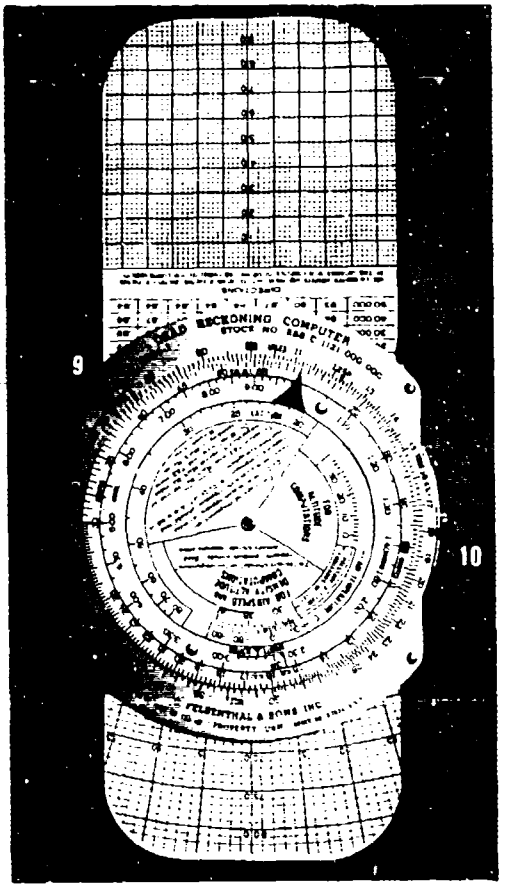


Figure 10–13. Solving for radius of action

6. *At the top of the computer opposite the variation (10° E.) read the M. H. outbound, 28°.*

7. *Place the true course inbound (225°), the reciprocal of the outbound course, opposite 7° left drift. (On a reciprocal heading the drift will be opposite in direction, and this saves one step). Check the actual drift. Since it is 7° L., no juggling is necessary to determine heading. In this operation, keep TAS set at 360 knots.*

8. *Read the ground speed inbound (382 kts.) at the wind point; read the T. H. (242° T.) at the True Index; and read the magnetic heading (232° M.) opposite the variation of 10° E. at the top of the computer.*

This completes the solution of ground speed

and true heading, outbound and inbound. You solve the remainder of the problem on the slide-rule side of the computer in the following steps:

9. *Place the ground speed inbound (382) on the inner scale opposite the total of ground speed outbound plus inbound (332+382=714) on the outer scale.* (See Figure 10-13.)

10. *The fuel supply provides a total available flight time of 3 hours, or 180 minutes. Opposite 180 on the outer scale, read time to turn, 96 min. or 1 hr 36 min., off the inner scale. You now know that you can fly out for 1 hr 36 min. before you must turn back, but you don't know the distance.*

11. *Set the rate arrow (speed pointer) at the ground speed outbound (332 kts) and on the inner scale opposite the time allowed for outbound flight (96 min. or 1 hr. 36 min.) read the miles off the outer scale, 529 miles. This is your radius of action.*

SOLVING FOR FLIGHT TO MOVING BASE

Flying to a moving base, such as a carrier, or intercepting a moving target involves the solution of problems of relative motion. Such problems can be solved on the computer by use of the rectangular grid. This grid permits speeds of motion for the destination of up to 50 or 100 knots, depending on direction and location of the wind point. If the destination speed is too great, you can use 50% of all speed readings while working on the wind face, and then double the speed answers after you finish.

As an example, consider a situation where you have the following information:

Ship: Course 200° T. at 24 kts.

TAS: 180 kts.

True Bearing of Ship at Time of Turn: 171°.

Distance to Ship at Time of Turn: 170 mi.

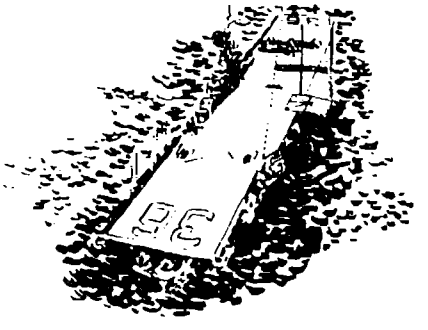
Note: The true bearing of the ship may be determined by plotting it on a chart for a future time of turn. This would usually be based on a radio message or predetermined data on its position and speed. If it is determined by Tacan, and the aircraft has no proper chart or navigation gear, turn to home on the ship after determining the bearing. Then work out on your computer a relative-motion problem based on that bearing and a distance which you will be from the ship at about the time you have worked the computer problem. The magnetic bearing which is obtained from Tacan or other RMI indicators may be simply converted to true during the process without calculations. You do this on the computer by setting the magnetic bearing against the variation scale and reading true bearing at the index. The true bearing of the ship is called "direction of relative motion," and the distance to the ship "miles of relative motion," DRM and MRM respectively.

1. *Plot in your wind as usual (100°/32kt). Mark this point "Wind" or whatever you like.* (Don't plot wind on the high-speed side of the slide for relative-motion problems. Use the slow-speed range scale or the rectangular grid part of the slide.)

2. *Insert the rectangular grid side of the computer slide under the translucent disk.*

3. *From the wind point determined in step #1, plot the ship's course and speed. In this case, rotate the plotting disk until 200° is at the index, and measure 24 knots vertically down from the wind point. Mark this point "S" or whatever will distinguish it.*

4. *Set TAS under the grommet, reversing the slide in this case in order to do so.*



5. *Set the true bearing (171° T.) of the ship at the True Index (or magnetic bearing at the proper point on variation scale for the area).*

6. *Observe preliminary drift (6° R.), and adjust and juggle until the point "S" (ship course and speed drawn from wind point) indicates the same relative drift as is shown on the top drift scale opposite the DRM (171°). In this case, you*

will find it to be 5° R. (This is not actual drift. You will read actual drift later at the wind point.)

7. Read off the data: At point S speed of relative motion, 148 kts. At the wind point read ground speed, 170 kts, and drift, 9° R. At True Index read T. H. 166 (at proper variation read M. H.). At 9° right drift, read Track, 175° T.

8. Obtain minutes to intercept ship by determining MRM (170 mi.) at SRM (speed or relative motion, previously found to be 148 kts). Place the speed index at 148 on the slide rule face, and read the answer, 69, off the inner scale opposite 17 miles on the outer scale.

9. Obtain distance to intercept by finding out how far you will fly in the 69 min. Set ground speed (170) at the speed index, and at 69 min. time to intercept, read off the outer miles scale 196 miles. If you have no chart on which to plot positions, you can omit this step.

PERFORMANCE CALCULATIONS

The material in this section does not relate strictly to instrument flight, but to flight planning for any sort of flight, especially cross country. Weight and balance is precomputed for single-place aircraft so that the only difference is caused by fuel and armament. Standard load tabulations eliminate the need for the pilot to compute this. In multi-place aircraft, each individual flight must be checked to establish whether the load limits and center of gravity are within safe limits.

Cruise control, on the other hand, is vitally important to jet aircraft on every flight, and on conventional aircraft in longer flights. Calculators and tables provide data for both cruise control and weight and balance.

The theory of aircraft weight and balance is extremely simple. You can see its application in the old familiar steelyard scale which is in equilibrium or balance when it rests on the fulcrum in a level position. The influence of weight, of course, depends directly on its distance from the fulcrum. For equilibrium or balance, the weight must be distributed so that the turning effect is the same on one side of the fulcrum as on the other. Therefore, a heavy weight near the fulcrum has the same effect as a lighter weight farther out on the bar. (See Figure 10-14.) The scale is in balance only when the horizontal center of gravity (CG) is at one location, the fulcrum.

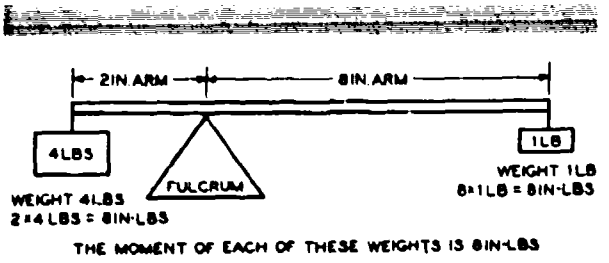


Figure 10-14. Principles of balance

Unlike a scale, an airplane can be balanced in flight with the CG anywhere within the specified fore-and-aft limits by operation of trim tabs or elevators. CG locations outside the specified limits result in unsatisfactory or dangerous flight characteristics. The allowable variation is called the CG limits; its exact location, which is always near the forward part of the wing, is specified for each aircraft model. Obtaining this balance is simply a matter of distributing the load so that the CG of the loaded aircraft falls within the allowable range. Heavy loads near the wing location can be balanced by much lighter loads at the nose or tail of the airplane. The moments of the loads determine this exactly.

In practice, it has been found desirable to measure all distances from an arbitrary reference datum at or near the nose of the airplane. Measuring all arms in the same direction makes all moments positive and eliminates possible errors in adding plus and minus moments. When the total moment about this reference datum is divided by the total weight, the resulting arm is the distance to the center of balance, or CG, from the reference datum. If the CG falls within the specified limits, the loading is satisfactory; otherwise, the load must be shifted until the CG falls within the limits. The allowable CG range is determined by calculations and flight test. Limits are usually expressed as a percentage of the mean aerodynamic chord or in inches from the reference datum.

To obtain the gross weight and the corresponding CG location for the loaded airplane, it is necessary to know first the basic weight and

corresponding CG location of the unloaded airplane. This may be found by weighing the basic airplane. When the weight, arm, and moment of the basic airplane is known, it is not difficult to compute the effect of fuel, crew, cargo, armament, and other weights as they are added. The CG of the loaded airplane is established by adding all the moments of these additional items to the basic moment of the airplane and dividing this total moment by the sum of the basic weight and the sum of these additional items. The calculation may be performed by arithmetic, loading graphs, or a balance computer.

Definitions

The following definitions will serve as standardized terminology for all data in the practical application of weight and balance. It is important to know them thoroughly.

Basic Weight—the weight of an airplane including all operating equipment that has a fixed location and is actually present in the airplane; that is, airframe, powerplant and accessories, trapped fuel and oil, full hydraulic cooling and anti-icing fluid systems and reservoirs, armor plate, ordnance (less ammunition and bombs), and chemical, navigation, oxygen, pyrotechnics, and radio equipment.

Gross Weight—the total weight of an airplane and its contents.

Reference Datum—an arbitrary point at or near the nose of the airplane from which all horizontal distances are measured for balance purposes. Diagrams of each airplane show this reference datum as balance zero station.

Arm—for balance purposes, the horizontal distance in inches from the reference datum to the CG of the item.

Moment—the weight of an item, multiplied by its arm. The moment divided by a constant is generally used to simplify balance calculations by reducing the number of digits. In most handbooks, moment divided by 1000 has been made standard practice.

Center of Gravity—CG, the point about which an aircraft would balance if suspended. Its distance from the reference datum is found by dividing the total moment by the gross weight of the airplane.

CG Limits—the range of movement which the CG can have without making the aircraft unsafe to fly. The CG of the loaded aircraft must be within these limits at take-off, in the air, and on landing. In some cases, take-off and landing limits may also be specified.

Balance Computer Index—a simple reference that is mathematically related to the center of gravity grid which appears on the inside of the load adjuster.

Mean Aerodynamic Chord—the chord of an imaginary airfoil which, throughout the flight range, would have vectors identical with those of the actual wing. It is often referred to as MAC. Determining the exact length and location of the MAC is a complex process involving many variables. The MAC is determined by the manufacturer and included in the technical literature. In the case of most aircraft (but not helicopters), GC limits are stated and determined in percent of MAC. In Figure 10-15, the TV-2 appears approximately as it is shown in the weight-and-balance sheets for that model aircraft. You will see the MAC shown at the top and the allowable limits in percentages of MAC at the bottom.

1A-01-1B-40—the general designation of the *Handbook of Weight and Balance Data*. Besides general instructions, blank chart forms are provided. This book plus the specialized instructions for each aircraft model form the bible of loading each aircraft. A separate set of charts is made and kept for each individual airplane.

HOW TO COMPUTE WEIGHT AND BALANCE

There are three ways to determine a safe load and the location of CG for your flight.

1. Load according to Form NAVAER 2300, Authorized Standard Loadings, which is prepared in advance by the weight-and-balance officer. This is authorized for Class 1B aircraft. Class 1A aircraft require no weight-and-balance control, provided that no loads are carried other than those for which provision is made in the structure of the plane.

2. Compute CG on the Load Adjuster ("slip stick"), and prepare Form DD-365F, Weight-and-

Balance Clearance Form. Class 2 aircraft are required to file a DD-365F with every flight clearance DD-175.

3. Compute CG from the charts in AN-01-1B 40 for your aircraft, and prepare Form DD-365F. This last system is necessary when no load adjuster is provided for your aircraft. Load adjusters are provided for transport aircraft and those with a critical CG range, and apply only to the specific airplane for which they are made.

The Load Adjuster or Balance Computer

The colored top strip of the load adjuster is the guide to a safe loading. The yellow sections indicate further restrictions to prevent exceeding the most forward and most aft limits at landing. Flight in the yellow caution area is not permitted under instrument or night conditions.

The movement of the indicator translates the change in balance position as load is added or expended in terms of the INDEX SCALE which appears on the bottom of the rule. This index scale is merely a simple reference that is mathematically related to the center-of-gravity grid which appears on the inside of the load adjuster.

The CENTER-OF-GRAVITY GRID on the inside of the rule is the basis on which the load adjuster is designed. The forward and aft red sections show the CG limits in terms of percent MAC (mean aerodynamic chord), and it is from these limits that the top strip of the load adjuster is derived. The CG position in terms of percent MAC and inches from the reference datum may be read directly from the CENTER-OF-GRAVITY GRID.

All loading calculations start with the hairline of the indicator over the basic index. From there on it takes only two operations to load each of the totals shown on the Form DD 365F. The first step is to move the slide until the "0" vertical starting line of the scale involved is under the hairline. The next step is to move the indicator until the hairline is over the weight that is to be added. You then read the new index under the hairline on the index scale at the bottom of the rule. Repeat these two operations for each loading total that appears on the Form DD 365F.

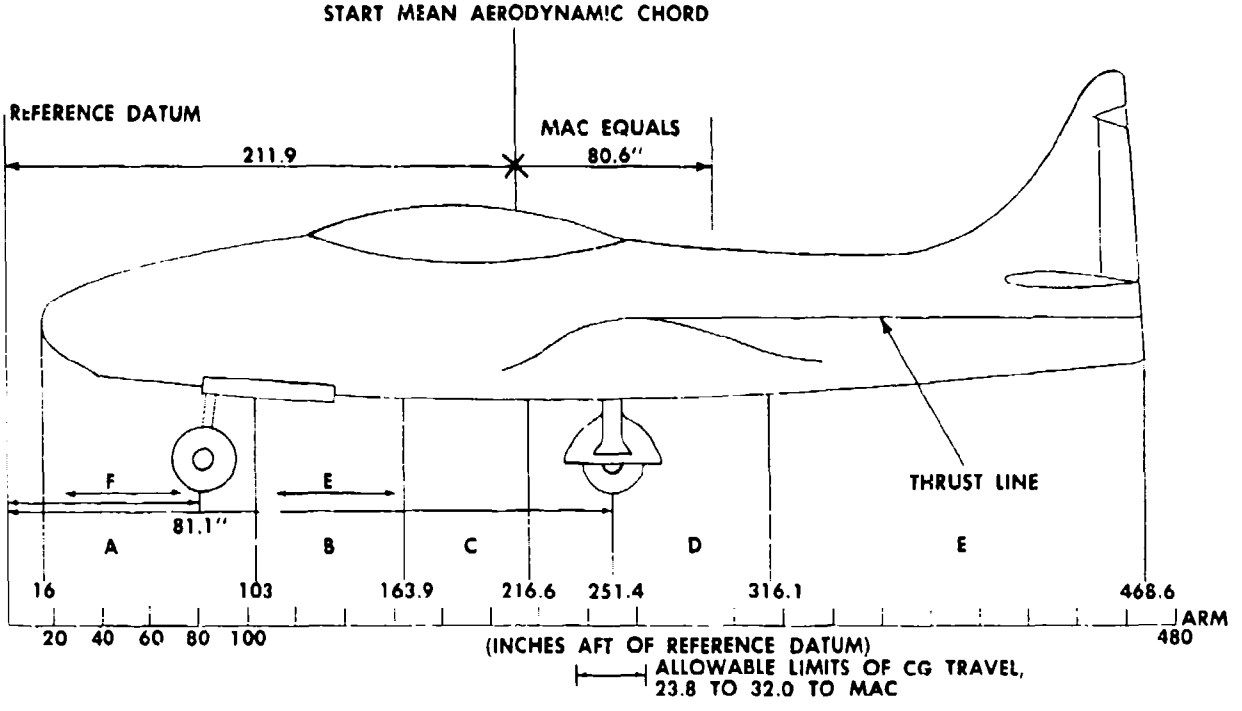


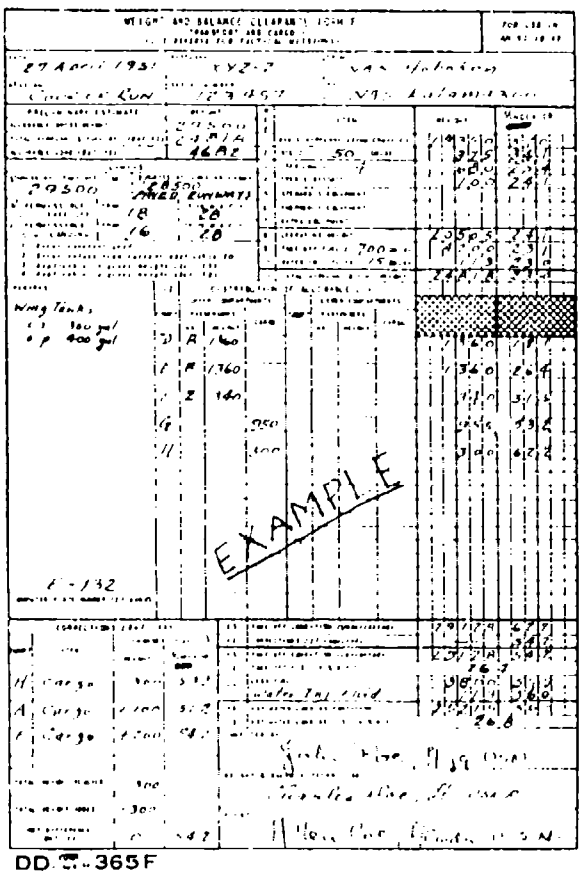
Figure 10-15. TV-2 weight and balance

Make the computations in the order that the items appear on the Form DD 365F and enter the resulting index reading in the next index column.

When moving the slide, be sure that you do not move the indicator; and when moving the indicator to add your totals, see that the slide remains in position.

USE OF WEIGHT AND BALANCE CHARTS

The DD-365 chart forms come in series, and one series is made up for each individual airplane. Chart A (DD 365A) gives the weight, moment 1000 (or 100), and arm for each item of equipment or accessory by compartment. It provides a continuous record of what is or is not in the airplane. Chart B is a weighing record, in which the final result is the weight, arm, and moment of the basic airplane without accessories. Chart C, filled out by maintenance or O & R shops, carries the total weight and moment of the basic airplane forward as accessories are added or removed. The last entry of this chart is the first item in the charts used by the pilot.



DD FORM 365F

Figure 10-16. Weight and balance form, transport and cargo version

You take the weight, moment, index from this entry on Chart C for the first item on Form DD 365F, the clearance form. You use the index when using the load adjuster, but you use the moment when using the charts. Chart E provides the moment for different cargo and passenger weights in the various compartments, for fuel and oil by tank location, and for various armament loadings. Look up in Chart E the moments for the various items in your aircraft and enter them on DD-365F in the appropriate boxes, adding or subtracting in the 1/INDEX column in accordance with their location in the aircraft. You also add the weights of the items to get the total weight at take-off.

The total weight must not exceed the recommended maximums shown in Chart E for take-off. The moment at take-off must be within the forward and aft limits shown in Chart E for take-off gross weight. If the weight is too much or if the moment does not fall within the proper range, make corrections in the space provided on Form DD 365F to arrive at new totals which are within acceptable limits. Chart E has a table of gross weights showing the forward and aft limits of moment for units of weight; compare the actual weight and moment to these, interpolating as necessary. After computation, the Form DD-365F must be checked by a weight and balance officer before clearance. Usually this officer will assist you in preparing the Form DD 365F if desired.

Form DD-365F

Form DD-365F, the weight and balance clearance, comes in two versions: "Transport and Cargo" and "Tactical."

For a balance computer or a load graph to be used satisfactorily, the total of the variable

loads in each compartment must be known. On Form DD-365F they must be tabulated.

Form DD-365F is the summary of the actual disposition of load in the aircraft. It records the balance status of the aircraft step by step. It is necessary to accomplish Form DD-365F before flight whenever an aircraft is loaded in a manner for which no previous tabulation is available or, in the case of Class 2 aircraft, if the previous tabulation is more than 90 days old. Look over the sample Forms DD-365F shown in Figures 10-16 and 10-17. One is the transport version and the other the tactical version.

CRUISE CONTROL

In long-range transport aircraft and in jet aircraft, it is essential to regulate the fuel consumption and to make sure that fuel is not being used too fast. This general subject is called cruise control. Cruise control is affected by such factors as aircraft configuration, gross weight, altitude, engine performance, power control, temperature, and so on. The pilot must make a choice before takeoff of the gross weight, fuel carried, and altitude. He must compute from this data the rate of fuel consumption so that he knows the amount of fuel at destination in order to have adequate reserves. In jet aircraft, this computation must be in considerable detail because the pilot has neither the working space nor the time to do elaborate recomputation in flight. The jet uses fuel so fast, especially at low altitudes, that failure to plan this aspect of flight would often result in fuel exhaustion.

A study of cruise control involves power settings, optimum operating altitudes and other considerations which are not within the province of this manual. The details of cruise control can be found in the Pilot's Operating Handbook for your airplane.

With respect to fuel consumption, transport aircraft use the "howgozit" chart to keep track of their progress. Before take-off, a line is drawn to show anticipated fuel consumption per hour. In flight, another line is drawn in another color to show actual fuel used per hour. If more fuel is used than was anticipated, faster speed may have been obtained. For that reason if faster or slower

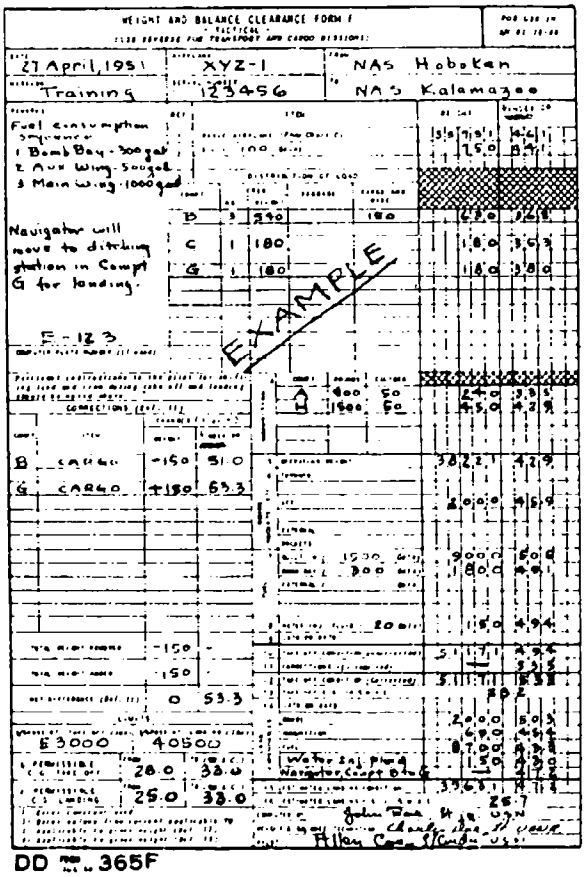


Figure 10-17. Weight and balance form, tactical version

speed is obtained, the actual fuel-used line is adjusted by the number of minutes the aircraft is ahead of or behind the scheduled position at certain check points. This adjusted line is compared with the predicted consumption line to determine whether the flight is in danger of fuel exhaustion.

On any trip, there is a point where it will take the same time to continue to destination or return to origin. The location of this point depends upon wind direction and velocity. This point is called Equitime Point (or Point of No Return). The distance to it is figured by determining the following on the computer, using forecast wind.

1. GS outbound (GSo), all engines working, to the halfway point.

2. GS returning (GSr), with one engine inoperative, based on optimum range airspeed and altitude, from the halfway point.

3. GS continuing (GSc), with one engine out from halfway point.

The distance to ETP (equitime point) is then:

$$\frac{\text{Total Dist. of Flight} \times \text{GSr}}{\text{GSr} + \text{GSc}}$$

The time to ETP is the distance to ETP at GSo, figured on the computer. This time is shown on the "howgozit" chart. As the aircraft approaches ETP, the decision must be made whether it is safe, so far as fuel consumption is concerned, to continue to destination.

The arrangement of a "howgozit" chart could take many forms, depending upon the type of aircraft for which the chart is prepared and the nature of its routes. No particular arrangement is recommended here.

Figure 10-18. REST computer for the TV-2 airplane

Jet Performance Calculators

For jet aircraft, two calculators or computers are used to determine fuel range before and during flight. One—called the REST computer—is used for straight-and-level flight; the other—the Climb and Descent Tabulator—is used for climbing and letting down. Usually these two cruise-control tools appear on the reverse sides of the same device, which is a conventional circular plastic computer. Check your computer to make sure it is the appropriate one for your airplane and its type of fuel.

REST Computer

The large disk of the REST computer consists of CAS to TAS conversions at various altitudes, maximum-endurance IAS (CAS) indexes, and a circular time scale divided into hours and minutes. (See Fig. 10-18.) The medium disk, which rotates relative to the large one, has a nautical mile-to-speed scale relative to the time on the large disk. The smallest disk has a scale of fuel quantities in gallons (or pounds; check which one in your case), and windows (often colored) for various altitude ranges with and without external tanks. Underneath these windows are Indicated Airspeeds—from maximum-range IAS (farthest to the right) to maximum-continuous IAS (farthest to the left). The encircled dot is a definite indicated airspeed for all altitudes, which will give maximum endurance. A transparent rotating arm contains an index line used in taking readings.

To determine fuel to be consumed for a selected IAS for a given time at the desired cruise altitude, set the index line over the desired IAS in the proper altitude-configuration box on the small disk, and over the corresponding maximum endurance IAS index of the large disk. Convert IAS to TAS by use of the conversion table on the large disk. Place this TAS on the miles scale of the medium disk opposite the 60 index on the minutes scale of the large disk. Now the fuel, time, and miles ratio is properly aligned. By holding the disks in this position and rotating the index arm to the given time, you can read the minutes of flight time available and the miles you will cover in a no-wind condition.

This procedure is based on the following: the first setting of the small disk establishes a fuel consumption rate for a certain altitude, external tank condition, and altitude. Setting the large disk relates this fuel consumption to time. The conversion to TAS and the setting of that TAS

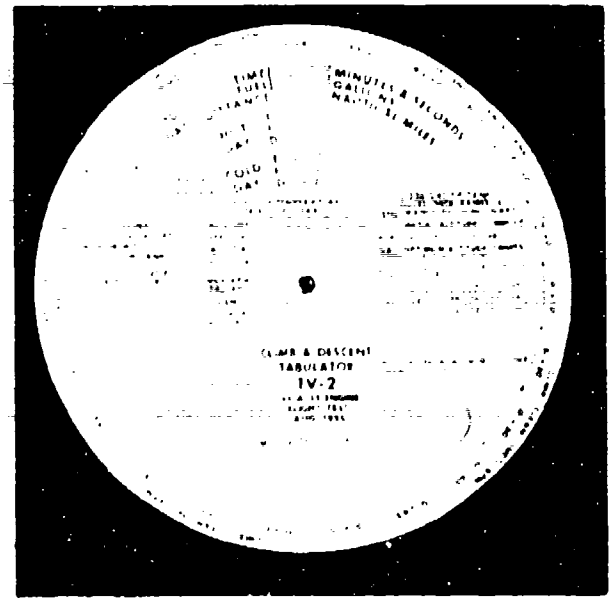


Figure 10–19. Climb and descent tabulator

at the speed index (60 min) serve to establish on the medium disk the relation between the rate of consumption, in time, and the miles covered.

To determine maximum endurance fuel, figure an airspeed of approximately 200 knots. (That is close enough to the maximum endurance airspeed and the aircraft is more comfortable to fly at that airspeed.)

Wind effect upon ground speed may be determined either before take-off from forecast winds, or in flight from observed ground speeds. After setting up the fuel/time ratio on the REST computer, rotate the medium disk so that the ground speed appears where you have otherwise set TAS against the speed index. The miles-*es*-minutes ratio is now corrected for wind. This is entirely unnecessary on flights from a base out-and-back because a wind which provides a headwind on one leg will provide a tailwind on the other leg. In the case of cross-country flights to another base, however, if there are high winds, wind effect should be considered both in preflight planning and again later in flight after actual ground speed is known. Wind effect correction is not normally made when the wind is only 30–40 knots.

Even experienced pilots sometimes use the wrong altitude-configuration window on the REST computer. Do not rely on a color code or other device to remember the proper window; read the altitude-configuration designation each time to be certain.

Climb and Descent Tabulators

The Climb and Descent Tabulator is usually provided on the back of the REST computer. The outer scales are marked to show whether they are for climb or descent and the configuration to which they apply (Fig. 10–19). Climbs and descents are computed for a standard day plus 15° C. A standard day is used here to mean a day when the temperature is the same as the temperature in a standard atmosphere, shown in Figure 10–21. As you can see from this table, a standard day at or near sea level means a temperature of 15° C, with the lapse rate about 2° C per 1,000 feet up to 35,000 feet.

In effect, then, this computer has three temperature settings which are equivalent to a hot day, a normal to cool day, and a cold day. Set the proper temperature index below the altitude to or from which you plan to climb or descend on the appropriate outer scale. Time, fuel, and distance covered for the climb or descent will appear in windows so marked. In addition, the climb and descent tabulator has a schedule for climb and another for descent, showing airspeeds for different altitudes. The indications of the tabulator are based on operation at those particular airspeeds.

SUMMARY

For every flight which is more than a short, local hop, there must be at least an hour of flight planning. This means more than just planning the route, obtaining weather, and preparing a clearance. It is equally important that you determine that the gross weight on take-off is not in excess of limits, that the take-off run at that weight (based on the density altitude of the airport) is within runway limits, that the load is properly distributed for balance, and that there is enough fuel aboard to make the trip plus an adequate reserve. The rapid fuel consumption of jets requires careful attention to this point and computations on the REST computer and on the Climb and Descent Tabulater.

CHAPTER 11

PUBLICATIONS

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2. Radio Facility Charts (Radfacs) 11-2
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   b. VOR System of Airway (Blue-Print Edition) 11-3
   c. Minimum en Route Instrument Altitudes .. 11-4

3. Supplementary Flight Information Document 11-5

4. Naval Airways Pilot (H. O. 510) 11-6

5. USAF-USN Instrument Approach Procedure Charts 11-6

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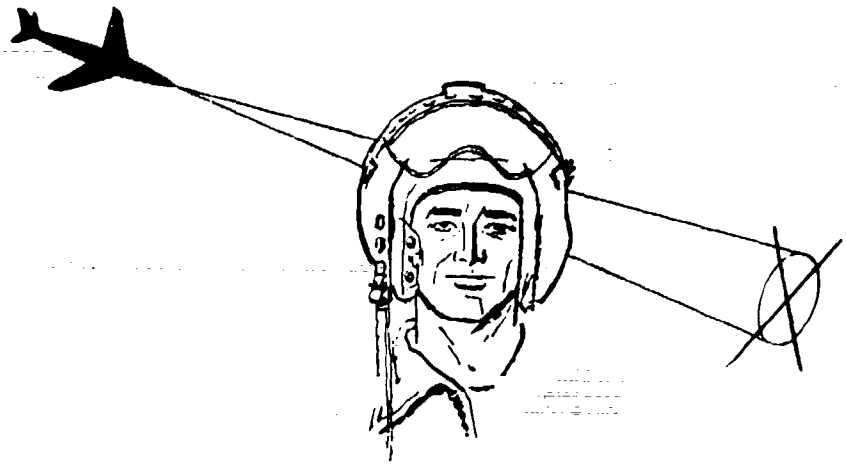

CHAPTER 11

PUBLICATIONS

AN essential part of flight planning involves the use of applicable publications, which are provided for the pilot in Operations. Some of these publications are also carried in the airplane for use during flight. Routes, altitudes, fuel stops, destinations, and alternates are determined from aeronautical charts, Radio Facility Charts, and NOTAMS. From these a flight plan is prepared. Other publications provide helpful information of many kinds. The US Air Force-US Navy *Instrument Approach Procedure Charts* for both high and low altitude, compiled in a small book sometimes called the "Pilot's Handbook," for example, provide information on approaches and letdowns. To avoid mistakes and to acquire greater speed in flight planning, you should be thoroughly familiar with the publications involved in flight planning and flight execution.

PUBLICATIONS AVAILABLE

Here are the publications which the Flight Planning Section of each naval air station must keep on hand for the use of pilots in a place near the Operations and Aerology Offices. Publications in the list below which are marked with an asterisk are discussed in greater detail later in this chapter. For further information on these publications, see the *Catalogue of Aeronautical Charts and Publications*, H. O. I-V(R).

1. Directory U. S. N. A. F. and N. A. F. Outside Continental U. S., H. O. Publ. D-501.

2. Directory U. S. N. A. S. and N. A. F., Continental U. S., H. O. Publ. D-502.

*3. USAF-USN *Instrument Approach Procedure Charts* ("Pilot's Handbook")—ILS, VOR, and Tacan books, Landplane Series (high and low altitudes), and Seaplane Series.

*4. *Naval Airways Pilot*, H. O. 501 series ("Jeppeson").

*5. Radio Facility Charts Series.

*6. Supplementary Flight Information Document.

7. Notice to Aviators.

*8. NOTAMS (Notices to Airmen).

9. Memorandum for Aviators.

10. Air Almanac and Astronomical Tables.

11. Standard navigation and communication reference books.

12. Copies of local regulations governing field operations.

13. Flight Clearance Forms, DD-175.

14. Navigator's Log Forms.

In addition to these, you will find W. A. C. charts, a master danger area map, a large flight planning chart for cross-country flights, and other aids at or near the Operations and Aerology Offices.

RADIO FACILITY CHARTS

The title, *Radio Facility Charts* (or, in abbrevation, Radfacs or Rafacs) is a general title for a series of ten booklets which provide information on radio and radar aids to the aviator in various regions of the world. Two of these, familiar to all pilots, concern the United States area: *Radio Facility Charts* United States LF/MF Edition (black print), and VOR Edition (blue print). The others, concerning areas outside the continental U. S., are discussed later under the heading of Foreign Navigational Aids.

With the exception of two areas, Africa-Middle East and Australia-New Zealand, the printing of the *Radio Facility Charts* is done by the Aeronautical Chart and Information Center. Africa-Middle East is printed by the British Government and Australia-New Zealand is printed by the New Zealand government. The contents and corrections of these books are handled through all of the armed forces. In the case of the Navy, the Division of Air Navigation of the Navy Hydrographic Office is cognizant. The U. S. editions are revised and reissued every two weeks. The other editions appear periodically. Be sure you consult the current edition.

In addition to the chart and radio facility tables, Radfacs also contains valuable information on homing and radar assistance services, voice procedures, warning areas, ILS, GCA, and many other items of useful information.

Perhaps the most useful single item in each issue is the "Special Notices" section. These notices "flag" important changes on their first appearance. For this reason you should try to see every single issue as it appears. For instance, the doctrine for position reports and in-flight weather reports is often changed. Immediately after a change, the change is listed as a "Special Notice." Some of these "Special Notices" are later incorporated in the appropriate section, while others appear later as changes in other books, such as the Supplementary Flight Information Document.

Remember, though, that the Radfacs books are not infallible. It is important for commanding officers and individuals to report any discrepancies which come to their attention.

Abbreviations and symbols are used widely in the Radio Facility Charts, but none are used without explanation of their meaning. Learn the primary abbreviations and symbols, and look up any you do not know when you see them.

LF/MF System of Airways (Black-Print Edition)

The low and medium frequency system of airways is designated on the chart pages by number and color. Green and Red airways are plotted east and west. Amber and Blue airways are plotted north and south. Pilots proposing IFR flight along controlled civil airways should indicate in their flight plans the even or odd thousand-feet altitude above seal level they intend to fly, depending on the direction of flight. Generally, on Green and Red airways, eastbound flights should be conducted at odd thousand-foot levels, westbound at even thousand-foot levels; on Amber and Blue airways northbound flights should be conducted at odd thousand-foot levels, southbound at even thousand-foot levels. (See Figure 11-1.)

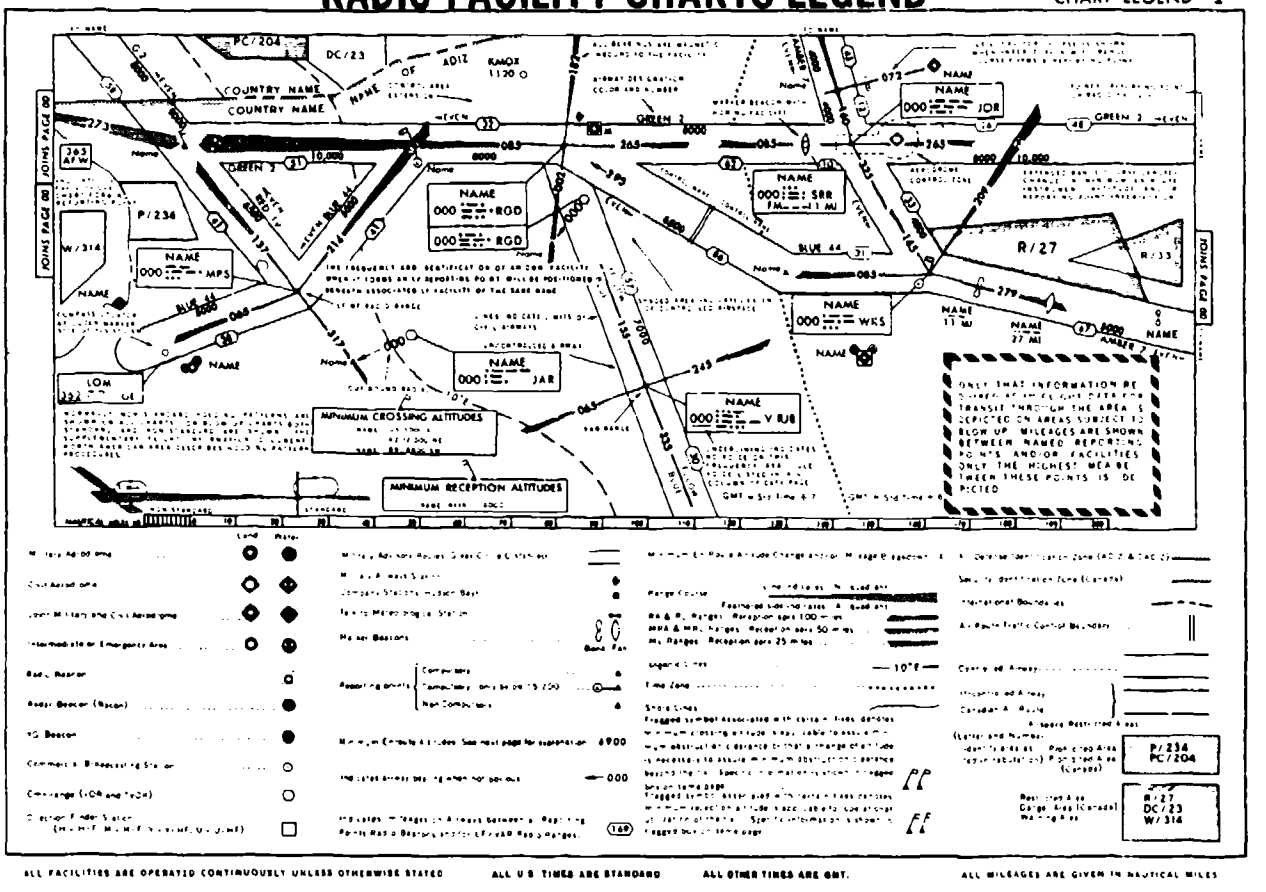

Figure 11–1. Radio facility Charts Legend—LF/MF

VOR System of Airways (Blue-Print Edition)

The VHF omnirange airways system as shown in the Radio Facility Charts consists of "main" airways and "alternate" airways ten statute miles (or 8.7 nautical miles) in width. (See Figure 11–2.) Main airways normally are designated on a straight line between successive omnirange stations. Alternate airways are laid out on the side of the main airway, usually departing from the main airway at an omnirange station at an angle of at least 15° and returning at an angle of at least 15° at the new omnirange station. Alternate airways are designated primarily for the purpose of establishing lateral separation between aircraft operating on IFR flight plans, when traffic conditions on the particular airways segment necessitate such action by Air Traffic Control. Lateral separation of this type is not used, however, within 15 miles of an omnirange station. Within a radius of 15 miles from the station where courses converge, ATC uses altitude or time separation.

VOR airways are numbered in a way similar to the numbering of U. S. highways. Airways which run generally north and south have odd numbers, and those which run generally east and west have even numbers. As in the highway numbering system, a segment of an airway which is common to two or more routes carries the numbers of all the airways which coincide for that

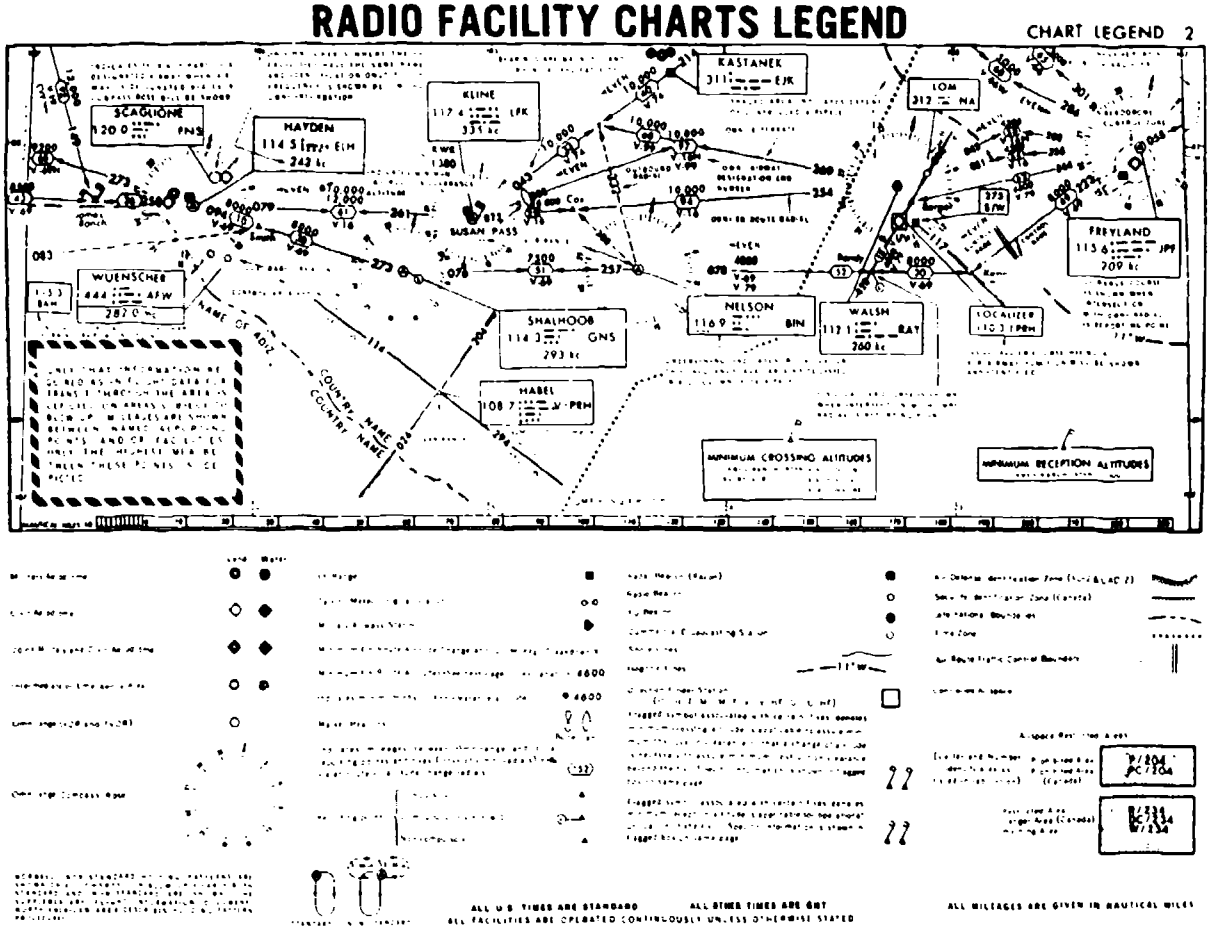

Figure 11–2. Radio Facility Charts Legend—VOR

segment. For example, between St. Louis and Farmington (Mo.) "v (Victor) 9" (Chicago-New Orleans) and "v (Victor) 69" (St. Louis-Walnut Ridge) are common, and aeronautical charts show both airway numbers. In such cases, when you file a flight plan, you need indicate only the number of the route which you will be using. If the flight will be from St. Louis to New Orleans, for instance, you will specify Victor 9 in the flight plan. If the flight is from St. Louis to Walnut Ridge, you will specify Victor 69.

Alternate airways are identified by their location with respect to the associated main airway. "Victor 9 West" indicates an alternate airway associated with, and lying to the west of, Victor 9. Since there are a number of west alternate airways along Victor 9, a traffic clearance specifying Victor 9 West must include the names of the omniranges forming the particular alternate airway to be used so that there will be no doubt.

Minimum En Route Instrument Altitudes

Altitude levels shown on charts for airways in the U. S. apply to airways between radio ranges or between radio ranges and reporting points. The established minimum altitudes are those within the actual limits of the Civil Airways (5 miles either side of their center). IFR flights along the airways are not to be conducted at lower altitudes than those specified. Flight levels are

specified in true altitude in feet above sea level. Indicated altitudes may vary considerably from true altitudes. So use higher levels if you are in doubt as to temperature and/or barometric changes. This is especially true around mountainous areas when a wind is blowing over the mountain and causing low pressure areas on the lee side. Differences of 3,000 feet have been known to exist between true and indicated altitude.

SUPPLEMENTARY FLIGHT INFORMATION DOCUMENT

The Supplementary Flight Information Document is a matching volume to go with the Radio Facility Charts. It is published and distributed in similar fashion and has the same general appearance. It contains information of a more or less permanent nature, useful to the pilot, radioman, and navigator. It is reprinted approximately every six months, the schedule varying with the need for revision. It is corrected when necessary by Military Aviation Notices which should be attached to each copy when received. A copy should be carried in every radio-equipped naval aircraft on civil airways in the U. S. The coverage extends to all North America, and the book is also an official document of the Royal Canadian Air Force and Royal Canadian Navy.

The Supplementary Flight Information Document includes many items which the pilot needs to know and often can't find:

1. Conversion Tables: Barometer, Inches to Millibars; Temperature, C. and F.; Altitude: In. Hg. to feet; Meters/Feet; Kilometers/Miles (Stat. and Naut.); Miles (Stat./Naut.), Arc to Time. (Some of these conversions, however, are easier to make on the E6D computer, explained in Chapter 10.)

2. Sunset/Sunrise tables.

3. Time Signal Data.

4. Commercial Broadcast Stations: Commercial radio stations make fine homers because they often have much more power and range than aviation radio facilities. This table lists the stations by state, with the latitude and longitude of the transmitter, magnetic bearing from transmitter to airfields, frequency, hours of operation, and other data. Only the more powerful stations of a city are listed.

5. Loran Coverage Chart.

6. NOTAM Code.

7. Q and Z Signals.

8. Data on airports and procedures for clearance to foreign countries.

9. Direction Finder Procedures.

10. CIRVIS reports: Reports from aircraft of intelligence sightings.

11. International Communications Procedures.

12. Weather Broadcast Codes (mostly international): AERO, TFAWS, ROFOR, FIFOR, TAFOR (TAF), TAFOT/TAMET, ROFOT/RAMET, AIREP (Flight log form), POMAR.

13. Ocean Station Vessels. Ships in mid-ocean which provide weather, position, and rescue services.

14. ICAO place name abbreviations (4-letter instead of 3-letter as in U. S. A. U. S. names are the same as in domestic use except preceded by "K").

15. Table of Units of Measure used for various aviation purposes in U. S., Canada, Iceland, and ICAO. Example: Is weather report of visibility in nautical or statute miles, yards, kilometers, or meters? (U. S.: Stat. Mi.)

16. Metro Station Index (weather, international).

17. Weather Broadcasts outside U. S.

18. Air Traffic Control Procedures (C. A. R. Part 60, Air Traffic Rules).

19. Flying Regulations, Clearance Rules, USAF, USN, RCAF.

20. ADIZ Rules.

21. Approach procedures to certain U. S. cities for overseas flights.

22. Designated Mountain Areas, to which special IFR minimums apply.

23. ATC definitions.

24. VOR receiver check services. How accurate is your Omni gear?

25. Definition of services of ATC, Flight Services, GCA, ILS.

26. Air Traffic Control Procedures: Flight Plans, clearances, approach control, airport traffic control, aircraft lights, taxi signals, position reports, in-flight and post-flight weather reports, emergency procedures, fuel and aircraft servicing.

27. Range Orientation Procedures.

28. Holding Procedures.

29. Emergency Procedures: Search and Rescue, Distress Messages, Ditching, Submarine Emergency Identification Signals, Reporting Accident or Forced Landing, Visual and Radio Emergency Signals from Survivors.

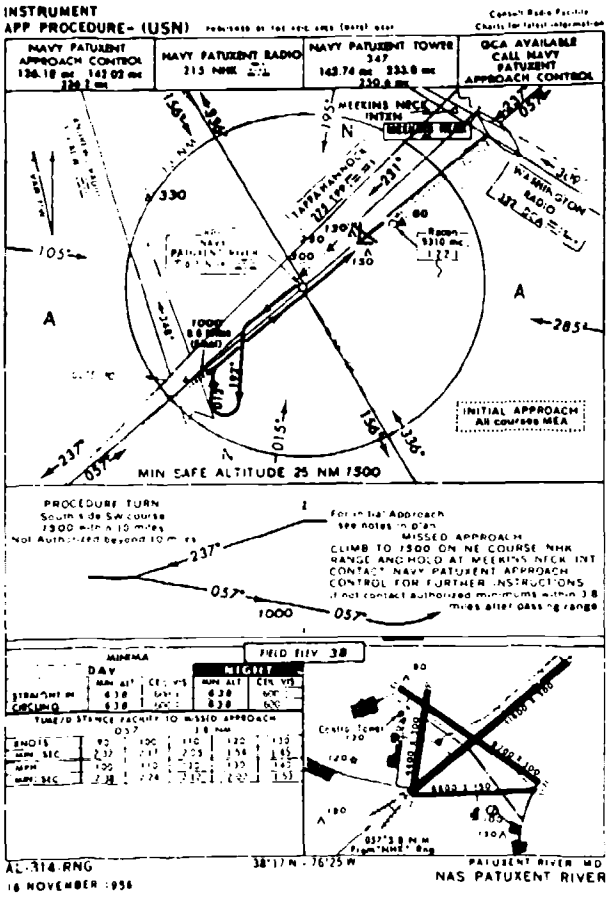

Figure 11-3. Instrument Approach Procedure Chart (Low Altitude)

Every pilot should know the existence of those portions of the above list which are applicable to his operations. If you have not previously read them, look at those indicated by bold face type before engaging in instrument flight.

NAVAL AIRWAYS PILOT (H. O. 510)

The *Naval Airways Pilot* (H. O. 510) is a series of volumes presenting important airways data. The pages are looseleaf, and regular revision pages are issued. H. O. 510 in two volumes covers all of the U. S. and Alaska. H. O. 510A, B, C, and D are regional volumes containing the same material as H. O. 510 but for a specific region. Normally, you will carry only one regional volume in your airplane. The full set is used in flight planning or on extended cross-country flights which enter many regions of the U. S.

As of July, 1957, however, the *Naval Airways Pilot* (H. O. 510) will be phased out of general operational use. At the time of its discontinuance, it will be replaced by the USAF-USN publication *Instrument Approach Procedure Charts*, also called the "Pilot's Handbook." This world-wide periodical publication, which is described in following paragraphs, will have been revised as of that date to fulfill Navy requirements and it will, in effect, replace the H. O. 510.

USAF-USN INSTRUMENT APPROACH PROCEDURE CHARTS (PILOT'S HANDBOOK)

This series of handbooks, consisting primarily of approach and landing charts, are published periodically in the following series of three:

1. Landplanes (*low altitude*, formerly designated *standard*) (Fig. 11-3).

2. Seaplanes, providing instrument-visual approach procedures (Fig. 11-4).

3. High-altitude aircraft (formerly designated *jet*) (Fig. 11-5).

There are 13 landplane (low altitude) books, seven seaplane books, and six high-altitude aircraft books, the different books covering different geographic areas. The area coverage of the individual books can be found in H. O. Pub. I-V(R).

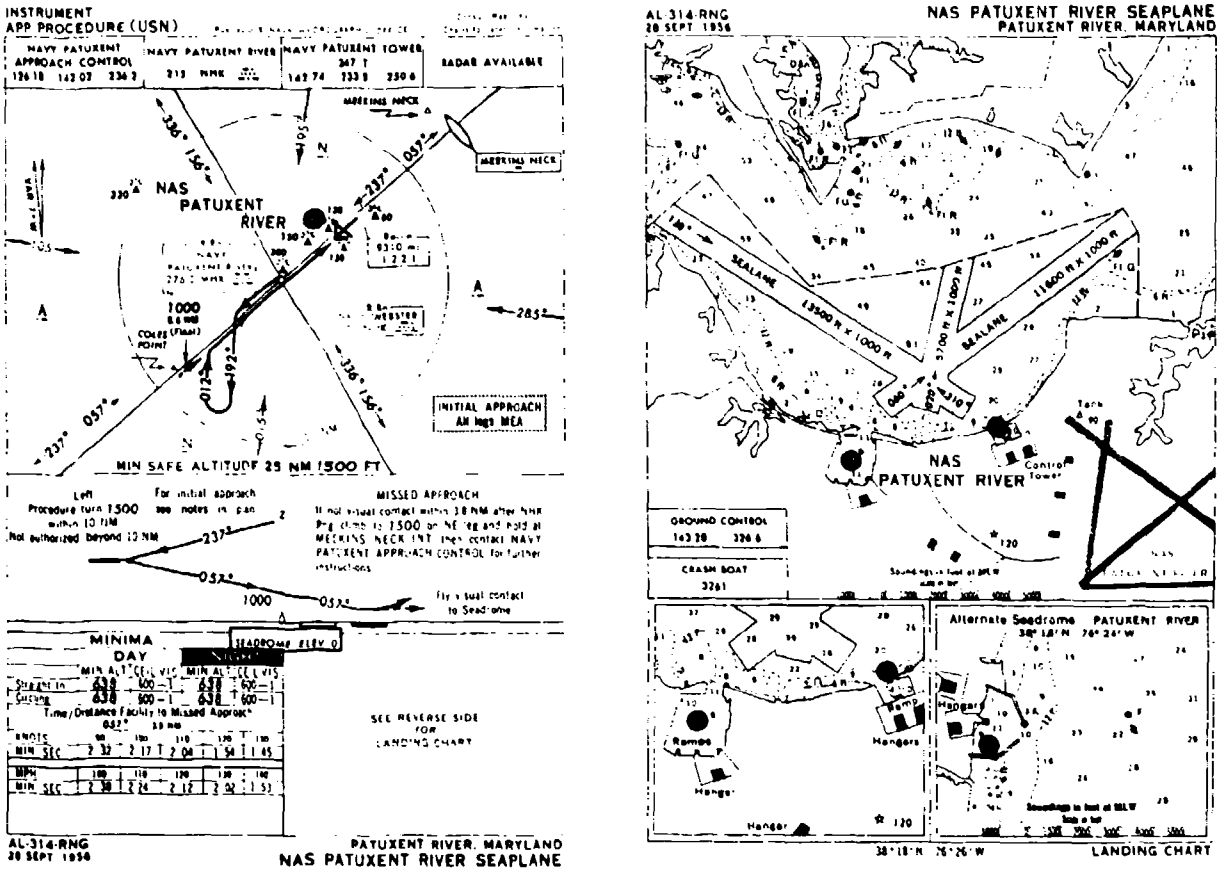

Figure 11–4. Instrument-Visual Approach Procedure Chart for seaplanes

Under an international agreement reached by Working Party 64 for Maps, Charts, and Flight Information of the Air Standardization Committee for the U. S. between Great Britain, Canada, and the United States, the size, arrangement, and format of presentation of approach and landing charts in the USAF-USN *Instrument Approach Procedure Charts* and in the handbooks published by Great Britain and Canada are identical. This means that when U. S. Navy pilots obtain Canadian or British instrument approach charts, the charts will be similar to the ones they are accustomed to. It also means, of course, that our charts will be familiar to British and Canadian military pilots.

Designed for in-flight use, the *Instrument Approach Procedure Charts (Low Altitude)* contains instrument approach and landing charts for aerodromes having approved instrument approach procedures and for which USAF or USN requirements have been established. The handbooks covering areas outside the continental United States also contain ILS charts for aerodromes having approved ILS procedures and for which USAF or USN requirements have been established. The books also contain associated route information.

The *Seaplane Instrument Approach Procedure Charts*, with charts showing greater geographic detail as an aid to visual approaches, are area publications designed primarily to furnish information of assistance to the air navigator on extended flights outside of the United States. The seaplane books provide data of value in opera-

tional planning for long-range seaplanes. They contain information on seaplane anchorages and instrument approach procedures, the text being supplemented by visual area charts. The books are arranged in loose-leaf form to permit the addition of corrections which are issued as revised pages.

The *Instrument Approach Procedure Charts (High Altitude)* are loose-leaf publications containing jet instrument approach and landing charts for aerodromes having jet instrument approach procedures and for which USAF or USN requirements have been established.

TACAN APPROACH PROCEDURE CHARTS

Approach procedure charts for Tacan-equipped aerodromes (Fig. 11-6) are being disseminated by the Navy Hydrographic Office for inclusion in the *Instrument Approach Procedure Charts* loose-leaf books. Since the acceptance of Vortac (of which Tacan is a component) as the U. S. common civil-military air navigation system, installation of Tacan ground equipment is moving ahead. For each such installation, a Tacan approach procedure chart will be distributed. When Tacan installations become sufficiently numerous, Tacan approach procedure charts will be removed from the regular *Instrument Approach Procedure Charts* loose-leaf books and bound in a separate Tacan loose-leaf binder to be procured and made available for this purpose.

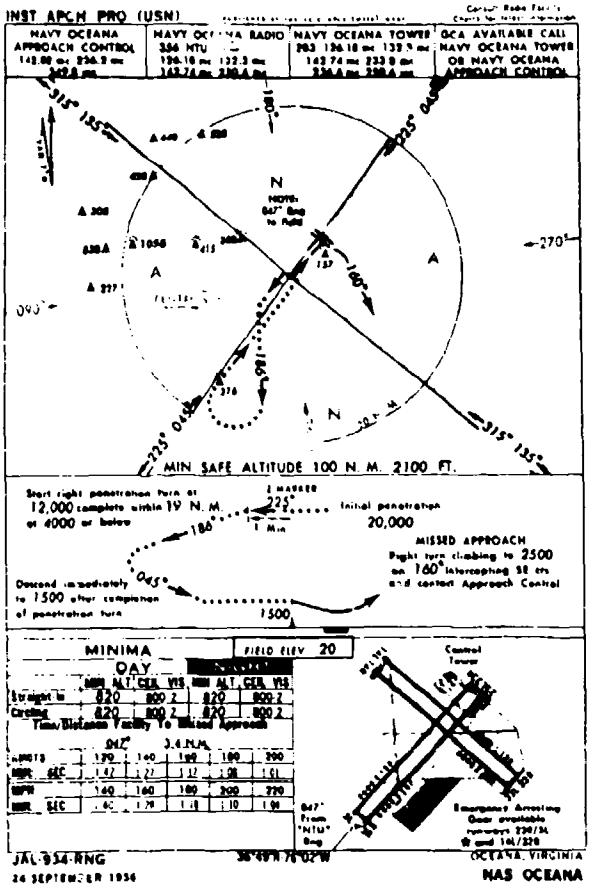

Figure 11-5. Instrument Approach Procedure Chart (High Altitude)

NOTICE TO AIRMEN (NOTAMS)

Notices to airmen are transmitted on the teletype, often as part of teletype weather reports. They are transmitted by means of the NOTAM code, found in the *Supplementary Flight Information Document*. This code consists of a five-letter word beginning with the letter Q. "Q" identifies the code being used as the NOTAM code. The second and third letters designated the facility being discussed. The fourth and fifth letters give the status of that facility. Additional words or numbers follow if needed for clarity.

For example, "QAROS 116.9 MC 210800 means that the VHF on 116.9 megacycles at Indianapolis will be out of service for an indefinite (unstated) period beginning at 0800 GMT on the 21st of this month. These NOTAM's should be decoded by the pilot from current teletype weather messages. Those for earlier days must be decoded and filed by states in an accessible place in the Operations Aerology flight planning area of every naval air facility or station. A master file of older NOTAM's, as mentioned before, may also be found in the Airman's Guide (CAA).

FOREIGN NAVIGATION AIDS

The USAF Aeronautical Chart Service and the USN Hydrographic Office provide many of

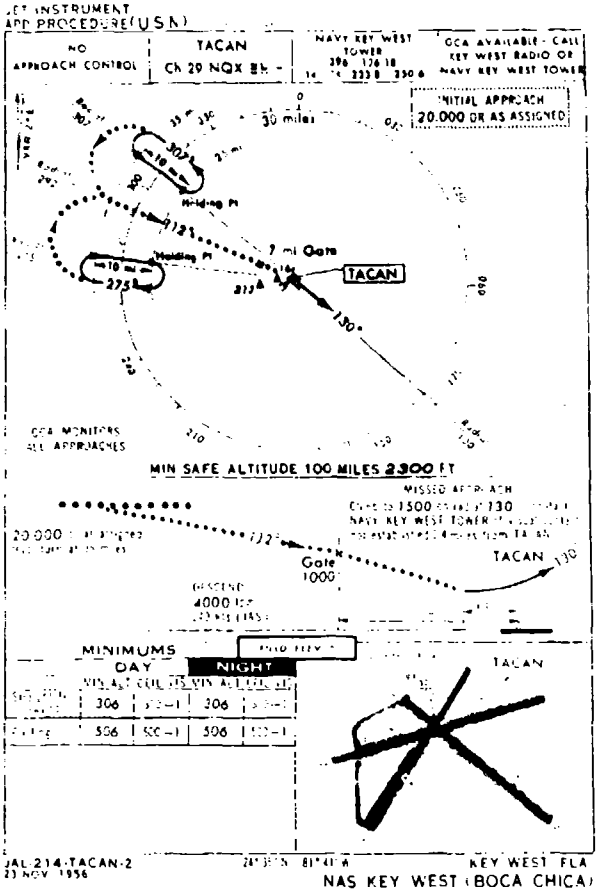

Figure 11–6. Instrument Approach Procedure Chart (Tacan)

the same aids for U. S. aircraft in regularly traveled foreign territory as are provided in the U. S. In other areas, pilots must rely on local products. The primary aids are W. A. C. charts, Radio Facility Charts, *Supplementary Flight Information Documents* and "Pilot's Handbooks." Radio Facility Charts are available for Africa and Middle East, Caribbean and South America, India and Southeast Asia, the Pacific, Australia and New Zealand, Europe, North Atlantic and Eastern Canada, and Western Canada and Alaska. Another aid is the ICAO Regional Supplementary Procedures for International Flight, a book which provides information for other areas similar to that provided in the Supplementary Flight Information Document.

DANGER AREA MAPS

A large map of danger areas must be displayed in Operations Offices and kept current. Use this map in connection with your flight planning. In addition, danger areas are shown on the charts in Radio Facility Charts, and identified with a letter number. The letters are P for Prohibited Area, R for Restricted Area, and W for Warning Area. In a separate section of Radfacs there is a table listing all these by numbers and giving the altitude of the limitation and the hours affected. Since the area map may not be entirely current, check NOTAM's in the file for changes. A restricted or a warning area is one which is prohibited while it is in use. A prohibited area is one which is forbidden to aircraft at all times; consequently, there are fewer such areas.

CHAPTER 12

FLIGHT PLANNING

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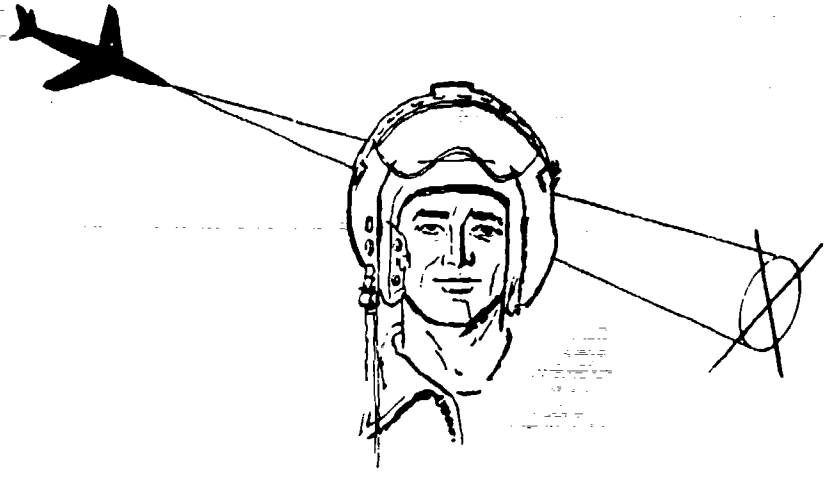


CHAPTER 12

FLIGHT PLANNING

THE safety and efficiency of any flight depends largely on the quality of the flight planning before take-off. Important as this is for flight under VFR conditions, it is far more important for instrument flight. As the weather becomes more marginal, more and more planning and preparation are necessary.

Actually this chapter is the third on the subject of flight planning. In the previous two chapters, we covered the computers, calculators, and publications which you will use in planning a cross-country or transoceanic flight. This chapter covers the actual process of flight planning except for the aerology phase which is taken up in Chapter 26.

FACTORS IN FLIGHT PLANNING

Destination and fuel stops. Check the facilities of the appropriate airports for landing, lighting, servicing, radio aids, and the condition of these facilities on NOTAM's.

Route and altitudes. Some factors involved in choosing the best route and altitude are: weather, minimum en route altitude, terrain, danger areas, and radio-aids facilities.

Choice of alternate. Check the alternate not only for weather but also for field facilities the same as for the destination. Also plan the route and altitude from destination to alternate.

Radio aids to navigation. You should familiarize yourself with the radio aids along your

route and check to make sure that you have the necessary charts, publications, and let-down procedures, and that they are up to date.

Flight plan. Making out the flight plan involves entering fixes, mileage, frequencies, and headings, and computing time en route for each leg and for the entire flight.

Aircraft clearance. The aircraft clearance consists of a summary of the flight plan together with other information identifying the flight. This is submitted to ATC for approval for IFR flight and to Flight Service for both IFR and VFR flight. Weather is an integral part of the clearance to insure that the pilot is briefed on the destination, alternate, and en route weather.

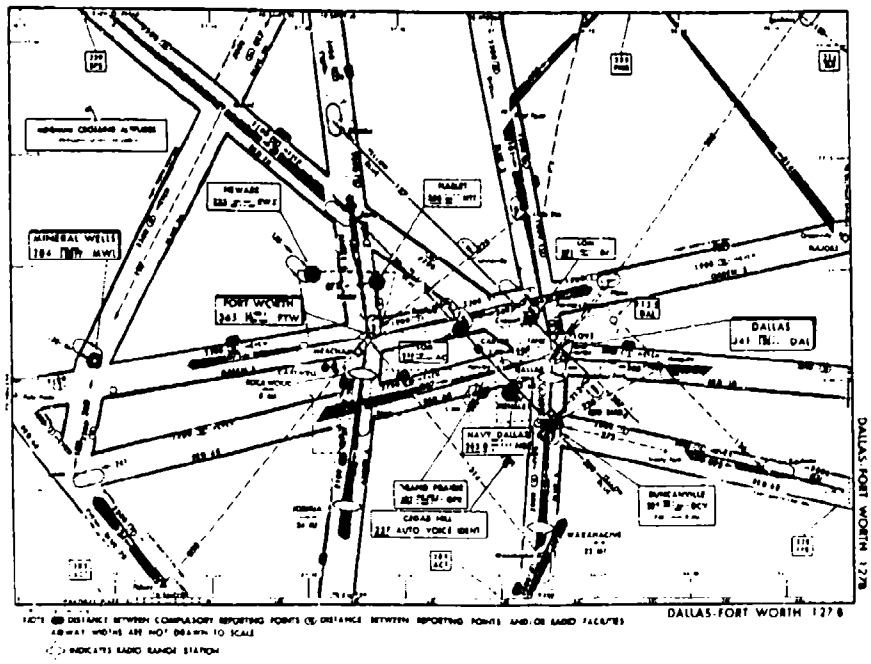
Flight Clearance. Before takeoff, you receive from the tower, either civilian or military, the ATC-approved flight clearance giving the route and altitude which you must follow.

Flight log. En route, you must keep your flight log to follow your progress along the route in accordance with your flight plan, to make estimates over fixes, to note gasoline consumption, and to do en route planning in case it becomes necessary to change your flight plan.

There are many different flight log forms. No standard forms are prescribed because of the different problems involved in log entries for different aircraft and different kinds of flight. Usually your own squadron or unit will provide a form, and you should become familiar with it. On cross-country flights, therefore, it is wise to take along some extra forms of the type you prefer and are accustomed to using. A check of your Navy forms-management catalog for your area will usually reveal just the form you desire for your aircraft.

In the following flight-planning problems, certain typical forms are used. A good way to learn flight-planning techniques would be to follow these problems with your own computer and Radio Facility Charts, making up your own log form. Remember, though, that some of the ranges, distances, fuel consumption figures, and the like in the examples shown here may become obsolete. Don't use the sample problems, therefore, in plan-

Figure 12–1. Radio Facility Chart showing Hensley Field, Dallas



ning an actual flight over the same route. They show only a suitable procedure to follow. They do not show the only possible procedure.

FLIGHT PLANNING FOR CONVENTIONAL AIRCRAFT

In order to describe flight-planning techniques, this chapter follows through a typical cross-country flight plan for an SNB airplane. It is a flight based on the use of LF/MF radio ranges. Though you have not yet studied Chapter 26, "Flight Planning from Available Weather Data," you should have covered enough aerology to understand the weather phase of the problem.

Radio Facility Charts

The proposed flight will be from Corpus Christi, Texas, to Dallas, Texas. So you start by making a check of the destination in the Directory of Airfields section of the Radio Facility Charts to determine what facilities are available for military use. If the facilities are sufficient to merit their use, you will undertake further route study and planning.

A check of the charts in Radio Facility Charts shows Hensley Field at Dallas. (See Figure 12-1.) Further investigation in the Directory of Airports section of the same publication indicates sufficient facilities as Hensley Field to make it a suitable destination. With a suitable destination established, further route study is possible. You make the initial study on the planning chart in the center page of the Radio Facility Charts. It is obvious that the shortest airways route is via San Antonio, Austin, and Waco. The distance is about 351 nautical miles.

While working with the planning chart, you can select some probable alternates. Distance, weather trend, and available facilities will enter into the selection. Depending on further study of these factors, Waco, Abilene, Wichita Falls, and Texarkana can be considered because of their geographical location. However, the weather sequence indicates a warm front extending from Dallas. The frontal movement is northward. Texarkana is now below minimum for an alternate, and the weather picture indicates it will get worse. The prospects for Waco are equally bad since it is the center of the low-pressure area. The remaining two considerations are Abilene and Wichita Falls. Existing weather trends indicate that they will be the best selections.

After consulting the planning chart, you get more information concerning the selected route. You can inspect smaller portions of the route in your Radio Facility Charts; then select larger-scale charts of portions of the route from the back of this publication. These charts will provide much of the information needed to fill out the flight plan. The radio aids to navigation, airways, and en route minimums will enable you to determine check points, distance between check points, minimum altitudes, and the *magnetic* course between check points. (Remember, Radfacs gives the *magnetic* headings of the range legs.)

THE FLIGHT PLAN

The "From" "To"

The first step in filling out the flight plan is to break down the entire flight into smaller segments, or legs. Normally, each compulsory reporting point constitutes a leg. Any point from which further information might be obtained might also constitute a leg; for example, a fan marker, or airways intersection. From departure point to airways entry constitutes a leg, as does the segment from airways entry to the next compulsory reporting point. This flight, therefore, will consist of nine legs. The leg terminals will be, in order: Gregory FM, Corpus Christi Radio, Losoya Intersection, San Antonio Radio, Cibolo FM, Austin Radio, Waco Radio, Waxahachie FM, and Dallas Radio. (See Figure 12-2.)

Altitude and Temperature

Since the course is northwesterly, the selected altitude will be an odd number. Since the flight is long enough to make it worthwhile to climb to 5,000 feet to gain TAS, the flight altitude will be 5,000 feet. The temperature will be estimated after determining the altitude to be flown and examining the prevailing ground temperatures. (Rule of thumb: temperature decreases 2° centigrade per 1,000 feet.)

True Air Speed

The cruising speed of the SNB-5 is 140 knots. Correct this speed for altitude and temperature and you will find the true airspeed to be 152 knots. Climbing airspeed is CAS 115, TAS 120 kts.

True Course and Variation

You can get the variation from any available chart or from the Radio Facility Charts. You can find the magnetic course from the WAC charts or from Radfacs. If the desired leg is not along a beam heading, you can find more detailed information on the WAC charts. Applying the variation to the published courses will give true course.

To avoid confusion or the need to remember formulae such as "Can Dead Men Vote Twice," use the index on the computer to convert true headings to or from magnetic headings.

Here are the magnetic courses for this flight as taken from the Radio Facility Charts. The general variation is 9° E.

		MC	VAR	TC
NGP	GRG	351°	9° E.	360°
GRG	CRP	219°	9° E.	228°
CRP	LOS INT	319°	9° E.	328°
LOS INT	SAT	354°	9° E.	003°
SAT	CIB FM	354°	9° E.	003°
CIB FM	AUS	037°	9° E.	046°
AUS	ACT	009°	9° E.	018°
ACT	WAX INT	012°	9° E.	021°
WAX INT	DCV	356°	9° E.	005°
DCV	DAL	356°	9° E.	005°

Wind

You get the wind from the winds aloft report, which is available at any Military or Naval Air Facility. Determining the areas in which these winds will be effective is largely a matter of interpolation. If the reporting stations are far apart, interpolate the wind values.

The methods of requesting weather information from CAA facilities are covered in the Supplementary Flight Information Document. Weather en route can be obtained when filing a flight plan with military airways. Weather reports are available also at all CAA stations and can be obtained by radio by listening to stations listing scheduled weather broadcasts 15 minutes before and after the hour. It's not a good idea to request weather information when making position reports, for this is a needless loading of the radio frequency. It detracts from your performance as a professional naval aviator.

The winds at 5,000 feet are 290/15 at CRP and 325/20 at AUS. This windshift is gradual and not too large. You can, therefore, consider the shift as commencing at CIB FM. Use the Dallas wind from Waco.

Drift and Ground Speed

Knowing both the true course and wind, put the wind on the wind face; then compute and write down the drift, ground speed and headings for each leg. It is unnecessary to adjust the computer for any wind change until you reach CIB FM, where you plot in the AUS wind. It is helpful to set up a wind drift on the computer for the letdown at Dallas. You can determine the drift correction for the winds at the lower levels and check them flying the radio range. If the wind velocities were very high and no range leg were available, you could have set up the average wind at the lower altitudes on the computer to determine headings and drift in letdown.

Distance and Ground Speed

You noted the distance when checking magnetic courses in the Radio Facility Charts or the WAC charts. You entered the ground speed with the drift computation.

Point-to-Point Time

Calculate the point-to-point and cumulative point-to-point times on the slide-rule face of the computer. This distance from NGP to GRG is 16 miles. With the ground speed based on the climbing airspeed of 120 mph, it will require 8

From	To	Alt.	Temp.	True Air S	True Course	Wind	Drift	True Head	Var.	Mag. Head	Dist.	G/S	Pt.-Pt.	Acc. Pt.
NGP	GRG	5000	10	131 MPH	360	290 15	6°R	354	9E	345	18	125	9	9
GRG	CRP	"	"	131	228	"	6°L	234	"	225	12	124	6	15
CRP	LOS INT	"	"	175	328	"	3°R	325	"	316	116	163	43	58
LOS INT	SAT	"	"	"	003	"	5°R	358	"	349	25	170	9	67
SAT	CIB FM	"	"	"	003	"	5°R	358	"	349	10	170	3	70
CIB FM	AUS	"	"	"	046	325 20	7°R	039	"	030	61	170	22	92
AUS	ACT	"	"	"	018	"	5°R	013	"	004	90	163	33	125
ACT	WAX FM	"	"	"	018	"	5°R	013	"	004	63	163	23	148
WAX FM	DAL	"	"	"	005	"	4°R	001	"	352	27	160	10	158
											--			----
											422			2+38

Alternate(s)	ABI	ICH
Distance	174	123
Ground Speed	172	157
Time	61	47
Fuel to Alt(s).	47	36
Fuel to Dest.	121	121
Inst. App. (15 Min.)	12	12
Res. (45 Min.)	34	34
Fuel Required	214	203
Total at Dep.	253	253
Rem. Usable	39	50

Flight No. | Plane | Date

Remarks

MH: DAL to ICH: 303°
DAL to ABI: 253° to LIPAN INT. (24 min.)
309° to PALO PINTO INT. (7 min.)
253° to ABI

(Editor's Note: Headings, courses, and distances in this problem are shown for study only. Do not plan a flight based upon these figures.)

Figure 12-2. Flight Plan

minutes to reach GRG. Enter this time in the column headed "Pt.—Pt." The second leg is also covered at climbing airspeed and requires 6 minutes. Enter the 6 in the "Pt.—Pt." column; in the column, "Acc. Pt." or cumulative point-to-point time, enter the total elapsed time, 8 + 6, or 14 minutes. The total time required for the flight is 2 hours and 37 minutes.

Alternates

In the lower left-hand corner of the flight plan is a table for entry of information concerning the alternates. Two alternates are selected as suitable for this flight. Tabulate the necessary information for these alternates as follows.

From the Radio Facility Charts you can see that it is 108 miles to Wichita Falls (Red 10), and 149 miles to Abilene via Red 68 and Gr. 5. Enter these distances in the distance row of the alternate(s) table.

The winds aloft for Dallas are reported PIRA (no pilot balloon observation due to rain). The upper wind at 4,000 feet over Wichita Falls and at 5,000 feet over Abilene is 340°/20. This will be suitable for computing time to the alternates. Plot in this wind on the wind face of the computer. The magnetic course to Wichita Falls is 301° (taken from the Southeast leg of ICH); the true course is 311° (add 10° E VAR), and you find a ground speed of 134. Use the same procedure for Abilene. (The inbound magnetic course from the Northeast leg is 247° + 10° E.

VAR equals 258° true course.) The distance is 65 miles to LIPAN INT, 13 miles to PP INT, 71 miles to ABI, a total of 149 miles. Use an overall GS of 148 kts for MH 255°. There is no log space for entry of course and heading information, but you can note the information in the remarks space for ready reference.

You can compute the time readily on the slide rule face of the computer. The time to Abilene is 61 minutes and to Wichita Falls is 48 minutes.

Determine the fuel to alternates on the back of the computer, using the time to alternates and a rate of fuel consumption of 46 gph. Forty-seven gallons are required to reach Abilene (61 min. at 46 gph) and 37 gallons to reach Wichita Falls (48 min. at 46 gph). In the same manner, you will find the fuel to destination to be 121 gallons; enter this figure as "Fuel to dest." Similarly, compute gas comsumption for a 15 min. instrument approach (12 gal.) and a 45 min. reserve (34 gal.). Fuel consumption at cruising power setting is normally somewhat less than 46 gph, especially later in the flight when the gross weight drops off because of the fuel consumed. This difference will compensate for a pull-up at Dallas, in case you have to divert to an alternate.

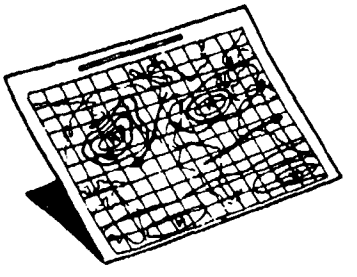
The fuel required is the total of "Fuel to Alt(s)," "Fuel to Dest.," "Inst. App." (15 minutes) and "Res." (45 minutes). Adding these columns shows 214 gallons required to take off from Navy Corpus, proceed as planned to Dallas, and make an instrument approach, then proceed to Abilene and arrive with at least 45 minutes' fuel remaining. The requirement is 204 gallons if the alternate used is Wichita Falls.

The total at departure with a nose tank is 253 gallons. The difference between "Total and Dep." and "Fuel Required" is the "Rem. Usable."

The "Rem. Usable" fuel is your insurance. If wind direction and velocity are different than forecast or if TAS is slower than estimated, this fuel balance can be used and the original flight plan carried out.

Weather Annex

General Situation. A low-pressure area is centered near Waco, Texas, and moving northeastward. A cold front extends southwest from the low, lying just northwest of Austin and San Antonio at 0730E and expected to move southeastward about 29 miles per hour. A warm front extends east from Waco and along a line just south of Shreveport. It is moving slowly northward. The low has developed as a wave on the cold front, which previously extended from west to east in this area. The precipitation area extends north of the warm front including Dallas, Texarkana, and Shreveport. There is scattered thunderstorm activity along the cold front. The PROG report indicates that the icing level in the western portion will be 10,000 to 11,000 feet with icing in clouds. In the eastern portion, the icing level is lower: 9,000 to 10,000 feet, with icing in clouds.



JET FLIGHT PLANNING

The problems of jet-flight planning are by no means new, but their solution may be. Range, endurance, and weather are still the basis of all good flight planning. However, the range that can be covered within a given time has been increased by the high speed; so has rate of fuel consumption. The greater range also means that it is possible to encounter a greater variety of weather on a single flight. Thus, the jet combines several of the old problems into a single flight and makes it imperative that a jet instrument pilot complete an organized plan of action before takeoff, because there is very little time or space for studying or computing when on instruments. The precedures for solving these problems before takeoff are not drastically new, but they do require a greater attention to detail and a knowledge of more publications. Any pilot who has learned basic navigation, pilot techniques, and where to find the information, will find that the procedures work as well at 40,000 feet and 400 knots as they

did at 4,000 feet and 150 knots. It is still flight planning, only more detailed.

The procedures discussed here apply primarily to flight along the civil airways under instrument conditions. This is commonly known as radio navigation. No mention is made of flights elsewhere or under other conditions. It may be assumed that a competent instrument pilot, with some additional instruction and practice, can do other types of navigation, such as pilotage and dead reckoning.

Destination

You must choose a destination within your range that has adequate facilities. Start the planning with this basic selection of a destination. Some of the principal considerations and requirements are:

Length and type of runways.
Availability of a jet starting unit.
Hours of operation.
Type of servicing.
Fuel available.
Oxygen available.
Expected ground roll-out on landing.
Lighting.
Navigational aids.
Type of letdown and approach.
Instrument landing aids (GCA, ILS).
Elevation of field.
Traffic pattern.
Obstructions.
Radio frequencies.
Expected distance required for take-off.
Closest VHF or UHF/DF steer equipment.

A check of current NOTAMs will give you the status of facilities, danger to aircraft in flight, search-and-rescue facilities and the like.

Weather

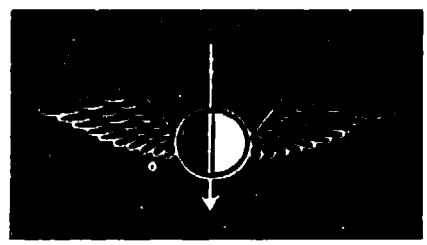
Since an instrument flight depends on the weather, you will logically check the weather now to see if you may proceed to, and land at, your selected destination. If this check reveals that the flight can be conducted under Visual Flight Rules, the problem may seem to be simplified, but remember that it is safer to be pessimistic. Besides, *you cannot maintain instrument proficiency without practicing at every opportunity.* Plan and conduct an IFR operation unless the weather is well above VFR minimums. When you go to the weather office, don't just make a general inquiry about the weather from here to there. You won't get complete information that way. Tell the aerologist your type of aircraft, destination, approximate altitude, time en route and give him any other additional information he needs to visualize your problems. If you tell him what he needs to know about your flight, he can tell you what you need to know about the weather on the flight. You should find out the existing weather and also the forecast and trends. You should know the following about the destination and possible alternates:

Ceiling.
Visibility.
Precipitation.
Winds.
Temperature-dew point spread.
Tops of clouds and freezing level.

You need the following information about conditions en route:

Visibilities.
Ceilings.
Precipitations.
Fronts and their movements.
Thunderstorms, line squalls, etc.
Cloud types at flight altitude.
Tops of clouds.
Areas of turbulence.
Freezing level.
Temperatures and winds aloft at flight altitude.

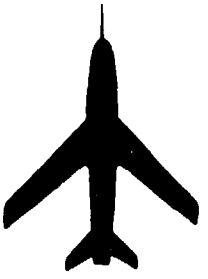
You should know, too, where to expect VFR weather along or near the intended route in order to know where to land in case of complete radio



failure. Also look at several of the various millibar charts to get a good picture of winds aloft, both as to direction and velocity, and pressure patterns. Most weather offices usually have the following millibar charts:

500 mb, which is for winds at roughly 18,000 to 20,000 ft.
300 mb, which is for winds at roughly 28,000 to 32,000 ft.
200 mb, which is for winds at roughly 37,000 to 41,000 ft.
150 mb, which is for winds at roughly 44,000 to 46,000 ft.

Use the average wind between check points not more than 200 miles apart. If you use the average wind throughout a flight, you cannot make an accurate check of ground speed, fuel consumption, and ETA's over various points en route. For example, if the average wind is 50 knots on the tail for an 800-mile trip, you can estimate the total time en route, but you can't estimate accurate times en route for individual legs. The wind does and can vary considerably. For one portion of a flight, a tail wind of 100 knots could give a ground speed of 460 knots and in another portion of the flight the wind could shift to give a head wind of 10 knots with a resultant decrease of ground speed to 350 knots.



It is essential that you get the wind forecast and compute it in the flight plan for each 200-mile leg. The use of definite radio aids as fixes will give you an accurate basis of flight planning and enroute checks on time and fuel. Also remember that variation can change over an extended flight—use its correct value.

When you obtain the weather information, do not neglect the weather at the point of takeoff. You should know the following:

Ceiling.
Visibility.
Precipitation.
Surface Wind.
Spread.
Freezing level.
Temperatures and winds up to cruising altitude.

Since weather is not a stationary phenomenon and since conditions as shown on the latest weather map may change during the flight, get a forecast of the changes before departure.

Even though this sounds rather complicated, you will be surprised that you can obtain all of this information in a very few minutes, especially if you have a good working knowledge of aerology. You should be able to interpret the overall weather picture yourself, which you may have to do sometimes if a trained forecaster is not available.

When you have obtained all of the weather information mentioned, you can safely plan an instrument flight and also have several areas in mind that you may go to in case an in-flight emergency occurs. With all the weather information understood and recorded as necessary, you now withdraw into a secluded corner with your charts, computers, publications, and flight-planning-and-navigation log.

Selection of Route

The center planning page of the Radio Facility Charts gives a good picture of the airways of the United States and is very helpful in determining the route to the destination. Select the route by using a combination of airways and direct legs as appropriate. *Do not* think that you are saving a great amount of time by flying "direct" everywhere. Actually it is poor judgment to ignore the additional safety available in controlled airways.

By going "direct" you usually save only a few minutes. For example, it is 947 nautical miles "direct" from NAS Atlantic City, N. J. to NAS Olathe, Kansas. The wise pilot would file for "direct" from Atlantic City to Philadelphia, Green Airway 4 from Philadelphia to Kansas City, and

"direct" from Kansas City to Olathe. The total mileage in flying two short "direct" legs plus Green 4 is 982. Thus, by flying about 35 miles farther (only about 6 minutes flying time at 360 knots), the pilot will have the additional safety of the controlled airways, adequate and accurate position checks, a good running check on his fuel "howgozit," and the satisfaction of knowing that trained CAA men are tracking him and providing positive separation.

Selection of Altitude

The basic considerations for selecting a cruising altitude are:

Winds aloft.
Temperature in terms of freezing level.
Upper clouds.
Areas of turbulence.
Distance to destination.
Fuel consumption.

Normally, for a flight of long range, the altitude will be in the vicinity of 40,000 feet. You can determine the optimum altitude for the aircraft from the cruise charts in the Pilot's Operating Handbook for the particular model aircraft or from the REST computer. For short flights of 500 miles or less, it may not be feasible to climb to the optimum altitude; remember this fact when planning the phase of the flight from destination to alternate.

Selection of Alternate

To select a good alternate, you should consider the same general factors as in picking a destination, paying special attention to weather at the alternate at the estimated time of arrival (ETA) and its trends. Generally, you should choose alternates approximately 100 to 200 miles from the destination because bad weather is usually localized and will not cover a large area.

It is good procedure to have several possible alternates chosen along the route that can be used in case of an in-flight emergency. You should also know where to obtain VHF/DF or UHF/DF steers along the route and near the destination and alternate.

Other Considerations

Computing the fuel, time, predicted ground speed, penetration, and the like, is the most important part of flight planning but that is by no means all there is to it. To do a thorough job of such a detailed operation, you should utilize some type of check-off list.

You will also need some type of personal check-off list to remind yourself of some of those all important small details that can be embarrassing if you neglect them, such as leaving your Instrument Card in your locker.

Current instructions require that an up-to-

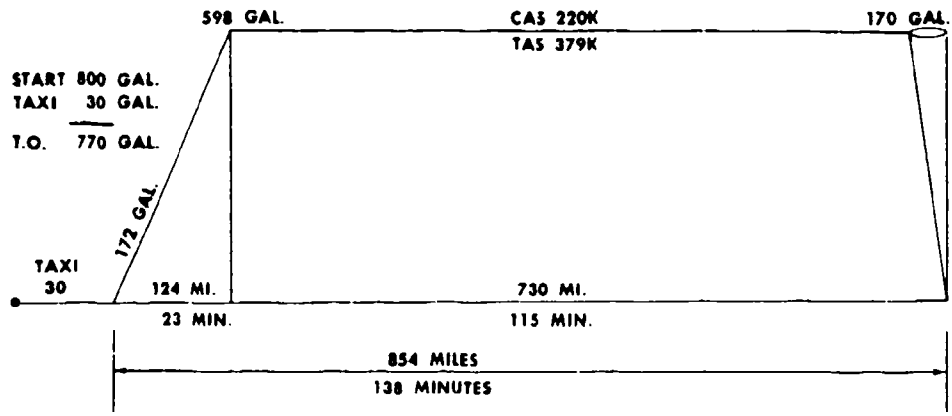


Figure 12–3. Fuel Requirements Problem

date Instrument Navigation Kit be carried on an instrument flight. Its minimum contents are:

Latest Radio Facility Chart.

H. O. 510 or *Instrument Approach Procedure Charts* ("Pilot's Handbook") for high-altitude aircraft.

Supplementary Flight Information.

E6D (AN 5834-18) Computer.

Navigation forms (Flight Log).

Appropriate WAC charts.

Appropriate Sectional charts.

Pilot's penlight (readily changeable from white to red).

While these are the minimum requirements, it is good procedure to carry the following also.

REST Computer and pilot's flight book for the particular aircraft.

Cross Country Gas Packet with signed forms to obtain fuel at either Navy, Air Force or Civil fields (Bring back a signed copy of each form used).

Spare batteries for penlight.

Several sharp pencils.

When the aircraft is to be away from the home base overnight, you must send an RON (Remain Over Night) message similar to this—

TV-2 BUNO 931868 LT DOE ROVNITE ELLINGTON AFB (Reason, if necessary, MECHANICAL, etc.) X ETD 261200Z.

When the aircraft is not serviced by the regular plane captain or crew chief, it is good practice to observe the fueling operation, personally check the fuel level in each tank, and check each tank cap for positive closure. Know how to pre-flight the aircraft just as the plane captain does each morning and *do it*. The Maintenance Officer will be glad to furnish the blank forms.

Fuel Requirements

To understand the relationship of fuel to time to miles, consider the cross section of a maximum-range, no-wind, flight at 35,000 feet in "standard conditions," as shown in Figure 12—3.

If you start with a full load of fuel, you have 813 gallons of fuel available in a TV-2 with centerline and tip tanks. However, you set 800 gallons on the totalizer in order to compensate for the possible 1% error in the totalizer and fuel measuring flowmeter. When you reach the destination, you will need 100 gallons for a 25-minute reserve and also 70 gallons for the *average* jet penetration and approach to landing under instrument conditions. (In each case, however, you have to check the specific situation to see whether you might need more because of the type of penetration.) Therefore, your should reach the destination with a minimum of 170 gallons, plus fuel to an alternate if required.

Since you will use 30 gallons for starting and taxiing, 172 gallons for the climb to 35,000 feet, and will need 170 gallons at the destination, you will have 428 gallons (of the 800 you start with) available for cruising to destination and to alternate (if required) at 35,000 feet. Using the REST computer and setting it for MAXIMUM RANGE, you find that the CAS is 220 K, TAS is 379 K, and that fuel consumption is 224 gallons per hour (GPH). The total fuel aboard, expressed in hours and minutes, is thus 3 hours and 4 minutes, as shown in the following summary:

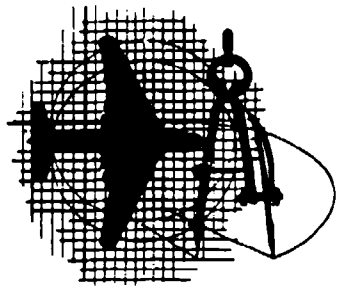
Taxi	30 gal.		
Climb	172 gal.	124 miles	23 minutes
Cruise	428 gal.	730 miles	115 minutes
Total	630 gal.	854 miles	138 minutes
Approach	70 gal.		46 minutes
Reserve	100 gal.		
Total	800 gal.		184 minutes=3+04.

Enter the time in the "Fuel in Hours" block on the DD-175 as 3+04. If you consider the alternate airport, you must remember that the distance from the destination is subtracted from the maximum range. This data gives you an idea of the no-wind range on a "standard day." However, each flight is always actually planned using existing winds and temperatures and may vary considerably.

AIRCRAFT CLEARANCE FORM DD-175

After you have filled out the flight plan portion of the flight log form you prefer, you are ready to prepare the clearance form DD-175. Filling out a clearance is not permission to make the trip in the manner planned, and such permission may later be granted subject to some changes. Therefore, if you prefer, you may file your clearance before you have finished the log form. However, you will observe that most of the log must be prepared first. The data needed from the flight log form to use on the clearance is:

1. Destination and mileage.
2. Route (Airways).
3. Altitudes.
4. TAS (also dependent upon altitudes).
5. Estimated time en route (ETE), which requires previous determination of ground speed and wind.
6. Fuel on board, computed in hours and minutes.

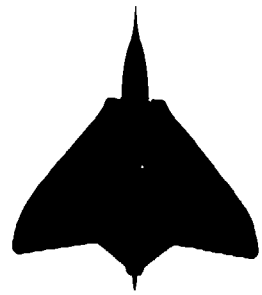


7. Alternate and ETE to alternate.

Form DD-175 is required for the clearance of all naval aircraft except local VFR flights, certain training flights, and international flights by Fleet Logistics. Approval by CAA's Air Traffic Control (ATC) is required for all IFR flights unless they are wholly outside control zones or control areas. Passenger stops not to exceed 15 minutes may be made without re-filing a DD-175 provided conditions are VFR and the original DD-175 showed full data on the stop.

For the method of preparing form DD-175 refer to the same DD-175 (Figure 12-4) which shows all the entries which are made by the pilot. The pilot fills out sections A, B, and C. The forecaster fills out section D. Section E is filled out in part by the Operations Duty Officer at the point of departure, except the last line which the pilot executes on the carbon copy at destination. The original, signed by the Operations Duty Officer in behalf of the Commanding Officer, remain at the station of departure. The carbon copy is taken by the pilot, and turned in to the Operations Duty Officer at the destination.

Sections A and B of Form DD-175 are more or less self-explanatory. Supply the first name and last name of occupants; not just initials.



Show the home station, but not the unit at that station. For example, a pilot assigned to FAWTULANT at NAS Key West, would just write "NAS Key West." Personnel on leave should show their unit; not home address. Personnel in transit should show the next duty station, since they are currently detached from their old station. Reserve personnel not attached to a unit should show the Naval District (or River Command) at which their records are kept.

Section C of the Clearance Form DD-175 is called the flight plan. This portion of the clearance form is the source of information sent to the Air Route Traffic Control (ARTC) center for the region, a service of the Air Traffic Control (ATC) division of the Civil Aeronautics Administration. ARTC, or "ATC" as it is often called in conversation, must approve the flight plan before any IFR flight is begun. This may be before takeoff by telephone to Operations and delivered in person or by radio to the pilot, or it may be by radio to a pilot who is flying a VFR leg before beginning IFR flight. In the sample form, for example, the clearance must be granted by ARTC before the

plane passes Savannah. Because of traffic conditions ARTC may make their approval conditional upon acceptance of revisions of route or altitude, or of delays in time to begin the IFR flight.

The Operations Office at the point of departure notifies ARTC of the following data from the DD-175: Radio call (last 4 numerals of aircraft serial number), type of aircraft, pilot's last name, point of departure, portions to be IFR or VFR, altitude(s) desired, route, destinations (first landing point), TAS, pilot rating, frequencies, ETD, ETE, alternate, hours of fuel aboard.

AIRCRAFT CLEARANCE
(DELIVER DUPLICATE TO BASE OPERATIONS AT DESTINATION)

DATE: 12 Dec. 1956

A. OPERATIONS OFFICE: NAS JACKSONVILLE — AIRCRAFT BUREAU NO.: 125079

B. OCCUPANTS (State whether crew or passenger. List only transient passengers on clearance when and if desired.)

DUTY	NAME AND INITIALS	GRADE	SERVICE NO.	ORGANIZATION	HOME STATION
PILOT IN COMMAND	GISH, JOSEPH R.	LCDR	128702	USN	NAS GLENVIEW
PASS	DOE, HAROLD A.	RADM	111201	USN	NAS NORFOLK
COPILOT	ANDREWS, JOHN (N.)	LT	368942	USNR	NAS GLENVIEW
PASS	RAUSCH, RAMON Q.	SOC	785014	USN	NAS NORFOLK

C. FLIGHT PLAN

RADIO CALL: NAVY 5079 — AIRCRAFT TYPE: SNB-5 — POINT OF DEPARTURE: NAS JACKSONVILLE — DESTINATION: NAS NORFOLK

ROUTE TO BE FLOWN

IFR	VFR	ALTITUDE	ROUTE	TO
	V	↑7000	A-7	SAVANNAH, GA
V		7000	A-7	CHARLESTON, S.C.
V		7000	A-9	GREENSVILLE
V		7000	DIRECT	NAS NORFOLK

RELEASE: 493 — ETD: 1120
EST FLIGHT TIME: 1 45 — ETA: 3 + 20
ALTERNATE: NAS CHINCOTEAGUE — ETE TO ALTERNATE: 0 + 33
TRUE COURSE: 255.4
PILOT'S LAST NAME: GISH
FUEL ON BOARD: 5 — 0

INSTRUMENT RATING

NAVY	AIR FORCE	ARMY
PERSONAL PILOT	PILOT RATING	PILOT RATING
STANDARD PILOT	INST RATING	CERT RATING

DATE INSTRUMENT CARD EXPIRES: 12 JULY 1957
DD FORM 1801 FILED AT: NAS KEY WEST — DATE FILED: 1 NOV. 56
PRESENT RANK OR GRADE: RADM

REMARKS: Request GCA at destination

Joseph R. Gish
SIGNATURE OF PILOT

D. ROUTE FORECAST (CLEARANCE)

DESTINATION	TIME OF ARR.	ALTERNATE (1ST)
ALTERNATE	TIME OF ARR.	ALTERNATE (2ND)

ROUTE	ETD	ACT. DEP.	TRUE COURSE	TRUE	VAR.
	ETE PLT. LVL.	MAGN. HDG.	DRIFT	MAG	FUEL
	ETA PLT. LVL.	ACTUAL	PRS PSTN	GNDSP	WIND VEL AND DIR
				DISTANCE	

E. FLIGHT CLEARANCE AUTHORIZATION

CLEARED TO	TIME	BY	DESIGNATION OF ISSUING AUTHORITY
INSTRUCTIONS AND OPERATIONAL TIMES TO BASES OR PILOT IN		ACTUAL T. O. TIME	
CLEARANCE ISSUED BY	TIME	NAME	GRADE OR POSITION

DD FORM 1 JAN 54 175 PREVIOUS EDITIONS OF THIS FORM MAY BE USED.

Figure 12-4. Form DD-175, pilot entries

Use the *Remarks* space on the Form DD-175 for any or all of the following:

1. Climb on course: In the case of jets or other aircraft going to a high altitude, the long period of climb will interfer with other aircraft along that portion of the route at all intermediate altitudes. While little interference with traffic may be expected in a climb to altitudes up to about 8,000 feet, a climb on course to high altitudes along any airway may cause trouble unless there is no other traffic. For that reason ARTC may not approve a flight plan involving a long climb on an airway. If you propose a climb on course, you should so state on the DD-175 in the *Remarks* space.

2. Position report locations: If you are below 15,200 feet altitude and on airways, list the compulsory reporting points. If you are above 15,200 feet on airways or at any altitude off airways but in a control zone or area, position reports are required at least every 200 miles. The locations proposed for the 200-mile position reports must be listed in the *Remarks* space where required. If you plan to fly on airways below 15,200 feet, you don't have to make entries, as your position report locations are predetermined by your route.

3. Requests: Requests for special services, especially GCA or ILS approaches, should appear in the *Remarks* space.

4. Other information: The *Remarks* space is used to report missing or defective equipment which will affect use of airways or airport aids (such as "ADF inoperative" or "No marker beacon receiver"). The instructions also require an indication regarding the reception to be given to any Flag Officers or other Very Important Persons (VIP's) on board. Use the code word "VIP" followed by "Fox" for "accord honors," "Love" for informal visits without honors, "XRay" for no honors but transportation furnished, or "Sugar" for no honors but servicing aircraft only, followed by title or rank and name of VIP.

CHAPTER 13

AIRWAYS SYSTEM AND CIVIL AIR REGULATIONS

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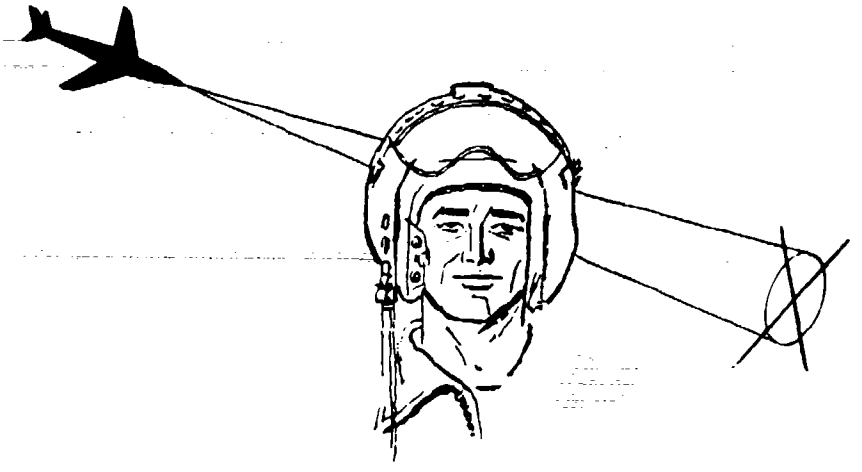


CHAPTER 13

THE AIRWAYS SYSTEM AND CIVIL AIR REGULATIONS

IN THE United States, as in most other countries, military aircraft are required to operate in accordance with civilian rules. Thus any flight in any aircraft in the United States is subject to Civil Air Regulations. There are only two exceptions to this general statement, and neither is a matter of pilot choice.

1. When the appropriate military authority determines that non-compliance is *required*, he may give notice to the Administrator of the CAA and order non-compliance.

2. Certain special military flights may be authorized by the CAA through a certificate of waiver that compliance with flight rules is not required. Furthermore, the CAA by its own rules permits a pilot to make emergency deviations from flight rules for safety reasons, but may require a written report from the pilot.

This is a matter of law, of course, and you have no choice but to comply. Aside from the law, though, you do benefit both in safety and in the advantages of using the CAA system of airways and navigational aids. To the Civil Air Regulations, the Navy has added certain flight restrictions of its own so that the Navy pilot is doubly restricted when flying in the United States.

THE AIRWAYS SYSTEM

The civil airways were initiated when the Aeronautical Branch of the Department of Commerce, in 1927, identified and surveyed the routes

followed by the air traffic between important terminals. Later, with the rapid increase of airways traffic during the late twenties and early thirties, it became apparent that controlled separation of traffic was necessary during periods of restricted visibility.

As the airway mileage increased from 1,200 miles in 1927 to 40,000 miles in 1949, a great expansion occurred in radio facilities and it became necessary to form an agency specifically authorized to assure aircraft separation during instrument flying weather conditions. Under the present organization of the Air Traffic Control Division of the Civil Aeronautics Administration, two services are furnished: Air Route Traffic Control and Airport Traffic Control. Since these two services overlap they are generally referred to by the single designation Air Route Traffic Control (ARTC).

The civil airways of the United States consist of a well-defined network of aerial highways. The Air Traffic Control division of CAA has authority to control air traffic operating within the boundaries of these airways and their intersections and terminal points. These airways are 10 miles wide and extend from an altitude of 700 feet upward.

All controlled airways are equipped with aids to navigation such as radio ranges, fan markers, homing stations, and z-type marker beacons used to mark the cone of silence over the range stations. In addition, some airways are marked with rotating light beacons for night visual flight. Airways which are uncontrolled and do not have these facilities are marked distinctively in the Radio Facility Charts.

Except for VOR airways discussed later, all airways are designated by color and number. The airway routes extending east and west have the designation of Green or Red and generally have even numbers; for example, the airway extending east and west between Camarillo, Calif., and Philadelphia, Pa., is identified as Green 4. Airway routes extending north and south have the designation of Amber or Blue and generally have odd numbers.

To simplify flight plan entries and clearances, the CAA has begun re-designating certain LF/MF airways. Figure 13-1 shows a typical example of the new method by which a single leg of an airway may bear two or more designations, with either the same or different color designations. Note here that the leg B to C is designated "Red 55/Green 91." It is not necessary to use both designations to refer to this leg; use either one. For example, a clearance from A to D would simply say "Red 55 to D." A clearance from E to D could read either "Green 91 to B; Red 55 to D" or "Green 91 to C; Red 55 to D."

VOR airways are designated simply by Victor numbers, such as V-14 between Oklahoma City and St. Louis. A given leg may have several designations, any one of which may be used in a flight plan or clearance. The airway from Phillipsburg, Pa. to Youngstown, Ohio, for example, is "V6, V30, V10," but at Youngstown these three airways separate and go off to different points, with V6 joining another airway which runs from Elmira to Cleveland via Youngstown, V72. A leg of a VOR airway can even bear both an odd and an even number, as, for example, the airway between Las Vegas and Mormon Mesa is V-21, V-8.

CONTROL OF AIR TRAFF ~ BY ARTC

ARTC was created in 1936 with the specific purpose of expediting the flow of air traffic along the civil airways during defined instrument flight conditions in a manner consistent with safety. This mission of ARTC necessitates control, which is delegated to 26 control centers in the continental United States, each center centrally located in the area over which it has jurisdiction. Each center controls an average of 2,100 miles of civil airways.

Each center is coordinated with all the CAA range stations located on the civil airways, with control towers at commercial and military airports, with military operations offices, and with airlines dispatch offices, by means of an interphone communication system. Each center is also connected with every other center by the interphone system.

The control of air traffic depends on the use of radio facilities. To establish effective control, the center must be in contact with all air traffic operating within the limits of the controlled areas. The same facilities that are used for air-ground

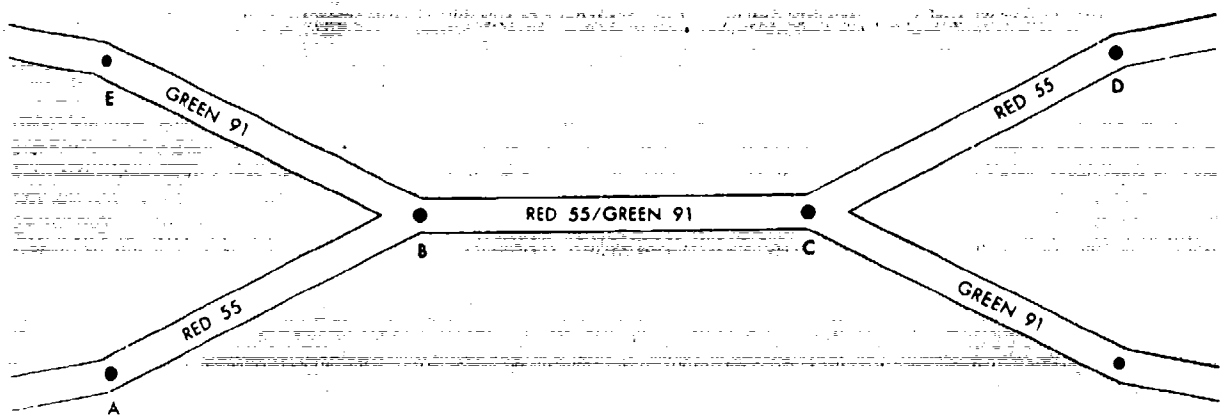


Figure 13-1. Designation of airways (LF/MF)

communications are used for radio navigation, for example, radio ranges. As a result, radio ranges and marker beacon facilities have become the basis for airways navigation and traffic control; without these, systematic traffic procedures could not have been developed.

Operating Procedures of ARTC

The successful operation of ARTC depends on coordination between the dispatching agency, the control towers, all the CAA radio facilities, and the control center. When flight conditions are below VFR minimums, and the pilot is planning a flight on or across civil airways, he submits the pertinent information to station operations. Station operations, in turn, submits the information to the appropriate ARTC center for clearance of the flight. Under no circumstances may the flight be conducted IFR unless clearance is granted by the appropriate ARTC center. ARTC clearance must be requested before take-off, but it may also be requested when the aircraft is in the air flying VFR and conditions change.

The significant feature of traffic control by ARTC is aircraft separation. This separation is provided in three dimensions: vertical, longitudinal, and lateral. Each dimension may be controlled when necessary.

Vertical Separation. Vertical separation occurs when the traffic is staggered at different altitudes. For instance, if several aircraft depart simultaneously from an airport with the intent of cruising in the same direction and on the same airway, they will be assigned different altitudes by ARTC. The minimum vertical separation is 1,000 feet, except on overwater and long flights.

Longitudinal Separation. Where the fixes are less than 100 miles apart, longitudinal separation is effected by timing flights so that a 10-minute interval exists between aircraft flying on airways at the same altitude and in the same direction. If the fixes along the airway are more than 100 miles apart, the time interval between the aircraft must be at least 15 minutes. This rule, however, is flexible and depends on the existing situation and the speed of the aircraft.

Lateral Separation. Lateral separation is effected by clearing traffic to fly on the right side of the airway or range leg. When this type of separation is used, the aircraft are cleared well to the right of the on-course of the range leg concerned. Lateral separation is generally used in combination with the other types of separation, rarely alone.

FLIGHT SERVICES (PLAN 62)

Flight Services is an Air Force function established to coordinate military flights, whether VFR or IFR. All military fields are connected by a

Flight Services teletype and interphone system. Since the actual control of IFR flights is handled by the CAA Air Traffic Control system, the function of Flight Services is keeping tabs on IFR flights rather than controlling them. VFR flights are fully under Flight Services Control. The Navy uses the communication facilities, rescue services, and in-flight advisory services of Flight Services. It does not usually utilize Flight Services clearance services. A Navy pilot is cleared from Air Force fields in accordance with Navy directives, the Air Force C. O. acting as if he were the C. O. of a Naval Air Station in its function as clearing authority.

Flight Services performs the following functions: (1) provides pre-flight briefings at Air Force stations, (2) operates as a VFR clearing authority for naval aircraft in some locations by agreement, (3) provides in-flight advisories (especially weather) on request through CAA radio facilities, (4) handles aircraft movement communications between military fields, (5) handles VFR clearances from fields where no CAA nor Flight Services communications facilities exist, (6) maintains a file of current military flight plans, (7) coordinates the air-rescue services of all types in emergencies, and (8) provides rapid assistance in regard to emergency landing fields. When airborne, a pilot contacts Flight Services through the nearest CAA ground/air radio station.

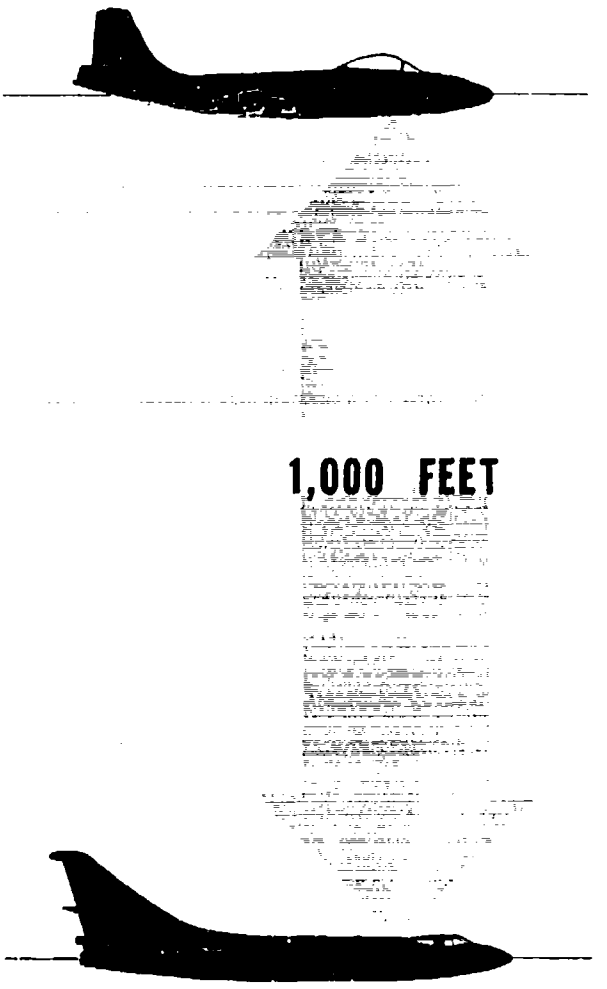


Figure 13–2. Vertical separation

APPROACH CONTROL

As an aircraft enters a control zone or area on IFR flight, Approach Control takes over from ARTC and handles holding and approach to the desired field. Approach Control functions by direct radio communication with the aircraft and operates from a designated tower, but on a different frequency. Where several airports are close together, one tower is designated as controller for approaches to all, and is staffed by specially trained men. This tower may be at either a CAA or a military field. Radio Facility Charts show the location of the approach control center handling a field.

Approach Control also controls IFR departures in its area or zone. The area of a control center is shown on the chart in Radio Facility Charts. At larger terminal points, such as Washington, D. C., Approach Control handles all IFR flights within an area of a certain designated radius from the master tower. Approach Control does not handle VFR operations.

Airport Traffic Control

Airport Traffic Control handles VFR air-traffic movements in the immediate vicinity of an airport. Traffic in the landing area, on the field, or in an airspace designated as a control area or zone comes under Airport Traffic Control jurisdiction. Radio communication is on the tower

frequency, and the tower grants permission and gives directions for landings, take-offs, and taxiing. When the aircraft is not radio-equipped, visual light signals are used. Under IFR conditions, however, landings and take-offs come under the control of Approach Control.

CIVIL AIR REGULATIONS, PART 60

Air Traffic Rules comprise Part 60 of the Civil Air Regulations. As a naval aviator, you should know these rules and keep up with changes. The full text is reprinted in the Supplementary Flight Information Document, and changes appear in Military Aviation Notices (MAN's) by teletype. These include the changes made from time to time in the limitations defining ceiling, visibility, clearance from clouds, and cruising altitudes for VFR and IFR which appear in C. A. R. Part 60. Naval aircraft are also bound by the current OPNAV Instruction titled "General Flight and Operating Instructions for Naval Aircraft" dealing with VFR/IFR limitations. These have occasionally been stricter than CAA standards.

Here is a summary of the parts of C. A. R. Part 60 which do not change very often. Check them for current accuracy, however, for changes may have occurred since this manual was printed.

CAR 60 General Flight Rules

Pre-flight action to be taken under IFR conditions includes only common-sense items such as a study of current weather forecasts and a study of fuel requirements, an alternate plan, and consideration of known traffic delays.

Careless or reckless operation of aircraft is prohibited and defined in part as a manner of operation which will endanger the life or property of others. Examples of such operation are buzzing buildings, vehicles, vessels, persons, or livestock. Another interesting example of endangering the property of another is the case of a person piloting in a reckless manner an aircraft which he does not own. Becoming involved in instrument flight without proper clearance, equipment, or rating is another case cited as a lack of vigilance on the part of a pilot.

Airspace Restricted Areas

Airspace restricted areas are defined as "designated areas in which flight is restricted . . . established by appropriate authority." They are shown on aeronautical charts and published in NOTAMS as "Prohibited," "Restricted," and "Warning" areas. In Prohibited Areas, flight is prohibited at all times. In Restricted and Warning Areas, flight is prohibited while the area is in use. The areas so designated are indexed and shown in Radfacs. To enter a Prohibited Area at any time and a Restricted or Warning Area when it is in use, you must have permission from the appropriate authority.

Right-of-Way

The right-of-way of one aircraft over another is broken down into the following circumstances or categories:

1. An aircraft in distress has the right-of-way over all others.

2. A priority of aircraft types converging is established on the order of (1) balloons, (2) gliders, (3) airships, (4) airplanes and rotocraft. Aircraft of a similar category converging at the same altitude are governed by the rule that the one on the right has the right-of-way. (See Figure 13-3.) Powered aircraft always yield to towed or towing aircraft.

3. Course is altered to the right by each aircraft when two aircraft approach head-on.

4. An overtaken aircraft has the right-of-way over an aircraft overtaking it, and it is the responsibility of the latter to avoid collision by altering to the right until past and clear.

5. Landing aircraft have the right-of-way over other aircraft in the air or on the ground. When two aircraft are in their approach, the lower has the right-of-way. Regardless of right-of-way, all pilots are responsible to avoid the possibility of collision with other aircraft.

Formation and Acrobatic Flight

Formation flight is prohibited except by prearrangement between pilots in command.

Acrobatic flight, defined as "maneuvers intentionally performed by an aircraft involving an abrupt change in its attitude, an abnormal attitude, or an abnormal acceleration," is prohibited under the following conditions:

1. Over congested areas of cities, towns, or over open air assembly of persons.

2. Within any civil airway or control zone.

3. When flight visibility is less than three miles.

4. Below an altitude of 1,500 feet above the ground.

Minimum Safe Altitude

In congested areas, a minimum safe altitude is one that is at least 1,000 feet over the highest obstacle within a radius of 2,000 feet. Enough altitude must be maintained to assure that, in the event of an engine failure, an emergency landing could be effected without endangering persons or property on the surface. Elsewhere all persons, livestock, vessels, vehicles, or buildings must be cleared by at least 500 feet.

Under IFR conditions, 1,000 feet clearance over the highest obstacle within 5 miles of the centerline of the intended course must be maintained or the altitude specified for each airway by the administrator.

Miscellaneous Rules

Left-hand traffic is the normal field pattern.

The pilot is responsible for giving an arrival notice to the tower or nearest CAA communications when a flight plan has been filed.

All aircraft in flight or operated on the ground or water must display position lights between sunset and sunrise. In addition, unless the aircraft is in an area marked with obstruction lights, it must be clearly illuminated or lighted between sunset and sunrise whenever it is parked or moved in dangerous proximity to the portion of an airport which might be used for night flight operations.

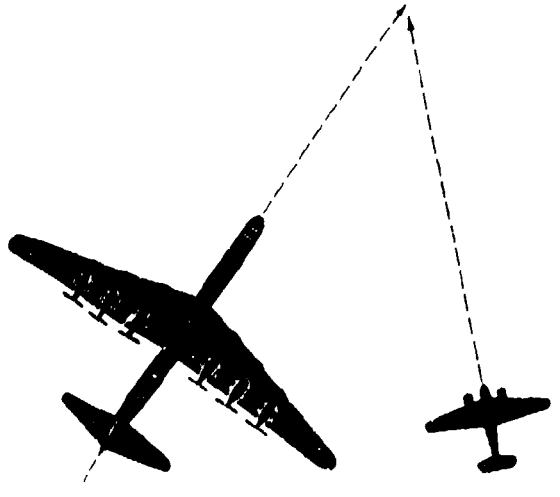


Figure 13-3. Which plane has the right of way?

Definitions

Air traffic clearance—authorization by air traffic control, for the purpose of preventing collision between known aircraft, for an aircraft to proceed under specified traffic conditions within a control zone or control area.

Air traffic control—a service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic.

Control area—an airspace of defined dimensions, designated by the administrator, extending upward from an altitude of 700 feet above the surface, within which air traffic control is exercised (Figure 13-3).

Control zone—an airspace of defined dimensions, designated by the administrator, extending upward from the surface to include one or more airports, and within which rules additional to those governing flight in control areas apply for the protection of air traffic. (Figure 13-4)

Ceiling—the distance from the surface to the lowest cloud layer reported as "broken clouds," "overcast," or "obscuration."

Cruising altitude—a constant altimeter indication, in relation to sea level, maintained during a flight or portion thereof.

Flight visibility—the average horizontal distance at which prominent objects may be seen from the cockpit.

Ground visibility—the average range of vision in the vicinity of an airport as reported by the U. S. Weather Bureau—if unavailable, by an accredited observer.

Visual Flight Rules (VFR)

Flights must be conducted in accordance with either visual flight rules (VFR) or instrument flight rules (IFR) in addition to complying with the general flight rules just outlined and discussed. Weather conditions permitting, VFR may be followed.

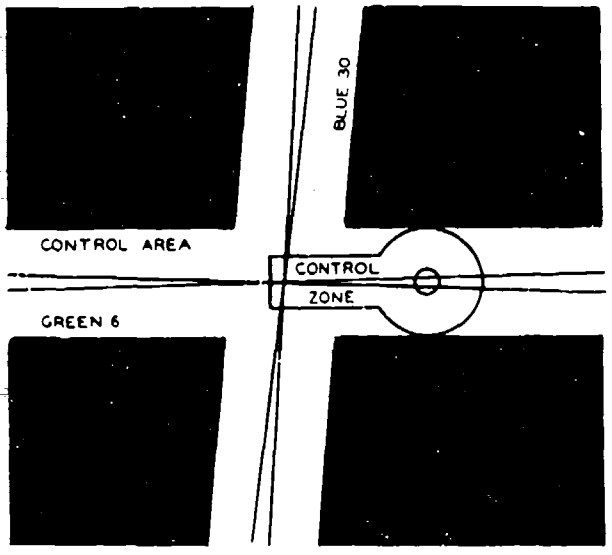


Figure 13-4. Control zone, control area

Cruising Altitudes

At an altitude over 3,000 feet above the surface and outside of control zones and control areas with flight visibility of less than 3 miles, the cruising altitude is regulated by magnetic course as follows (Figure 13-4):

1. 0° to 89° inclusive—odd thousands (3,000, 5,000, etc.).
2. 90° to 179° inclusive—odd thousands plus 500 (3,500, 5,500, etc.).
3. 180° to 269° inclusive—even thousands (4,000, 6,000, etc.).
4. 270° to 359° inclusive—even thousands plus 500 (4,500, 6,500, etc.).

Within control zones and control areas, an altitude of an odd or even thousand-foot level appropriate to the direction of flight as specified by the administrator shall be adhered to (Fig. 13-5).

Flight Plan

Though flight plans are not required by the CAA for VFR flight, Air Traffic Control will accept such plans when requested by the pilot. This is a provision incorporated for the benefit of the civilian pilot so that he may take advantage of the search and rescue facilities which may be available in emergencies. The information contained in such a flight plan is of importance to search and rescue operations. Since military pilots, however, file through "Flight Service," this feature would seldom be used.

Instrument Flight Rules (IFR)

When weather conditions are such that VFR flights are not possible or not desired, flight operations are conducted under IFR. Under IFR, the flight plan must be filed with air traffic control before take-off within a control zone or control area. The flight plan must include the information from Part C, Form DD-175.

Weather requirements for an alternate airport contain the provision that the current weather reports and forecasts must show a trend indicating that the ceiling and visibility will be at or above the prescribed alternate minimums at the time of arrival.

A flight under IFR must obtain an air traffic clearance from Air Traffic Control before taking off from a point within a control zone or before entering a control area or control zone.

For flights operating within control areas or control zones, cruising altitudes under IFR are any altitudes authorized by Air Traffic Control. Outside of control zones or control areas, the same magnetic-course-to-altitude relationship applies as under VFR above 3,000 feet outside control areas and control zones.

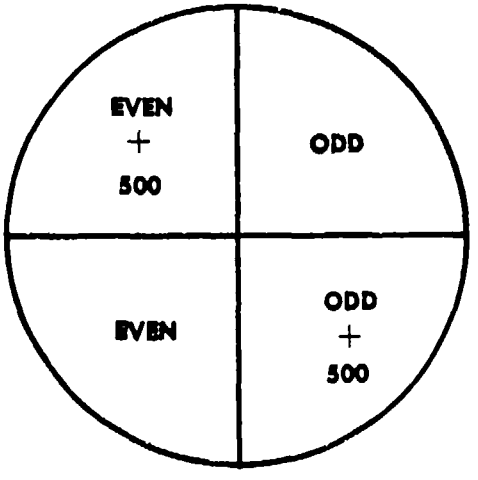


Figure 13-5. Odd or even levels are adhered to in control zones and control areas

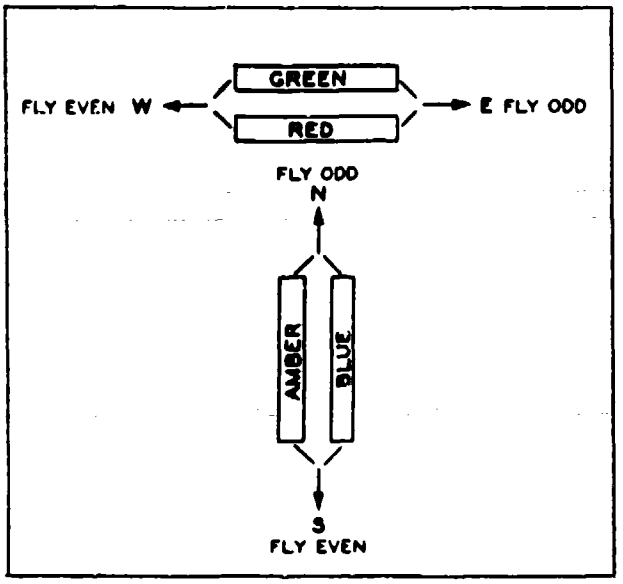


Figure 13–6. Cruising altitudes in control areas or control zones

Normally, aircraft operating along the civil airways must be flown to the right of the center line of an LF/MF airway, or on the radial designated as center line of a VOR airway.

Standard instrument approaches prescribed for individual airports must be used when instrument letdown to an airport is necessary. There may be an exception to this rule only when a different instrument approach is specifically authorized by the administrator, or a different instrument approach procedure is authorized by air traffic control for the particular approach.

Two-Way Radio Communication

A continuous listening watch must be maintained on an appropriate radio frequency during the conduct of a flight under IFR, and the time and altitude of passing each designated reporting point must be reported as soon as possible. Included in this report should be weather information which has not been forecast, such as icing or extreme turbulence, and any other information pertinent to safety in flight.

In case two-way radio communication cannot be maintained, the pilot must take one of the following courses of action.

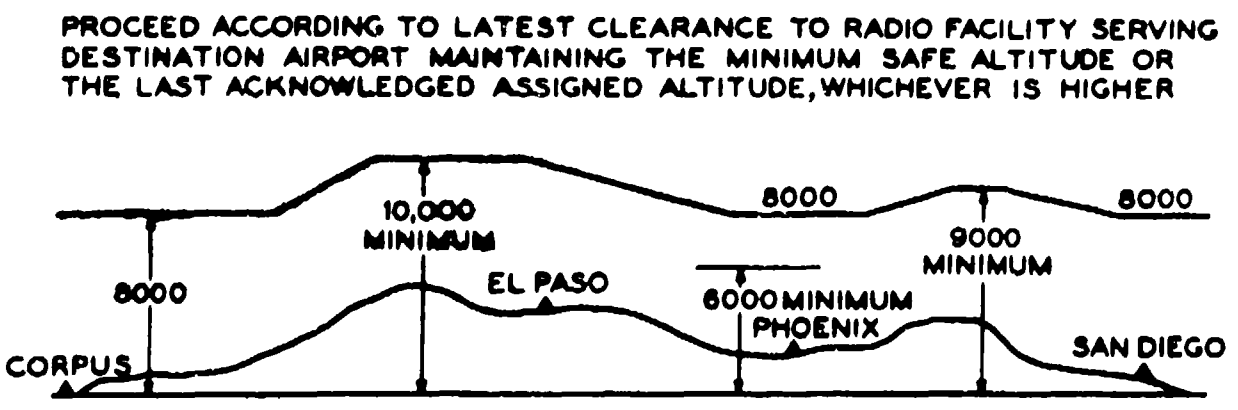
1. He must, if operating under VFR conditions, proceed under VFR and land as soon as practicable.

2. An alternate procedure is for him to proceed according to the latest air traffic clearance to the radio facility serving his destination, maintaining minimum safe altitude or the last acknowledged assigned altitude, whichever is higher. He starts his descent at the expected approach time last authorized, or, if not received and acknowledged, at the estimated time of arrival indicated by the elapsed time specified in the flight plan. (The expected approach time mentioned is defined as the time that an arriving aircraft will be cleared to commence approach for a landing.) (See Figures 13–7 and 13–8.)

VFR/IFR Ceiling and Visibility Minimums

Although the current regulations of the CAA and Navy in regard to the minimum of ceiling

Figure 13–7. Loss-of-communications procedure



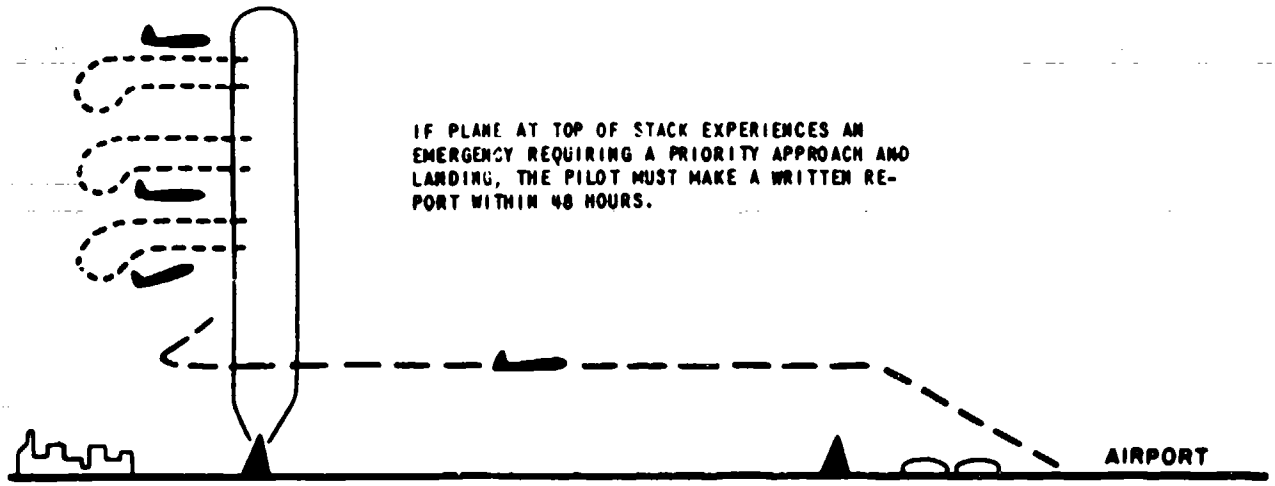


Figure 13–8. Emergency approach

and visibility for VFR and IFR flight may change from time to time, they are included here as general information. In actual operation, see the latest, revised edition of the *Supplementary Flight Information Document* for the current rules.

At present, the following are the minimums for VFR flight. These apply at the point of departure, along the entire route, and at destination unless authorization is obtained to ignore the visibility limitation within the airport control areas.

Visibility.—In control zones, 3 miles unless authorization for lower minimums is received; outside control zones and under 700 feet, the CAA requires 1 mile and the Navy requires 3 miles.

Ceiling and Distance from Clouds.—In control zones, ceiling 1,000 feet, and clearance 500 feet vertically under, 1,000 feet vertically over, and 2,000 feet horizontally from any cloud formation. Outside control zones and below 700 feet, the aircraft must remain clear of clouds. Outside control zones and above 700 feet, 500 feet vertically under, 1,000 feet vertically over, and 2,000 feet horizontally from any cloud formation.

The alternate airport weather minimums for IFR flight refer to the weather forecast for the time of arrival. If there are published minimums for the airport, of course they are the ones that apply. If there are no published minimums, the minimums are as follows:

For an airport with radio direction facilities—ceiling 1,000 feet, visibility 1 mile; or ceiling 900 feet, visibility 1½ miles; or ceiling 800 feet, visibility 2 miles. For an airport without radio direction facilities—ceiling 1,000 feet with broken clouds or better, visibility 2 miles.

CHAPTER 14

CONTROL OF AIRWAYS TRAFFIC

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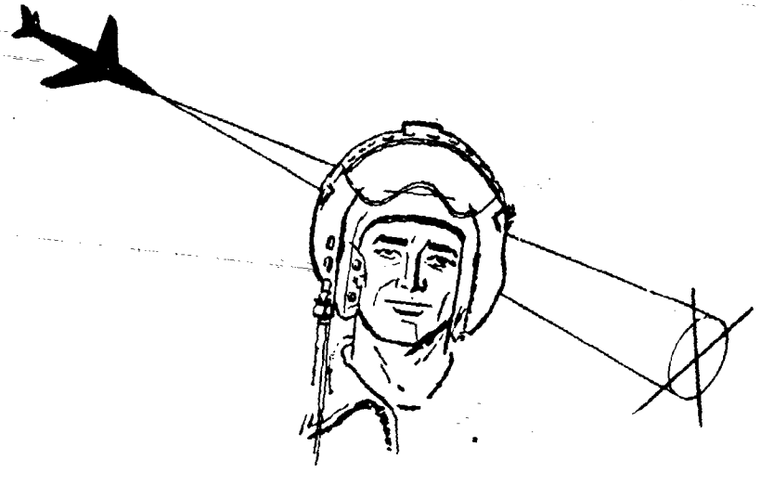


CHAPTER 14

CONTROL OF AIRWAYS TRAFFIC

WHEN an aircraft operates on the airways, as we have seen, it becomes subject to CAA control. If it flies by IFR, it must receive clearance by Air Route Traffic Control (ARTC), fly by the route and altitude instructions of ARTC, make position reports as required, and generally pass over to Approach Control at the holding point or fan marker of the destination area. If a military aircraft flies by VFR, either on or off airways, it is subject to Civil Air Regulations, its flight is reported to Flight Services, and at both take-off and landing stations it is subject to control by Airport Traffic Control.

Such operations necessarily create the requirement that the pilot follow certain procedure as to his requests and reports made by radio. Standard phraseology is one of the procedural aids to proper flight. Ability to understand and obey instructions is another requirement placed on the airways pilot. These procedures, are the subject of this chapter.

FLIGHT CLEARANCES

Every aviator, civilian or military, assumes certain responsibilities when he embarks on a flight utilizing the Civil Airways Network. The most important of these responsibilities is movement and control of his aircraft with regard to other traffic using the same routes.

The ARTC clearance is the authorization to proceed on an instrument flight. At military and

civilian fields with control towers, the clearance is relayed to the aircraft via the tower. Before the clearance can be considered, however, the pilot must declare his intent to make a flight and the routes which he desires to follow. This declaration is commonly known as the flight plan. The filing of a flight plan, in itself, does not constitute permission to make the flight.

Clearance, of course, may be requested and be received while in the air. The request is made verbally through a ground communications station and the clearance relayed to the aircraft via a similar agency. The inside cover (last page) of Radfacs shows the proper method of making this request.

The flight clearance constitutes the authority to proceed under the specified conditions only insofar as known traffic is concerned. Clearances are based solely on expediting and separating air traffic and do not constitute authority to violate the CAA regulations.

Types of Clearance

The type of clearance for the flight is determined largely by the weather involved. Since ARTC is not concerned with VFR flights, this type of clearance is not considered here. The weather minimums for VFR flights are important, however, as the basis for filing flight plans for IFR flights. These minimums were stated in the last chapter, but in practice be sure to check the minimums prescribed in current OPNAV instructions. IFR flight is necessary when VFR minimums cannot be maintained. Therefore, an IFR flight plan must be submitted to the appropriate ARTC center when such flights are in or across controlled zones or areas. Here are several types of IFR clearances issued by ARTC:

Specified Altitude Clearance. In this type of clearance, the pilot usually requests an altitude that will be maintained while flying on airways during the instrument weather conditions. If this altitude is not available because of other traffic, the ARTC center will specify an available altitude at which the flight can be conducted.

IFR 1,000 on Top. This type of clearance is used when the flight is to be conducted at least 1,000 feet above broken clouds or an overcast. Visibility must be at least 3 miles above the cloud layers for this type of flight.

There are many instances when the submitted flight plan cannot be approved and the center specifies a revised plan subject to the approval of the pilot submitting the original. This occurs when the ARTC center cannot approve the submitted flight plan because of congested traffic conditions or because aircraft have been previously assigned to the altitude requested in the flight plan. In this case, the control center recommends another altitude for the flight plan and the pilot can either accept the revised plan or accept a delay in the approval of the proposed flight plan. The flight may be rerouted also to eliminate long delays which would result from the presence of aircraft at all 1,000-foot levels on the desired airway route. When heavy traffic exists within the clouds, ARTC clears later traffic, when possible, for a "1,000 on top" flight, since horizontal visibility of 3 miles or better make traffic separation much easier.

What a Clearance Consists Of

Clearances consist of the following:

Flight or aircraft identification—for example, Navy 1234 or MATS 4904.

Clearance limit and route—normally to airport, range station, or tower at point of first intended landing. It might be an en route reporting point, because of uncertainty of traffic beyond certain points. The flight route is specified, for example, "VIA (color) AIRWAYS TO (reporting point)" or "VIA DIRECT (reporting point) TO (reporting point)." It may also be "VIA FLIGHT PLANNED ROUTE."

Altitude, Approach and/or departure procedure—altitude information consisting of:

1. Cruising altitude or altitudes.
2. Altitudes over reporting points to be crossed at other than cruising altitude.
3. Where to start climb and/or descent when necessary.
4. Departure or approach altitudes when necessary.

Special information—known traffic and its location and any other information which may be useful to the pilot in following the particular clearance.

Message delivery information and/or cancellation time if necessary—agencies through which messages may be relayed, either to or from the aircraft (which frequencies to guard), and, if applicable, the time at which the clearance expires, for example, "THIS CLEARANCE IS GOOD UNTIL (time) CST."

STANDARD PHRASEOLOGIES

All clearances issued by ATC and relayed to the pilot by any other communications agency is prefixed with the phrase "ATC CLEARS . . ." The cognizant center is usually identified at this time, for example, "SAN ANTONIO ATC CLEARS . . ."

Clearance Limit and Route

Here are some examples of phraseologies used for various clearance limits and routes:

1. ATC CLEARS NAVY 1234 TO ALAMO AIRPORT VIA DIRECT CORPUS CHRISTI, BLUE 30 LOSOYA INTERSECTION AND AMBER 4 TO ALAMO.

2. ATC CLEARS NAVY 1234 OUT OF CONTROL AREA/ZONE 25 MILES NORTHWEST OF CORPUS CHRISTI. (This type is normally used when aircraft will not again enter a control area.)

3. ATC CLEARS NAVY 1234 TO THE PENSACOLA RANGE STATION DIRECT.

4. ATC CLEARS NAVY 1234 FROM SAN ANTONIO TO MIDLAND AIRPORT VIA THE C. B. RANCH AND MERTZON INTERSECTIONS. (This makes the C. B. Ranch and Mertzon Intersections compulsory reporting points.)

5. ATC CLEARS NAVY 1234 FROM CORPUS CHRISTI TO THE HOUSTON AIRPORT. (The color and number of the airway are omitted because only one possible route exists. The airway must be followed unless the clearance specifically authorized direct.)

Attitude and Departure Procedure

Here are some examples of the phraseologies used for various altitude and departure procedures:

1. MAINTAIN 5,000 FEET. CLIMB VFR.

2. MAINTAIN 5,000 FEET UNTIL FURTHER ADVISED. (A further clearance will probably be received from a compulsory reporting point station.)

3. MAINTAIN 7,000 FEET WHILE IN CONTROL AREA, CLIMB WELL TO THE RIGHT OF COURSE, REPORT PASSING 3,000 FEET AND 6,000 FEET.

4. MAINTAIN 1,000 FEET ABOVE ALL CLOUDS, TAKE OFF RUNWAY 25, CLIMB ON HEADING 295. REPORT WHEN CLEAR OF ALL CLOUDS.

Approach and Holding Procedure

Here are some examples of the phraseologies used for various approach and holding procedures. (See Figure 14–1.)

1. CLEARED TO GOODFELLOW TOWER FOR A STANDARD RANGE APPROACH TO THE GOODFELLOW AIRPORT. The aircraft descends to the initial approach altitude for the San Angelo Range station (3,500 feet on S. W. leg) and makes initial approach at this altitude. After passing range station, the aircraft proceeds out on approach leg for 4 minutes, makes procedure turn, crosses low cone at approved minimum altitude and lands if possible (Air Traffic Rules, Part 60, Section II). Communications are maintained with ATC until VFR.

2. PROCEED FOUR MINUTES OUT ON SOUTHWEST (APPROACH) LEG. NOTIFY ATC WHEN COMMENCING STANDARD APPROACH. The aircraft must proceed outbound on letdown leg for 4 minutes before commencing procedure turn (standard range approach). Voice communication is to be maintained with ATC through the range station.

3. CONTACT CORPUS CHRISTI AP-

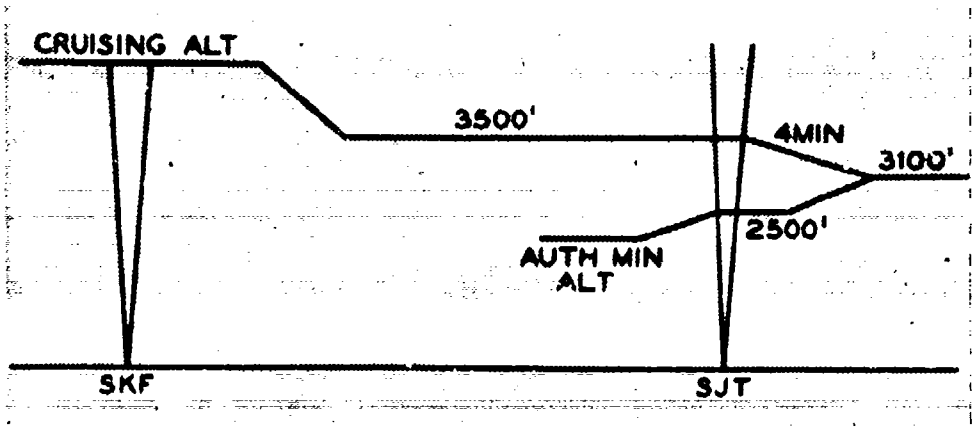


Figure 14-1. Typical range approach

PROACH CONTROL ON 382 KCS OR 126.18 MEGACYCLES FOR FURTHER CLEARANCE. Further instructions pertinent for letdown will be received from Corpus Christi Approach Control on indicated frequencies.

4. CLEARED TO THE ODEM FAN MARKER MAINTAIN 5,500 FEET. HOLD BETWEEN ODEM AND A POINT TWO MINUTES NORTHWEST. EXPECTED APPROACH TIME 1724. In case of two-way communication failure, the expected approach time (1724) is the time at which the aircraft should leave the last assigned altitude and commence a standard range approach. The term APPROACH TIME authorizes descent below the last assigned altitude at the specified time only in case of radio failure.

5. NAVY 1234 CLEARED TO DESCEND TO 1,500 FEET. DEPART ODEM 1724. This is a standard approach control clearance. The clearance does not include authorization to descend below 1,500 feet but to depart the Odem fan marker inbound at 1724.

6. VFR. This continuation of the approach under visual flight rules after ground contact has been established is authorized only after it is requested by the pilot.

CONTACT APPROACH APPROVED; IF NOT POSSIBLE—(alternate procedure, for example, maintain 3,000 feet) AND ADVISE.

VFR APPROACH; IF NOT POSSIBLE (alternate procedure, i. e., climb to 4,000 feet, well to right of course) AND ADVISE.

Special Information

There are no standard phraseologies for special information. The phraseology includes the desired information in clear, concise language and as briefly as practicable.

Message Delivery Information

Message delivery information and/or cancellation time, if necessary, is clearly presented in concise language and as briefly as possible. Instructions for relaying clearances are included as needed. The time at which the clearance will expire and require the filing of a new request is included if applicable.

DEFINITIONS AND SYMBOLS

Definitions

For clear understanding of clearance terms and agencies, some of these items are defined below.

Air Route Traffic Control Center—a facility established to provide adequate supervision of air traffic within a specified control area.

Essential traffic—traffic between which the required vertical, lateral, or longitudinal separation is not being maintained.

Cruising Altitude—a constant altimeter indication with the current altimeter setting in relation to sea level, maintained during a flight or portion thereof.

Penetration—For jet aircraft, a penetration is the name given the equivalent of a letdown and procedure turn for conventional aircraft.

Expected approach time—the time at which it is expected that the aircraft will be cleared to commence an approach procedure to landing and, lacking further instructions, the time at which the aircraft may start descent from the last assigned altitude.

Expected departure time—the time at which it is expected that the aircraft will be cleared to depart from the holding fix to commence an approach to landing, but which does not, in itself, permit descent from the last assigned altitude.

(See also the additional definitions in the previous chapter, especially "Control Zone" and "Control Area".)

Clearance Symbols

The volume of flight clearances which must be delivered does not permit excessive repetitions of the clearance. Nor does the normal speaking rate allow time for longhand copying of the clearances. As an aid in copying clearances, a series of symbols has been devised and standardized for use as clearance shorthand. Here are some of the more useful ones and their meanings:

C = ATC clears.
A = Airport.
T = Airport control tower.
R = L/MF radio range station.
O = VOR or omni range station.
OM = Outer marker.
FM = Fan marker.
V11 = Via victor airway eleven.
G5 = Via green airway five.
R20 = Via red airway twenty.
A7 = Via amber airway seven.
B25 = Via blue airway twenty-five.
→ = Via direct route.
⌒ = Via flight planned route.
M = Maintain.
IMM = Immediately.
↑ = Climb to.
↓ = Descend to.
+ = Cross.
X = Intersection.
/ = Until.
" = Minutes.
> = Reverse course.
_ = Over.
+/- = Intercept
1/• = 1,000 feet on top
@ = At
& = And
△ = While in control area.
△/ = Leave control area.
△\ = Enter control area.
= = While on airways.
+ = Cross airways.
+ = Join airways
No— = Not over or not above.
5 or up = 5,000 feet or higher.
RWR = Remain well to the right of,
cus = Course.
H 030 = On a magnetic heading of 030°.
T 030 = On a magnetic track of 030°.
R 030 = The 030° radial of a VOR or omni range station.
IR 030 = Inbound on the 030° radial.
OR 030 = Outbound on the 030° radial.
1 = 1,000 feet.
10 = 10,000 feet.
20 = 20,000 feet.
21 = 2,100 feet.
21, = 21,000 feet (comma after 21 and up indicates thousands).
PST = Past.
BLO = Below.
ABV = Above.
IF NO = If not possible.
ADV = Advise.
RT = Right turn.
LT = Left turn.
RS = Right side.
LS = Left side.
H = Hold.
Pat = Pattern.
○ = Contact.
c = Air Traffic Control Center (CLEc).
apc = Approach control (CLEapc).
TERC = Terminal control.
RL = Report leaving.
RR = Report reaching.
RP = Report passing.
Rep = Report.
APCH = Approach or approaching.
ffc = For further clearance.
UFA = Until further advised.
eac = Expect approach clearance.
∧ = No delay expected.
∨ = Delay indefinite.
EST = Estimat(ed).
PSG = Passing.
VFR = In accordance with visual flight rules.
Rem = Remain.
TFC = Traffic.

BND = Bound.
IBND = Inbound.
OBND = Outbound.
BFO = Before.
AFT = After.
NL = Not later than.

If you have prepared for flight on the airways, you have investigated the route, and this normally gives you a working familiarity with the identification symbols of the en route stations. Identification signals provide an excellent shorthand device for use in copying clearances. Where the symbols and abbreviations are not sufficient for copying the complete message, use plain language.

Here is a sample of a flight clearance as it might be transmitted to the aircraft followed by a sample of the same clearance written in symbols and abbreviations.

SAN ANTONIO ATC CLEARS NAVY 1234 TO THE SAN ANTONIO RANGE STATION VIA DIRECT GREGORY GREEN 6 CORPUS CHRISTI BLUE 30 AND AMBER 4 TO SAN ANTONIO. MAINTAIN 7000 FEET AND TURN RIGHT AFTER TAKEOFF. REMAIN WELL TO THE RIGHT OF COURSE. REPORT PASSING 3000, 4000, AND 6000 FEET, CONTACT SAN ANTONIO APPROACH CONTROL ON 344 KCS OR 126.18 MEGACYCLES AT LOSOYA INTERSECTION FOR FURTHER CLEARANCE: DELAY INDEFINITE, EXPECT APPROACH CLEARANCE NOT LATER THAN 1645 CENTRAL STANDARD TIME.

SAT C N1234 TO SAT R → GRG G6 CRP B30 LOS A4 SAT M7 RT AFT TO RWR CUS RR 346 O SAT APC 344 OR 126.18 @ LOS

X ffc V eac NL 1645C

ADIZ CLEARANCES AND REPORTS

To protect the United States, Alaska, and Canada from enemy attack, Air Defense Identification Zones, ADIZ, have been established on our borders. Unidentified aircraft entering these zones will be intercepted by fighter aircraft and may be shot down. Legitimate air traffic must obviously (1) be identified and authorized, and (2) adhere to the authorized route and schedule of arrival. This prevents needless air-raid alarms, interceptor scrambles, and hazards to the aircraft in the zone. ADIZ flights must, therefore, be authorized for route and time of penetration and must make position reports. This creates a special flight plan known as a DVFR flight plan—that is, a flight plan for VFR flight in an ADIZ.

Figure 14-2 shows a map of the Air Defense Identification Zones as established at the date of publication of this manual. These zones, however, are subject to change. Check the current ADIZ boundaries in the Supplementary Flight Information Document and on current WAC charts. ADIZ procedures are described in the Supplementary Flight Information Document. Refer to the data in the CAA Flight Information Manual for the interception pattern used by Air Defense Command in identification intercepts of transports aircraft.

Definitions

A *Coastal ADIZ* is one which is established over ocean areas adjacent to the coastal international boundary. Ten minutes before entering such an ADIZ, report your position and intended course to CAA radio (or, Alaskan Coastal ADIZ, to CAA or military airway station).

A *Domestic ADIZ* is an ADIZ wholly within the borders of the U. S. If you are already in the United States, report to the last CAA radio on (or adjacent to) your route before entering the Domestic ADIZ, and give your estimated time of entry and proposed route or course. Adherence to your flight plan is required.

A *Boundary ADIZ* appears where there is a Domestic ADIZ with one side of it the international boundary between the U. S. and Canada or Mexico. This ADIZ is a line rather than an area. Even though you are already in a Canadian ADIZ (CADIZ), for example, a report is required before crossing the Boundary ADIZ into a Domestic ADIZ.

A *Canadian ADIZ or CADIZ* is an ADIZ wholly within Canadian boundaries.

A *Security Identification Zone* (SIZ) is a narrow lane across a CADIZ for identification of

aircraft below 4,000 feet. Unlike the U. S., Canada permits VFR flights in a CADIZ without flight plans below 4,000 feet except in crossing southbound through the SIZ. Southbound flights through the SIZ must file a flight plan at least 15 minutes before intended entry into the SIZ. The SIZ is 20 nautical miles from north to south.

Flight Plans for ADIZ

Pilots of IFR flights, of course, always file a flight plan (through the Clearance Form DD-175) with ARTC. No further action is required of IFR flights to prepare for flight into an ADIZ. The pilot of VFR flight, however, must file such a flight plan, known as a DVFR flight plan, in order to enter an ADIZ or operate within an ADIZ. This flight plan must include route and altitude. (Aircraft without radio must remain below 4,000 feet.) The flight plan must be filed before take-off, and no flight plan may be submitted in flight or changed in flight to enter an ADIZ except in an emergency. If it becomes obvious that the route or schedule in a DVFR flight plan cannot be adhered to, corrected information must be transmitted immediately to the appropriate radio facility.

ADIZ Position Reports

Pilots of IFR flights make routine position reports in an ADIZ, except when not in a control zone or area, in which case they report as if DVFR. Pilots of DVFR flights must report position before actual entry into an ADIZ and while in an ADIZ at least once hourly as required. In the Alaska region, reports must be made every thirty minutes, unless IFR on airways. In Canada, position reports are only required when entering a CADIZ and when southbound into a SIZ.

Position reports consist of time, position, and

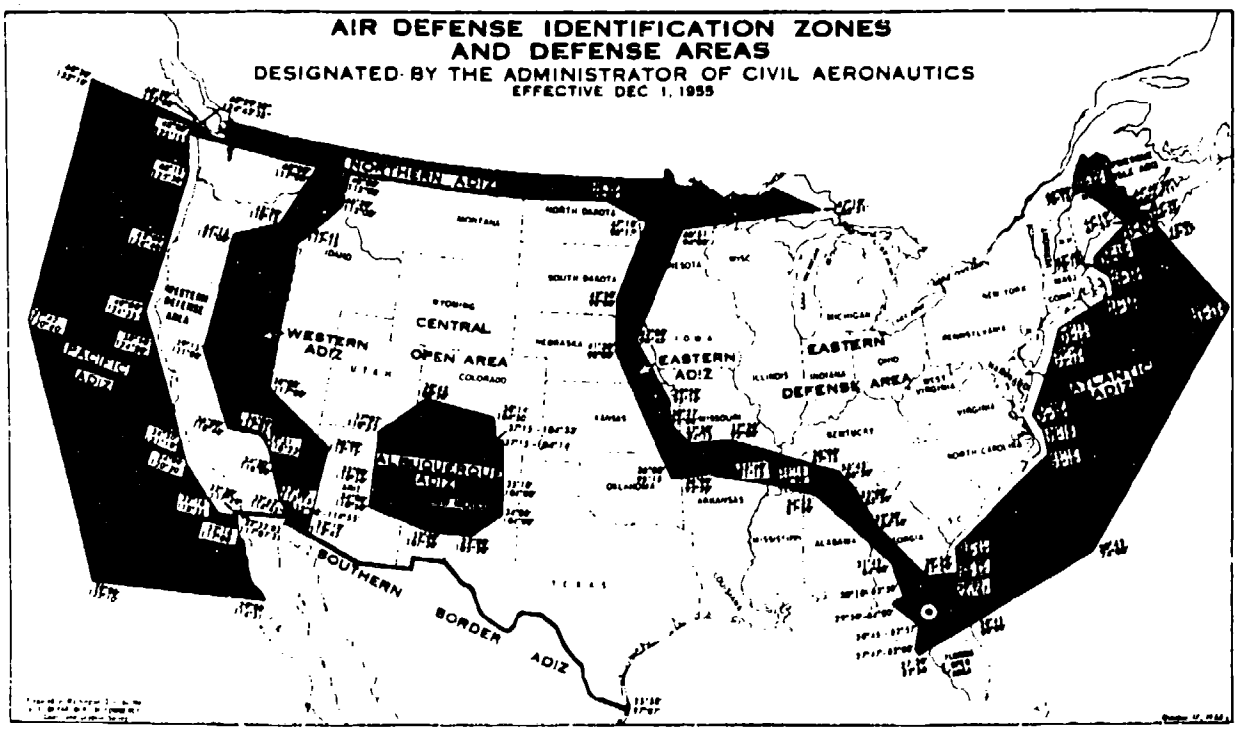


Figure 14–2. Air Defense Identification Zones

altitude over the last reporting point and the ETA at next reporting point; or, if that is impractical, report 15 minutes before penetration the time, position and altitude of intended penetration.

ADIZ Tolerances

IFR flights within control areas are subject only to the usual rules as to deviations from course, altitude, or time schedule. IFR flights outside control areas and DVFR flights must report immediately any deviations in excess of five minutes from the estimated time of penetration, over a reporting point, or take-off within an ADIZ. No altitude deviations are permitted in U. S. and Alaskan ADIZ's, except to begin a normal VFR descent within a reasonable distance of destination, unless prior notice is given to the appropriate radio facility. Deviations of more than 10 miles from the center line of the proposed route (20 miles in Coastal ADIZ) must also be reported immediately.

AIR TRAFFIC CONTROL

Air Traffic Control is established to promote the safe, orderly, and expeditious movement of air traffic. It is broken down into Air Route Traffic Control covering traffic between airports in Control Areas and Control Zones, Area Traffic Control in a specified Control Area, Approach Control handling IFR arrivals and departures to and from airports, and Airport Traffic Control which handles traffic in the vicinity of an airport either within a Control Area or at locations not covered by an Air Traffic Control Center. The airport handles the only separation control of VFR flights. IFR flights are under control of either ARTC or Approach Control while in the air or preparing to take off.

The ATC function of Air Traffic Control consists primarily of the granting of clearances and amending them as needed. As we have seen, this clearance is approval of an IFR flight plan.

A clearance authorizes flights within controlled air space only. No responsibility for separation of aircraft outside of these areas is accepted. The traffic clearance issued by a center is prefixed by "ATC CLEARS"; other traffic control messages originated by a center are prefixed by "ATC Requests," or, "ATC Advises," as appropriate. Air Traffic Control normally attempts to issue a traffic clearance specifying the altitude and route proposed in the flight plan. However, due to traffic conditions, it is frequently necessary that Air Traffic Control specify an altitude or route different from that requested by the pilot. (See Radfacs for procedures in using the term "Via Flight Planned Route.")

It is important that you pay particular attention to the Air Traffic Clearance and don't assume that the route and altitude are the same as requested in the flight plan. You ought to make a written record of clearances at the time they are received, and verify the clearance with Air Traffic Control if any doubt exists. Reading back the clearance as it is received is an accepted acknowledgment.

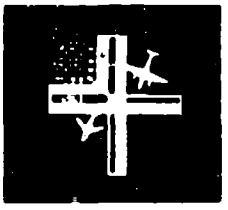
In case emergency authority is used to deviate from provision of an air traffic clearance, the pilot in command must notify Air Traffic Control as soon as possible and, if necessary, obtain an amended clearance. In an emergency situation which results in deviation from, or non-compliance with, civil or military air regulations and/or which requires Air Traffic Control to give priority to an aircraft, the pilot of such aircraft must make a detailed written report within 24 hours of such emergency situation to his immediate superior and the commander of the Flight Service Center in whose area the incident occurred.

Altitudes

Aircraft operating in accordance with IFR must be flown at not less than the minimum safe terrain altitude level established for that portion of the route over which the flight is being conducted. Minimum safe terrain altitude levels are shown in Radfacs. The established minimum safe altitudes are those within the actual limits of the civil airways, and IFR flights are not to be conducted *at lower altitudes than those specified in the Radfacs.* Altitudes are specified in indicated altitudes, that is, the reading on the altimeter after you have set the barometric pressure, corrected to sea level, in the window of the altimeter. However, indicated altitudes may vary consider-

ably from true altitudes; use higher levels in case of doubts as to temperature and/or barometric changes.

Unless otherwise specified by Air Traffic Control, aircraft which change to a higher or lower altitude while en route should normally begin climb or descent immediately after passing the fix beyond which the new en route altitude will be used. An exception to this is when the aircraft



is being flown at an en route altitude below the minimum crossing altitude established for the fix. In this case, begin climb before reaching the fix so you cross the fix at the established crossing altitude or at a higher altitude if specified in an Air Traffic Control clearance. Air Traffic Control may specify that climb or descent be made at a time which will be other than the time of passing a fix. If Air Traffic Control specifies that the fix be crossed at an altitude different from the en route altitude being flown, you must start the climb or descent before reaching the fix in order to cross the fix at the stipulated altitude. When you do, report the change.

Clearances

Traffic clearances are issued to flights through ground-air communications facilities, such as radio-range stations, air-traffic control towers, flight-service centers, air carriers, and military-communications stations.

The initial traffic clearance issued to an aircraft before departure normally authorizes flight to the point of first intended landing, with instructions to maintain the altitude at which the aircraft enters the next control area. If you desire an altitude change en route, request it. You can get better service if you request any altitude changes at the time you want the change.

An amendment to the initial clearance may be issued to a flight at any time an air traffic controller deems such action necessary to avoid possible conflict between aircraft en route, landing or departing. A flight is always cleared to a specified point or location (radio or visual reporting point), defined as a clearance limit. When an aircraft has been cleared to a point other than the designated airport, it is the responsibility of air traffic control to issue whatever further clearances are appropriate at least five minutes before the aircraft arrives at the clearances limit, unless holding instruction and/or the time which the pilot may expect further clearance have been received and acknowledged by the pilot.

If a pilot arrives at the clearance limit without having received either a clearance beyond or holding instructions at such fix, he should immediately request further clearance and hold at the clearance limit, maintaining the last assigned altitude, until further clearance is received. When a clearance limit is a point other than the destination airport, the altitude of the aircraft at this clearance limit will be protected so that separation will exist in case aircraft must hold, awaiting further clearance.

An air traffic clearance provides separation of aircraft only in weather conditions less than VFR minimums. In the U. S. it is the direct responsibility of the pilot to avoid other aircraft when flying in VFR conditions even with an IFR clearance, or when flying "1,000 feet on top."

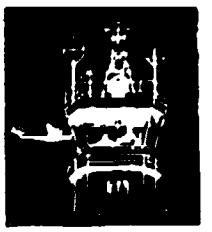
APPROACH CONTROL

Approach Control is a service whereby specified CAA and military airport control towers control IFR flights arriving at, departing from, and operating in the vicinity of airports, by means of direct communications with all aircraft operating under their control. Approach Control is the controlling authority in a control zone which usually consists of one or more airports and the associated approach and departure instrument flight patterns.

The locations at which Approach Control is established are shown in Radfacs. Approach control towers are responsible for providing separation between departing aircraft and all other air-

craft under their jurisdiction. The clearance to departing aircraft contains the clearance limit, including altitude, route, and other control. Approach Control also determines time of take-off, direction of turn, altitude restrictions after take-off, and other specific restrictions necessary to effect separations from aircraft under its jurisdiction.

The time of take-off is specified in the ATC clearance only if it is necessary to coordinate the departure with traffic not under approach control jurisdiction. In addition, if a delayed departure would result in conflict with traffic not released to tower control, the ARTC Center specifies a clearance void time. In that case, the clearance void time determined by the tower must not be later than that issued by the ARTC center. Close coordination is essential between approach control and the ARTC center. After coordination with the tower, a center may clear arrivals to hold at visual holding points until advised by approach control.



Limit of Clearance

An air traffic clearance from an air traffic control center ordinarily clears aircraft on IFR flights to a holding point (ILS outer marker, fan marker, or other radio fix) as the limit of the ATC clearance. Generally, appropriate holding directions are included by ARTC; for example, instructions to hold UNTIL FURTHER ADVISED BY (----------) APPROACH CONTROL ON (----------) KILOCYCLES/MEGACYCLES may be included by ARTC. This lets the pilot know on which frequency he will receive further instructions from the tower when he arrives over the holding point, and he listens on the frequency specified in the ATC clearance for further directions. Pilots should not contact Approach Control until over the specified holding point unless they are directed by ARTC to contact Approach Control at a specified time or at an en route point. Approach Control usually issues the approach clearance for an instrument approach to an airport, and the approach clearance is good for one approach only. This approach may be either a standard range, radar, ILS, or Tacan approach.

Approach Sequence

Each pilot in the approach sequence is given advance notice as to the time he should leave the holding point on approach to the airport. When he has received the time of leaving the holding point, the pilot should leave that point on approach to the airport. When he has received the time of leaving the holding point, the pilot should adjust his flight path to depart as closely as possible to the designated time. On receipt of a fixed departure time, the pilot should use up the intervening time in holding flight by adjusting his path within the limits of the established holding patterns so as to arrive over the fix inbound at precisely the specified time or as soon after that as possible.

The pilots should maintain communications by listening on the approach control frequency until cleared by the tower's local control frequency. If conditions become VFR during the approach and it appears that the remainder of the approach can be conducted in accordance with VFR, the pilot may cancel his IFR flight plan by transmitting the following message to Approach Control, "CANCEL MY IFR FLIGHT PLAN AT 0945."

Approach Communications

Here are the approach control communications the pilot should make to Approach Control:

1. Report, without request, the time and altitude upon reaching the approach control holding point or point to which cleared. For example, NAVY ONE TWO THREE FOUR, FLATBUSH TWO NINE AT FOUR THOUSAND FIVE HUNDRED.

2. Report, without request, when vacating any previously assigned flight level for a new assigned level. For example, NAVY SIX FOUR NINE THREE, LEAVING FOUR THOUSAND.

3. Report, without request, time of leaving any assigned holding point. For example, NAVY SEVEN FOUR THREE EIGHT LEAVING MOUNT VERNON AT FOUR SEVEN.

4. Report, *on request*, the time of starting procedure turn on final approach. For example, NAVY SIX TWO ONE SEVEN STARTING PROCEDURE TURN AT TWO THREE.

5. Jet aircraft report over final approach fix. For example, NAVY FOUR SEVEN EIGHT NINE, RANGE STATION, ON FINAL.

6. Report when visual reference to the ground is established. For example, NAVY ONE EIGHT FOUR TWO, GROUND CONTACT.

7. Report, without request, when an approach for a landing has been missed and request direction or clearance to alternate airport. For example, NAVY ONE NINE FIVE ZERO EXECUTING MISSED APPROACH PROCEDURE. REQUEST CLEARANCE TO (----------).

Missed Approach

If landing is not completed after one standard instrument approach, the pilot should follow the standard missed approach procedure (outlined in the "Pilot's Handbook") unless an alternate missed approch procedure is specified by air traffic control and further clearance is obtained from air traffic control. Air traffic control determines whether the pilot will be cleared for another immediate attempt or be directed to stand by on a designated leg of the range at an assigned altitude until another aircraft in line has landed or taken off. This decision is based on existing traffic conditions unless there is an emergency traffic condition.

A decision to route an aircraft to an alternate airport is made by the pilot after conferring with the air traffic control concerned. The minimum ceilings and visibility requirements for instrument approaches are listed in the "Pilot Handbook." When weather is below the landing minimum and the pilot elects to hold for an improvement in weather rather than proceed to the alternate airport, air traffic control may direct the aircraft to proceed to an adjacent holding point or to a position higher in the approach sequence. For alternate-airport procedures for jet aircraft, see the latest OpNav Instruction.

Methods of Approach

We noted before that an approach clearance was for one approach which might be either standard, radar, ILS, or Tacan. Standard approaches and Tacan approaches are the radio range approaches shown in the "Pilot's Handbook" series. Radar approaches fall into three categories: Ground Controlled Approach (GCA), Air Surveillance or Search Radar (ASR), and Precision Approach Radar (PAR).

GCA

GCA, or Ground Controled Approach, which is discussed fully in Chapter 21, is a full-fledged talk-down control, almost onto the ground at the end of an established runway. It combines ASR and PAR radar as its controlling elements. Most airports which have any radar landing aids are equipped with GCA. Air Force GCA units take over at a specific radar fix from Air Traffic Control. Navy and CAA GCA units may take over control at any point designated in ATC clearances or by local traffic authority. Full information on frequencies, radar fixes (at Air Force Bases), indicated altitude of flight minimums above MSL, ceiling and visibility minimums, runways used, and hours of operation are found in Radfacs under the heading of Radar Air Traffic Control (RATC) Facilities.

The altitude minimums are simple to use. Andrews AFB, for example, has an elevation of 379 feet, so a properly set altimeter in an aircraft on the runway should read 379. The GCA altitude minimums (from Radfacs) are:

Runway 1: altitude 529 feet, and ceiling 250 feet. (In other words, the minimum allows for being 100 feet below ceiling and 150 feet off the deck.)

Runways 1, 19, and 32, PPI only: altitude 879 feet and ceiling 600 feet. (Again, the minimum altitude is 100 feet below the ceiling and 500 feet off the deck.)

Thus you should not go below an indicated altitude of 529 on Runway 1 or 879 on other runways at Andrews AFB without being able to con-

trol flight by visual contact with the ground, unless you do so on your own responsibility. However, these minimums do not mean that the GCA unit ceases to monitor and advise the pilot below them.

A GCA Approach should be requested in advance—usually about 30 minutes—in order to allow for the time necessary to get the crew ready and the equipment warmed up and properly loaded. GCA facilities operate under the jurisdiction of Approach Control. They assist Approach Control by monitoring the control zone during IFR conditions to help prevent collisions, and they also help Approach Control keep "tabs" on the flights in the zone.

A GCA unit consists of ASR (Air Surveillance or Search Radar) and PAR (Precision Approach RADAR). ASR gives the azimuth (bearing) and range of an aircraft on a PPI scope, while PAR gives range, azimuth, and altitude within a glide path through use of expanded partial PPI scopes. Either the ASR or PAR may be provided where full GCA facilities do not exist.

ASR

It takes one hour's notice to alert ASR facilities when they are inoperative, so request this aid early. Of course, during IFR conditions the ASR will usually be in service already to provide air traffic monitoring assistance to Approach Control. ASR minimums are the same as radio range or ADF minimums unless otherwise shown in Radfacs Radar Data pages. ASR provides azimuth and range only, so it can only direct the pilot to a position off the end of the runway(s) serviced. The pilot must control his own altitude and rate of descent.

PAR

PAR equipment is not normally found without ASR. In those rare cases where it operates

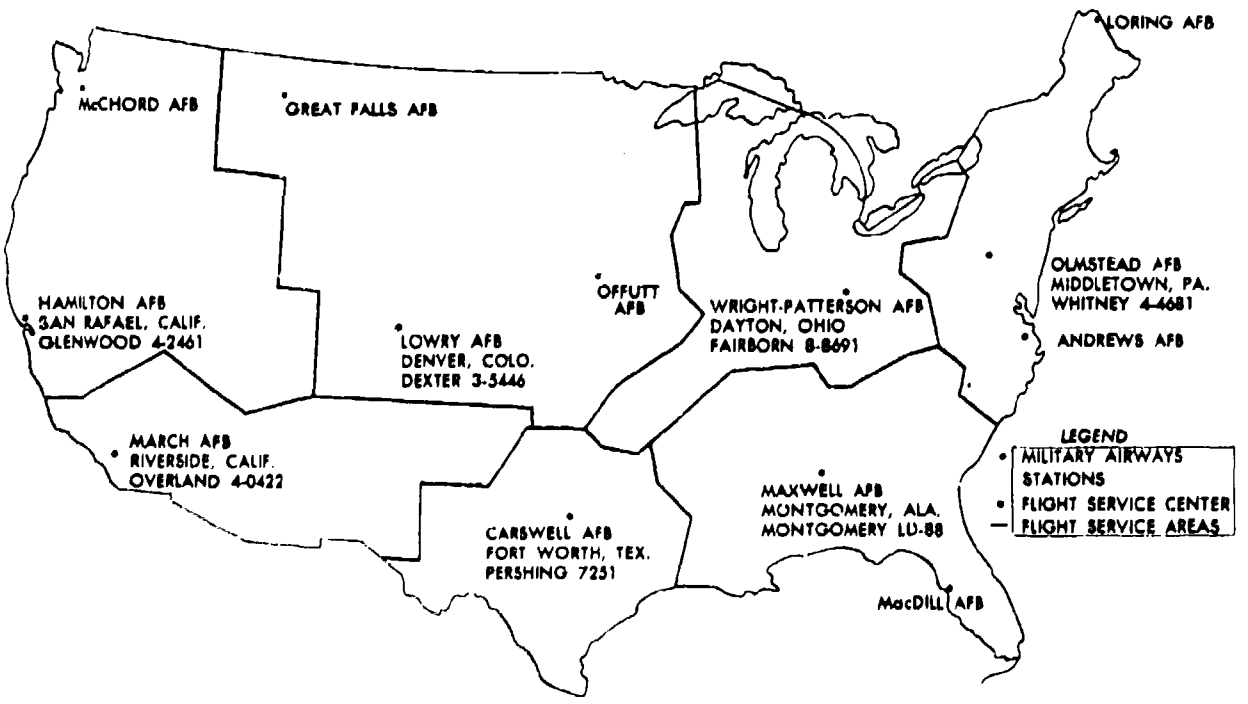


Figure 14–3. Flight service areas and centers

alone, the pilot must navigate by ADF, Tacan, Omni, or other means so as to get into the PAR scan area (20° azimuth, 7° elevation, within 10 miles range from the downwind end of the runway serviced). The 7° elevation means that the altitude of the aircraft at the 10-mile point must be less than about 6,000 feet *above the terrain* to be detected by PAR equipment.

ILS

ILS (Instrument Landing System) approaches are discussed in greater detail in Chapter 22. They are mentioned here only as another of the types of approach handled by Approach Control. The request for ILS approach should be made at the last reporting point before arriving at the holding fix. However, a request may also be made later when conditions require.

ILS approach requires ATC clearance under IFR conditions. Information concerning facilities, frequencies, marker locations, and altitude minimums are found in Radfacs. Further data and charts are found in ILS editions of H. O. 510 and the "Pilot's Handbooks."

FLIGHT SERVICES

So far as the Navy is concerned, Flight Services of Plan 62 is an auxiliary service which performs three functions:

1. Operates a communication service between military air facilities and with ARTC.
2. Accepts VFR flight plans and follows the flight through position reports and closing (arrival) report to be sure flight is proceeding normally. Also handles changes of flight plan VFR to or from IFR.
3. Provides pre-flight briefing services to pilots clearing from bases where no operations briefing facilities are provided (by phone).

Development of Flight Services

The end of World War II saw a great increase in military aircraft flying, as compared with the days of 1930 to 1941. The year 1946 found many Naval Air Stations and Air Force Bases connected together in a communication network that with a bit of polishing up could act as a Flight Watch Service. In 1946 it was decided to put into effect Plan 62 or Military Flight Service. Today, there is a teletype and/or interphone circuit to practically every military airfield in the United States plus those civilian fields which have National Guard or Naval Research Units based aboard. The vast communications network of CAA is connected to this military network.

When you file a flight plan at your local operation, you and your aircraft immediately become a part of this comprehensive work of communication facilities that make up Airways. In Radfacs, the Flight Service Area boundaries and Flight Service Centers are shown on the center-spread chart. The addresses and phone numbers are in a box in a corner of the chart.

If your flight is VFR, the Flight Services communications network passes word ahead of you; if you fail to report, it sets up a lost-plane procedure. If they cannot locate your aircraft after checking at your destination and along the route, air-rescue operations are instituted. It is especially important, therefore, to close your VFR flight plan (that is, report your arrival), using the following procedures as set forth in ACL 28-50.

Visual Flight

Departure from military installations which have Plan 62 communications. File Flight Plans with the appropriate Flight Service Center by station operations in accordance with current instructions.

Departure from fields not included in Plan 62. File a flight plan with the nearest Flight Service Center through (1) a CAA facility if available, or (2) long-distance telephone collect to a Military Flight Service Center or to the CAA facility. Before using long-distance telephone, make sure that no CAA communications agency is available and no Flight Service interphone connection is located on the field. However, you may take off under VFR and file a flight plan while in the air as soon as you can contact a CAA communications station, a military airways station, or a military tower. This is usually easier.

Change of VFR flight plan in flight. A pilot desiring a change of route or point of first intended landing of a VFR flight plan must advise Flight Service of the intended change at the first prac-

ticable opportunity by contacting a military airways station or a CAA communications station. A change to IFR is discussed later.

VFR position reports. When flying under VFR conditions, you must make position reports once each hour or 200 miles, whichever is oftener, to a CAA or military communication station.

Instrument Flight and DVFR Flight

Departure from military installations which have Plan 62 communications. Flight Plans are filed with CAA Air Traffic Control (ATC) and the appropriate Flight Service Center by station operations. Clearance is obtained from ARTC in accordance with current instructions before take-off.

Departure from fields not included in Plan 62. If the point of departure has a CAA communications station, file your Flight Plan with ARTC and Flight Service through the CAA station. Obtain your ARTC clearance before take-off. If no CAA or Plan 62 communications are available, you must reach a CAA communications station or military base by telephone.

Change of IFR flight plan, or VFR to IFR, or IFR to VFR in flight. Obtain clearance for change of IFR Flight Plan, or VFR to IFR from ARTC through a CAA station. Advise ARTC when you change a Flight Plan from IFR to VFR and shall also request that Flight Service be notified of the change. If you change to DVFR, file the Flight Plan through ARTC.

IFR position reports. Pilots of jet aircraft flying IFR-Direct or Airways flights maintain listening watch on CAA frequency and before changing to another frequency notify CAA of the change. Make position reports at least every 200 nautical miles and as requested by ATC regardless of altitude. These reporting points are listed in the flight plan and they should be those over which the position of the aircraft can be accurately determined. When practical, select as reporting points fixes which are shown as compulsory reporting points in Radfacs. Pilots of reciprocating-engine or turboprop aircraft on IFR-Airways flights must also maintain listening watch on CAA frequency and notify CAA if a change is made to another frequency. Their position reports are made over all compulsory reporting points along the route of the flight below 15,200 feet. Flights above 15,200 feet make position reports over all compulsory reporting points except those at which the symbol Ⓛ is currently shown. Flights of reciprocating-engine and turboprop aircraft flying IFR-Airways "1,000 on top" must report, regardless of actual altitude, only over those fixes that are high altitude (above 15,200 feet) compulsory reporting points unless additional reports are required by ATC. Position reports of IFR-Direct flights of reciprocating-engine and turboprop aircraft follow the same rules as those for jet aircraft, as described above. IFR-Direct flights of reciprocating-engine or turboprop aircraft proceeding "1,000 on top" on a direct route, regardless of actual altitude must report over each reporting point specified in the flight plan (approximately 200 nautical miles apart) unless additional reports are required by ATC.

Arrival Action

Closing of Flight Plans on military installations. Flight plans are closed by station operations in accordance with current instructions. In this connection, pilots are responsible for notifying operations that the Flight Plans are closed. Turning in the copy of Clearance Form DD-175 closes that Flight Plan.

Closing of Flight Plans from non-military fields. You are responsible for notifying Flight Service of the time and place of your arrival and RON. Inform the nearest Flight Service Center by notifying CAA radio after landing through a visit or phone call. If no CAA radio facilities exist, close the Flight Plan by radio to CAA in flight, requesting that ARTC (if IFR) or Flight Services (if VFR) be notified. Where a station has no CAA radio facilities and the air-ground call was impracticable, phone the nearest Flight Services Center collect as a last resort.

Designation of Fields

It is important to know the field classification before landing. For example, some civil airports are known as "P" fields and their use is permitted to transient military aircraft; others are "PC" fields and are the same except they have no CAA communications facilities; still others are

closed to some operations. Check the Directory of Aerodromes in Radfacs as to facilities of your destination and alternate.

Advisories

An advisory is a message issued by Flight Service to a pilot or to operations personnel concerning any factor that might affect the successful completion of a flight or proposed flight.

Contents of advisories. An advisory is issued when the following conditions exist or are forecast:

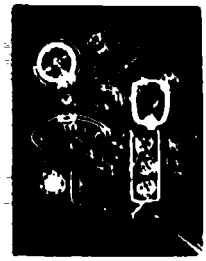
1. Weather conditions are below the minimum for the type of flight contemplated.
2. Hazardous conditions exist en route, such as icing, thunderstorm activity, line squalls, turbulence, or any other conditions affecting the safe completion of the flight.
3. There is an air traffic delay.
4. There is a serious error in the estimated elapsed time fuel supply.
5. A radio aid to air navigation along route of flight has failed.
6. The destination or alternate is closed, restricted, or in a hazardous condition.

How advisories are issued. An "in flight advisory" is delivered through military air ground stations, or CAA control towers and radio range stations.

Request for advisory. You may contact Flight Service through any military control tower or a radio range station, and request an advisory regarding weather or other flight information affecting safety of flight.

ICAO PROCEDURES

The International Civil Aviation Organization, generally known as ICAO, has done a great deal to promote standardized procedures for air traffic control, flight procedures, communication procedures, and units of measurement. In the past, international airline operations were seriously hampered by language problems; changes in airways procedures, terminology, and units of measure at every international border; lack of airways facilities in some nations; different frequencies and communication procedures at every border; and restrictive legislation in some countries. If aviation was to progress, it became obvious that some standardization was necessary. Because most American air travel has been sparked by U. S. companies or U. S. citizens employed by foreign airlines to establish a system, the ICAO procedures show a great deal of similarity to U. S. airways procedures.



National pride and tradition, however, have caused much refusal to compromise on standard procedures. Not all this reluctance has been with other nations; for example, ICAO settled on the metric system for most units of measure (altitude, land distances, barometric pressures and altimeter settings, temperature, and weight), but the U. S. has not seen fit to conform. We did convert fully to nautical miles and knots for most flight and weather purposes, except for visibility reports in the U. S. Our continued use of local standard time instead of Greenwich time for domestic aviation is another procedure in which we are in the minority. In short, further change may be anticipated. More nations will adopt ICAO standards, and U. S. standards may be adapted to conform to ICAO agreements.

The following paragraphs describe some of the principal differences between ICAO procedures and domestic procedures for control of air traffic. However, space will not permit a complete discussion of all ICAO procedures, and not all the points of difference can be covered. Furthermore, ICAO procedures, like all flight procedures, are subject to change from time to time. Therefore, do not consider this information as authoritative for flight planning. Before undertaking an international flight, read Radfacs and the *Instrument Approach Procedure Charts* booklet for the foreign areas involved, and read the ICAO procedure sections of the Supplementary Flight Information Document. In addition, you should arrange for

a longer and more detailed pre-flight briefing than for domestic flights. Ask questions if these sources have not made any item clear to you.

General Information

ICAO procedures apply on the open seas in international civil aviation operations, but are modified in any country which may have accepted such procedures subject to modification. An international flight from the U. S., for example, requires an ICAO clearance for the international portion of the route, and ATC clearance for the domestic portion of the route. While still in U. S., this flight must follow the usual domestic procedures

OPNAV Instruction 3770.1A, paragraph 4, directs compliance by Navy units with ICAO procedures. Although ICAO rules and procedures are binding on international civil aviation only, it has been agreed that military aircraft will have due regard for the safety of navigation of civil aircraft; therefore, the following procedures apply when U. S. Military aircraft are operating outside the United States over international air routes:

1. Clearance for routine flights must be secured from the appropriate ICAO Air Traffic Control Center and applicable ICAO traffic rules and procedures must be complied with.

2. Clearance for special missions requiring a fixed or moving block of airspace during a specific time period has to be secured from the appropriate ICAO Air Traffic Control Center concerned.

3. When missions are of such a highly classified nature that any advance notification to the ICAO Air Traffic Control Center would be prejudicial to the national security, no notification is given. However, operational commanders are required to evaluate carefully all such flights and to weigh the need for security versus safety of flight.

Communications Standards

Greenwich Mean Time is used by all stations in the aeronautical telecommunications service. The air-ground control radio station selects the frequencies to be used under normal conditions by aircraft operating under its control. The air-ground control radio station designates primary, secondary, and alternate frequencies for radiotelephony communications, and reporting schedules to the aircraft station. If a frequency selected by an air-to-ground control radio station or by another aeronautical station proves to be unsuitable for communication, the aircraft should suggest an alternate frequency.

When it is necessary for an aircraft to send radio signals for testing which are likely to interfere with the working of a neighboring aeronautical station, the consent of the station must be obtained before such signals are sent. Test signals must not continue for more than 10 seconds and must be composed of a series of V's in radiotelegraphy, or of spoken numerals (one, two, three, etc.) in radiotelephony, followed in each instance by the radio call sign of the station transmitting test signals.

The groups of the "Q" Code to be used by aircraft in contacting ICAO stations are those having A-N as the second letter; those groups having R-U as the second letter have been approved for use by ITU (International Telecommunication Union). These signals as well as the complimentary groups for use "Q" signals are in "Joint Communications Instructions," JANAP 131A, published by the Joint Communications Board, Washington 25, D. C.

Abbreviations approved for use in air-ground communications are contained ACP 124 (A), Communication Instructions Radio-telegraph (W/T) Procedures (Restricted) and in ACP 125 (A) Communication Instruction Radio-telephone (R/T) Procedures (Restricted). The major four-letter airport designators are in the Supplementary Flight Information Document.

Communication Failure

When an aircraft station is unable to establish communication because of receiver failure, it

must transmit reports at the scheduled times or positions, on the frequency in use, preceded by the phrase, "transmitting blind." The aircraft transmits its intended message and follows it with a complete repetition. During this procedure, the aircraft must also advise the time of its next intended transmission.

Radiotelephony procedures in effect provide that, when the aircraft calls the air-ground control station on the primary radiotelephone frequency and receives no answer within one minute, it should call again. If there is no response to the second call:

1. Call the primary station twice at 15-second intervals on the secondary frequency.

2. At 15-second intervals, call any standby station twice on the primary frequency and, if necessary, on the secondary frequency.

3. Broadcast the message in the blind to ALL STATIONS on the primary frequency.

4. Broadcast the message in the blind to ALL STATIONS on the secondary frequency.

5. Continue attempts to establish contact with the network trying all stations and all appropriate frequencies. Before leaving the assigned primary and secondary frequencies, the aircraft should announce the frequency to which it is shifting.

6. On oceanic routes where ocean station vessels are located, attempt contact with these vessels on the appropriate frequencies.

7. Monitor VHF 121.5 mcs for calls from nearby aircraft and attempt contact with other aircraft on this frequency.

If unable to maintain two-way radio communications, the pilot in command of an aircraft must—

1. Conduct his flight so as to fly in VFR weather conditions; or—

2. Land as soon as practicable in accordance with VFR; or—

3. Proceed strictly according to the current flight plan, maintaining the minimum safe altitude or the last acknowledged assigned altitude, whichever is higher, to the airport of intended landing. There he should commence descent at expected approach time last received and acknowledged, if any, or commence descent at the estimated time of arrival specified in the Flight Plan.

To preclude further notification to Search and Rescue Organizations, aircraft encountering communications failure in one area and reestablishing communication with another control area should notify the ATCC of the area in which contact was lost.

Radiotelephony Procedures

When words or initials are spelled out in radiotelephony, the ICAO phonetic alphabet as published in Radfacs should be used. Numbers are pronounced as given in Radfacs. All numbers except whole thousands should be transmitted by pronouncing each digit separatedly. The word THOUSAND should be pronounced as TOUSAND. For example, the number 10 is spoken as WUN-ZE-RO, 25,000 as TOO FIFE TOUSAND and 38143 are TREE AIT WUN FOW-er TREE. For numbers containing a decimal point, the word DE-CI-MAL must be used; for example, the number 118.1 would be spoken as WUN WUN AIT DAY-SEE-MAY WUN.

Categories of Messages

All messages submitted to or by aircraft must be in the following categories and order of priority:

1. *Distress messages, and distress traffic.* Distress messages are preceded by a priority prefix MAYDAY (radiotelephony) or SOS (radio-telegraph). These are used when an aircraft is threatened by grave and immediate danger and requires immediate assistance. Distress traffic comprises all messages relative to the immediate assistance required by an aircraft in distress.

2. *Urgency messages.* Urgency messages, which are preceded by three repetitions of the expression PAN (radiotelephony) or the group XXX (radiotelegraphy) are used to indicate that

the aircraft calling has a very urgent message to transmit concerning the safety of a ship, aircraft or other vehicle, or of some person on board or within sight.

3. *Safety messages.* Safety communications are preceded by three repetitions of the expression SECURITÉ (radiotelephony) or the group TTT (radiotelegraphy) and are addressed either to one or more specific stations or to ALL STATIONS. These messages are used when a station has a message to transmit concerning the safety of navigation or giving important meteorological warnings.

4. *Communications relating to direction finding.* Aircraft should normally make request for bearings, headings, or positions, to the aeronautical ground station responsible or to the station controlling the direction finding network. To request a bearing, heading, or position, call this station on the listening frequency and specify the type of service that is desired by the use of the appropriate phrase or Q signal (see JANAP 131 (A)).

5. *Flight Safety Messages.* These have the priority prefix FF and comprise the following:

a. Air traffic control messages.

b. Position reports from aircraft.

c. Messages originated by an aircraft operating agency or by an aircraft of immediate concern to an aircraft in flight.

6. *Meteorological Messages.* These have the priority prefix FF and comprise meteorological information to or from aircraft.

7. *Flight Regularity Messages.* These have the priority prefix JJ and comprise the following:

a. Messages concerning changes in aircraft operating schedules.

b. Messages concerning the servicing of aircraft.

c. Instructions to aircraft operating agency representatives concerning changes in requirements for passengers and crew caused by unavoidable deviations from normal operating schedules. Individual requirements of passengers or crew are not admissible in this type of message.

d. Messages concerning non-routine landings to be made by the aircraft.

e. Messages concerning aircraft parts and materials urgently required.

f. Messages regarding the operation or maintenance of facilities essential for the safety or regularity of aircraft operation.

Composition of R/T Messages

Aircraft are identified by the five-letter radiotelegraph call sign; or a combination of characters corresponding to official registration mark; or the five-letter radiotelegraph sign preceded by the radiotelephone abbreviations of the airline (after communication is established using this call sign, an abridged call sign may be used consisting of radiotelephone abbreviations of airline and last two characters of call sign); or radiotelephone abbreviation or airline followed by flight identification number; for example, MATS NIN-er ZE-RO TREE FOW-er. Radiotelephone call signs are not changed during flight.

Messages originated in an aircraft that require a specific address and retransmission over the Aeronautical Fixed Service must include the following elements in the order shown. Addresses must be placed with a KAO 4-letter place name designation or via such place

1. The call.
2. The address (preceded by the word "FOR").
3. The text.
4. The signature group (if used).

Example:

Santa Maria Radio this is MATS NIN-er ZE-RO TREE FOW-er (call)
for MATS Operations, Lajes Field, Azores (address)
Number Wun Engine Change Required on Arrival Over (text)

When messages do not require a specific address, the call serves to indicate the station of origin and the station of destination:

Example:

Santa Maria Radio this is MATS NIN-er ZE-RO TREE FOW-er (call)
May I Change from TREE to FIFE Megacycles (text)

The text of messages should be as short as practicable to convey the necessary intelligence; full use should be made of standard phraseologies wherever these are prescribed in the relevant ICAO documents or procedures. When used, the signature should be the abbreviated name of the

organization which originated the message, or an abbreviation representing a department or division of the organization, or the last name of an individual.

Position Reporting

The ICAO Procedure Chart contained in the supplementary Flight Information Document furnishes a visual guide with regard to position reporting requirements in the ICAO Regions. The general requirements for position reporting are as follows:

1. On routes having specified reporting points (shown in Radfacs) and when over other reporting points as may be specified by air traffic control.

2. On routes or portions of routes not having specified reporting points, position reports should be made as soon as practical after the first half hour of flight and each hour of flight thereafter, except that additional position reports may be required on portions of routes when operating conditions warrant.

3. Position reports should be addressed to Air Traffic Control Center of the area concerned. When necessary, due to transmitting difficulties, reports may be sent to any ICAO Communications stations but must in all cases be addressed to the ATCC of the area in which the aircraft is operating.

4. The last position reporting before passing from one flight information region or control area to an adjacent flight information region or control area should also be transmitted to the center for the region or control area that the aircraft is entering.

5. If the receipt of position reports is desired by the activity clearing the aircraft for the flight, major command, etc., position reports must include such operational addresses.

6. Position reports are to be made to Ocean Station Vessels within less than 100 miles of track.

Altimeter Settings

The altimeter setting of 29.92 is used in overwater areas 100 nautical miles from land; when within 100 nautical miles from land, use the altimeter setting furnished by the closest aeronautical radio station.

Units of Measurement

Dimensional units used for voice communication by U. S. Military aircraft are prescribed by the country over which the flight is conducted. The two tables of dimensional units now in effect (ICAO and Blue Tables of Units) are shown on the reverse side of the ICAO Procedure Chart, together with a list of states using each table, and any deviations thereto.

CHAPTER 15

LF/MF RADIO RANGES AND VAR RANGES

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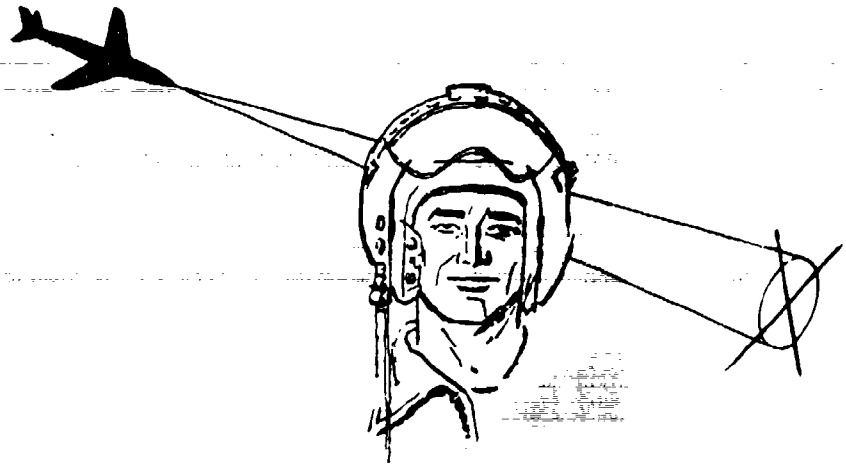


CHAPTER 15

LF/MF RADIO RANGES AND VAR RANGES

THERE are four types of radio ranges:

1. LF/MF Radio range, Loop type. This is the original type.

2. LF/MF Radio range, Adcock type. This type of range is an improvement on the Loop range.

3. VAR or Visual Aural range. This is a VHF facility, combining visual signals (blue or yellow sector) and audible ("A" or "N") signals. It features static-free reception but is limited to line-of-sight. VAR ranges are not widely installed.

4. VOR or Visual Omnirange. This gives no audible signal but infinite courses or radials which can be identified visually. This system is discussed in Chapter 19. A newer type of radio navigation aid with similar characteristics, Tacan, is discussed in Chapter 7.

The low and medium frequency ranges (types 1 and 2 above) are much more common than the VAR ranges. The Loop and Adcock types are about equally numerous. They comprise the radio range network which formed the original basis for our airways system.

ADVANTAGES AND DISADVANTAGES OF PRESENT SYSTEM

The present LF/MF range system has both advantages and disadvantages. The advantages include:

1. The system is federally operated and is available to all users.

2. It is in continuous operation.

3. A large number of pilots can use the same station.

4. Fixed direction of beams can be plotted on charts.

5. Means of voice contact with pilots is provided.

The disadvantages include:

1. There are only four courses on each range.

2. The direction of the courses is not controlled by the pilot.

3. There are inherent irregularities such as night effect, multiple beams, false cone, etc.

4. Off-airways flying is difficult.

5. Direct-line navigation is not possible.

6. Orientation is difficult and time-consuming.

7. Because the system uses low frequencies, signals are often difficult to hear and interpret as a result of static.

CLASSIFICATION OF LF/MF RANGES

LF/MF Radio ranges are classified by the type of antenna and the power they use.

Antenna Classification

Classifying the range on the basis of type of antenna, two types of low-frequency radio ranges are in use today:

1. Loop range (L).

2. Adcock range (A).

Power Classification

The normal power output of the station puts it in one of three power classifications:

1. High power—output of over 150 watts (H).

2. Medium power—output of 50 to 150 watts. (MH).

3. Low power—output under 50 watts. (M).

There are two types of Loop Ranges: The single-frequency type and the dual-frequency or "simultaneous" type. The single-frequency type transmits directional tone—modulated signals on only one frequency to form the range legs. The simultaneous type transmits simultaneously on two frequencies. One frequency, the lower one, is a non-directional signal that can be used for homing by direction finding equipment. The other frequency is directional to form the range legs. In this regard, the simultaneous loop range operates in exactly the same manner as an Adcock range. The only difference in the two is the type of antenna used. Only the single frequency type of loop range should not be used for direction finding purposes. It is a popular misconception that all loop ranges are no good for DF purposes.

Theory and Construction

A loop antenna is considered to be any closed ring of wire. It was discovered long ago that if current is fed to a closed wire, or loop, a definite signal pattern would result. This signal pattern is a figure eight with two circular sections, or lobes, emanating from the vertical portions of the loop. (See Figure 15-1.)

If two such loops are placed at right angles to each other and different signals are fed to each loop, specific combinations of signals are received at predetermined geographical points in relation to the antenna installation. (See Figure 15-2.) This is the basis of the loop-range installation.

Signal Transmission

In a loop-range station, two loop antennas are placed at right angles to each other. One loop broadcasts the N signal and is therefore known as the N antenna; the other loop transmits the A signal and is consequently identified as the A antenna.

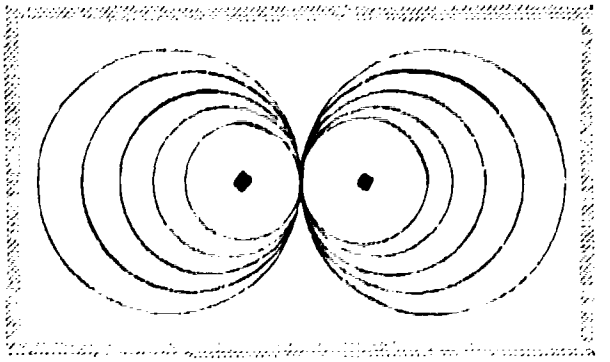


Figure 15-1. Radiation pattern of single-loop antenna

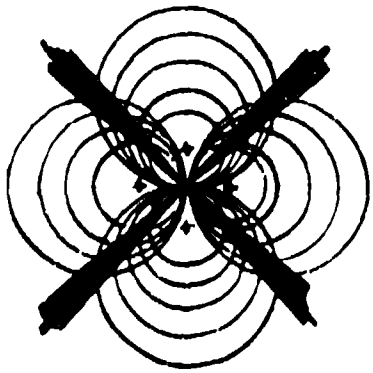


Figure 15-2. Radiation pattern of double-loop antenna

The signals are transmitted simultaneously and the combination of signals you receive at any given spot depends on your geographical location in relation to the range station. There are four line extensions from the transmitter on which the A and N signals blend together to form a steady monotone, or beam signal. These four line extensions, called beams, divide the signal pattern into four zones or quadrants. The predominant signal in two of the quadrants is an A and, in the other two, an N. The quadrant is identified by this predominant signal; that is, it is an N quadrant or an A quadrant. Here is how the signals are fed to the two loop antennas and how they can interlock to form a steady monotone or beam signal.

The transmitter feeds a tone of 1,020 cycles to the antennas. The tone is broken up into the dots and dashes of the A and N by a mechanical keying device and, through a cam arrangement, the proper signal is fed to the proper antenna. First, the dash of the N goes into the N antenna. Then during the pause between the dash and dot of the N, the dot of the A goes into the A antenna; the dot of the N then goes into the N antenna and the dash of the A follows going into the A antenna. (See Figure 15-3.) When the receiver in the aircraft is located on the beam, the A and the N are of equal strength and interlock to form a steady monotone.

There are 12 A and 12 N signals transmitted every 30 seconds, followed by a pause for the station identification signal. The identification signal, which consists of three letters in Morse code, is transmitted first on the N antenna, then on the A antenna. The transmission of each identification signal takes from 3 to 4 seconds, making a total of 36 to 38 seconds for one complete signal cycle.

THE ADCOCK RANGE

Experience with the loop range proves it has three serious shortcomings: (1) the horizontal component of the antenna can cause night effect; (2) simultaneous voice and range transmissions are not feasible; and (3) no constant carrier wave is produced, reducing the utility of loop range stations for radio direction finding equipment. To overcome these deficiencies of the loop ranging, the Adcock antenna was developed.

Construction and Operation

The Adcock range installation consists of five steel towers 125 feet high. Four of the towers are arranged in a square, 600–800 feet apart. The fifth tower is placed at the intersection of the diagonals of the square. The four towers forming the square are, in effect, the vertical components of two loop antennas placed at right angles to each other. The horizontal components are buried beneath the ground in shielded housings, eliminating the vertical signal emission and its resultant night effect. The signal pattern is exactly the same as that of the double loop.

The center tower transmits an omni-directional carrier wave on the station's assigned frequency (for example 224 kc at Alice, Texas). This signal is transmitted 24 hours a day. Voice transmissions are also made over this antenna. The other four towers broadcast an unmodulated carrier wave which is always 1.02 kc (or 1,020 cycles) above the carrier wave of the center tower—that is, in the case of Alice, Texas, 225.02 kc. Interference between the two frequencies creates a beat

Figure 15-3. Timing of A and N signals for interlocking

frequency of 1,020 cycles, which is the range signal tone, but which does not interfere with the frequency of the voice transmissions.

SIGNAL PATTERN

Because of the directional qualities of the loop antenna, definite signal zones are formed (see Figure 15-4) by either the Adcock or Loop Range.

Designation of Quadrants

On any range installation in the United States, the quadrant containing true north is designated the N quadrant. When the north leg and true north coincide, the quadrant to the west is designated the N quadrant. On a Canadian range, this rule does not apply. There the quadrant containing the inbound bearing of 135° true is designated the N quadrant. Range legs are numbered 1-2-3-4 clockwise from True North, and these numbers are used to identify fan markers (described later).

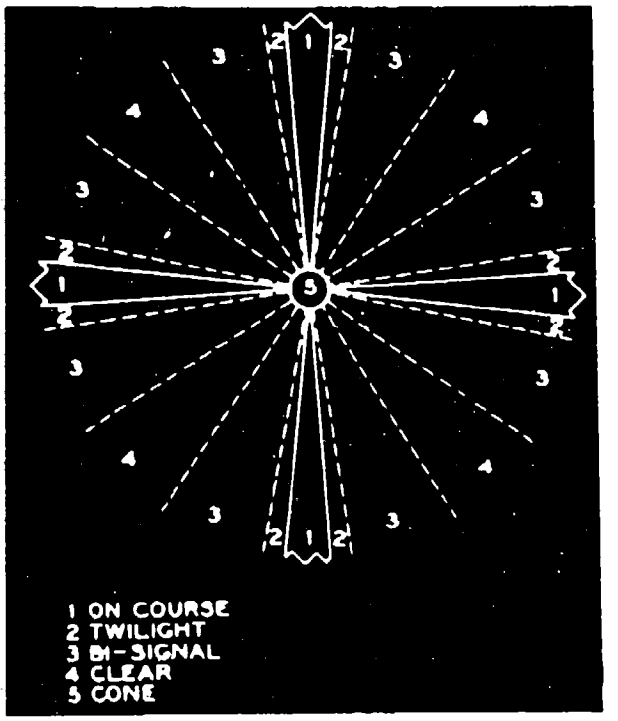


Figure 15-4. LF/MF range signal zones

The On-Course or Beam

The four line extensions from the transmitter along which the A and N signals are of equal strength and interlock are called the on-course lines or beams. They are shown on charts with their magnetic heading. For practical purposes the beam is 3° wide and varies in width from 50 feet at the station, to 2.6 miles at 50 miles from the station, and 5.2 miles at 100 miles from the station. The identification signals are of equal intensity.

The Twilight Zone

The twilight zone is an area 1½° on either side of the on-course, identified by a predominant beam tone, with one of the off-course signals detectable in the background. Often only the clicks of a transmitter keying device are heard. The average human ear can detect no noticeable difference in the intensity of the two identification signals in the twilight zone.

The Bi-Signal Zone

One third of the rest of the quadrant on either side of the beam is the bi-signal zone. In this area the quadrant signals are predominant, with the beam signal becoming weaker as the receiver moves toward the center of the quadrant. A definite difference in the identification signals can be detected in this zone, with the identification signal from the antenna associated with that quadrant being the louder.

The Clear Zone

The balance of the quadrant—that is, the center third—is an area in which only one quadrant signal is received and only the identification signal transmitted on the antenna associated with that quadrant signal will be heard.

The Cone of Silence

There is an area in the form of a cone extending vertically above the station in which *no* signal is received. This area is called the cone of silence. Its apparent size depends directly on the altitude and speed of the aircraft, the type of antenna used (a loop antenna will not detect a cone on the loop station), and the amount of volume used. (See Figure 15-5.)

RANGE SHAPES

As stated before, the basic signal pattern of the LF/MF range stations provides four line extensions from the transmitter on which the monotone, or beam, signal is received. These four line extensions are normally 90° apart. However, in establishing the airways, it was seen that this square range pattern would not necessarily provide a line extension toward other geographical locations to which it was desirable to have a beam. Therefore, methods were devised whereby the square range pattern could be purposely distorted to provide the desired connecting beams. From the various distortions, three basic range patterns have been developed. All retain the four beams, but the angular distances have been varied to suit the airways requirements.

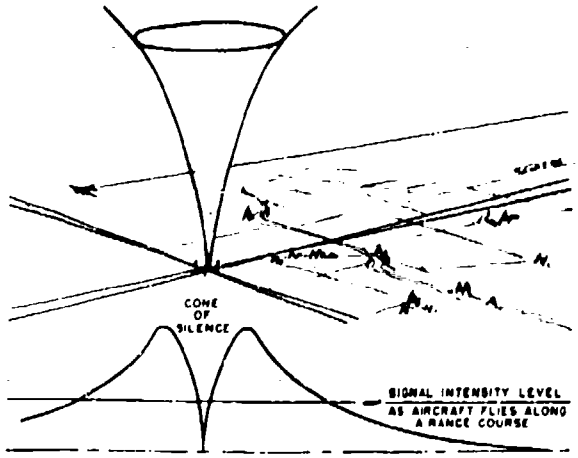


Figure 15-5. Cone of silence on LF/MF range

Square Range

The basic range pattern is the square range which results from a standard installation with no variation induced in the beam extensions. However, the entire pattern can be rotated by the use of a goniometer (an electrical device which alters phasing). (See Figure 15-6.)

Scissors or Squeezed Range

In a scissors or squeezed range pattern, opposing quadrants are of the same size, with two quadrants greater than 90° and two less than 90°. This pattern is produced by varying the signal output of the individual antenna, which reduces or increases the lobe size and moves the line extension on which the interlocking signals are received. The four extensions produce a pattern with reciprocal extensions forming a straight line. (See Figure 15-7.)

Crowfoot Range

The crowfoot range pattern involves the shifting of only one of the four line extensions and is accomplished most simply by changing the power output of one of the antennas or adding an extra antenna. (See Figure 15-8.)

RANGE IRREGULARITIES

The range signal pattern is the result of phasing two separate radio signals. However, many objects such as terrain, metallic ore deposits, large areas of water, the ionosphere, and large metallic structures reflect or absorb radio waves and cause an erroneous signal pattern in the area of reflection or absorption by changing the phasing. The degree of signal variation depends on the degree to which the radio wave is absorbed or reflected. Here are the irregularities which are commonly encountered.

Swinging Beams (Night Effect)

Swinging beams are on-course lines which swing away from their designated heading, generally at night. They are normally associated with the loop antenna but may be found in Adcock installations to a lesser degree. Here's how they come about.

The antenna of a loop transmitting station emits two general types of waves—ground and sky. Ground waves follow the surface of the earth and are used primarily for radio range communications. The sky waves go up as far as the Kennelly-Heaviside layer (an ionized layer of air located from 40 to 200 miles above the surface of the earth) and are reflected back to the earth. These sky waves normally return to earth at some point beyond 30 miles from the station. However, the reflected wave may or may not be in phase with the ground wave at the same point, and may cause an increase or decrease in the intensity of the N or

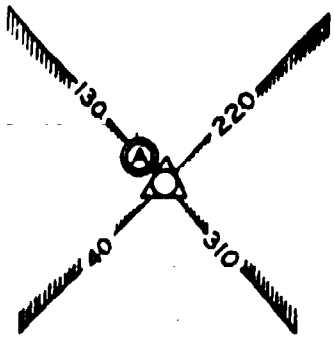


Figure 15-6. Square range

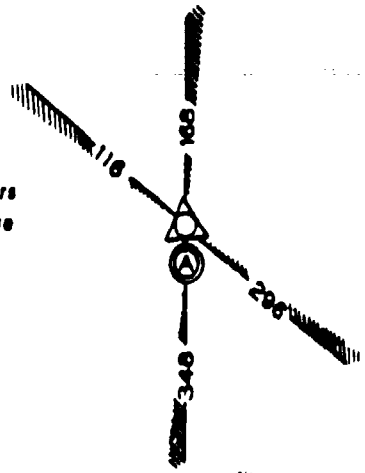


Figure 15-7. Scissors or squeezed range

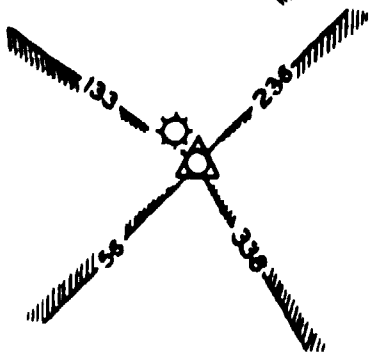


Figure 15-8. Crowfoot range

A signal. Because the Heaviside layer rises at sunset and goes down at sunrise, erratic phase combinations may occur at these times. This results in an apparent swinging of the position of the on-course.

Multiple Beams

Multiple beams consist of on-course signals off the true beam bearing. The condition can be recognized by the lack of normal signal reversal on opposite sides of the on-course. Multiple beams are usually found within 30° of the published beam heading.

Bent Beams

Bent beams are beams which have an actual change of heading on the beam. This change in beam heading is usually caused by an obstruction of some sort (mountains, etc.). The beam bends away from the obstructions. *Do not*, however, depend on this phenomenon to avoid obstructions!

False Cones

False cones are associated with the depressions in the earth's surface, such as quarries, mine shafts, canyons, and are merely momentary fades in volume. They are not accompanied by the signal sequence associated with the true cone.

Canted Cones

Canted cones are not a range irregularity. They are the result of power variations in the range antenna made to produce a squeezed or crowfoot range pattern. All beam courses emanate from the cone and, although the cone is not vertical above the station (thus tilted or canted), the cone will be intercepted by following the on-course signal. Canted cones are especially noticeable at high altitudes, where a pilot is also bothered by the great size of the cone.

Misaligned Beams

Misaligned beams are ordinarily the result of transmitter malfunctions. Ice and snow on transmitting antennas may change the phasing and effective power output of the radio signal and may cause a distortion of the signal pattern.

AUTOMATIC RANGE MONITORING SYSTEM

The automatic range monitoring system automatically indicates an abnormal condition on the final approach course of the radio range on which it is installed. Only the final approach course is monitored. When there is a course displacement of 5° or more or when the automatic keying device fails so that there is a steady tone on all antennas

(instead of an A or N), the automatic range monitoring system cuts out the range station identification letters. You then know the range is defective.

STATIC

When certain unlike substances rub together they generate charges of static electricity on their respective surfaces. These static charges may build up until they reach the electrical capacity of the surface and then discharge onto a nearby surface or into the air. When such a discharge occurs, it creates a noisy disturbance (static) in nearby radio receiving equipment.

Precipitation Static

An aircraft in flight accumulates static charges on its various surfaces, such as wings, tail, and propellers. When these charges become greater than the dielectric strength of the adjacent air, they discharge into the surrounding air. This discharge is called a corona discharge or St. Elmo's fire and causes precipitation static in aircraft radio receiving equipment. (See Figure 15-9.)

An aircraft generally accumulates little or no static charge when flying through a clear atmosphere. But an aircraft flying in particle-laden air may encounter precipitation static because of charged particles which (1) adhere to the craft, (2) create a charge through frictional contact, or (3) divide into charged fragments upon impact with the surface of the craft. Thus, at the lower altitudes particularly, in moderate to heavy rain, precipitation static is common. It is accompanied by St. Elmo's fire.

Precipitation static is common also in very high clouds or where high winds pick up and carry a substantial load of solid particles such as are found in dust storms. Precipitation static also results from atmospheric electrical fields, known as external fields, which are created by the presence of charged clouds normally associated with thunderstorms.

Ice Crystal Static

Another form of static similar to precipitation static is the result of ice crystals which are found in the atmosphere. Cirrus clouds, for example, are composed of ice crystals. In lower

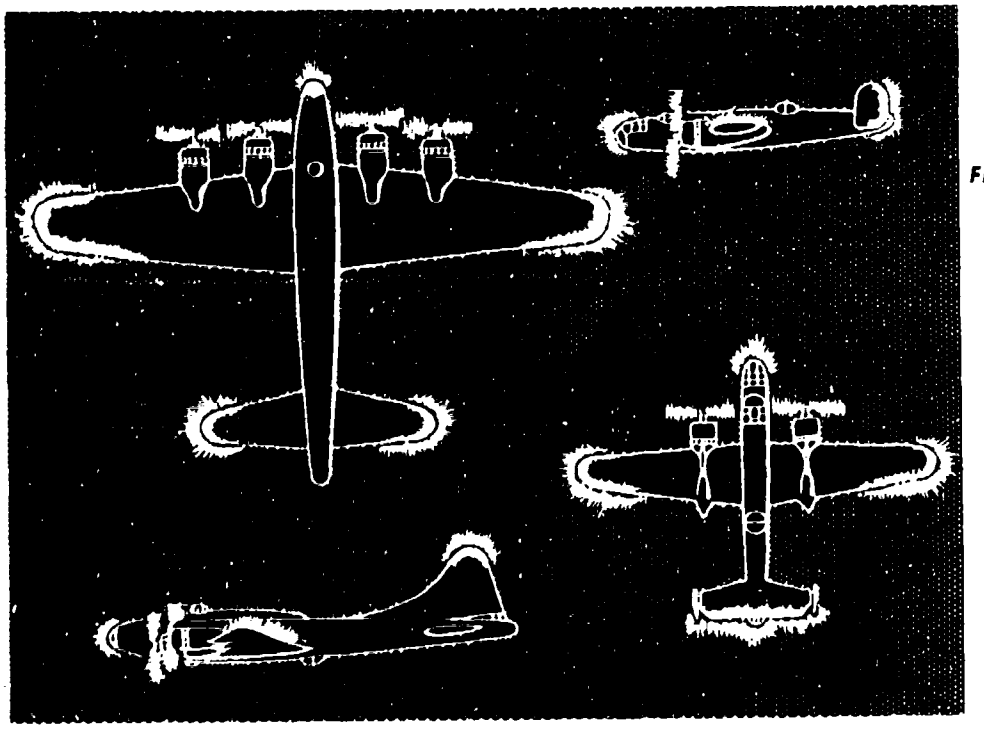


Figure 15-9. Areas of static discharge

latitudes, they usually occur above 30,000 feet. In the higher latitudes, and in middle latitudes in winter, upper portions of altostratus and nimbostratus clouds are composed of ice crystals. In winter, when the surface temperatures fall below −20° C., many of the lower clouds over the interiors of the continents are composed of ice crystals. For example, pilots' reports on flights near Whitehorse, Yukon Territory, show that when there are very low temperatures on the ground during the winter, severe precipitation static is encountered in almost every cloud.

A possible preventive measure in the case of ice crystal static might be to change altitude from a level where dry particles exist to one where moist particles predominate. However, if temperatures are right, an aircraft flying in a region of precipitation still in the liquid state can pick up a load of ice which may be a far greater hazard than static. Therefore, no hard and fast rules have been formulated. It is the responsibility of the pilot to decide on the best procedure.

Reducing Precipitation Static

The following methods are used to reduce precipitation static:

Static Dischargers. Static dischargers are used to promote the quiet discharge of accumulated free electrical charges from the airplane. Static dischargers are made of a fibrous conducting tube consisting of very fine discharge points which are constantly renewed by the fraying of the wick in the slipstream. (See Figure 15-10.)

Figure 15-10. Static discharger

Loop Antenna. Another way to combat precipitation static interference is to use the shielded loop antenna. The shielding on the loop lets the radio waves get through but prevents charged particles from hitting the antenna proper. When turned to a position parallel to the line of flight (that is, with the azimuth needle at 90°), the loop provides readable signals long after the conventional antennas are useless. Remember, though, that the loop is a directional antenna. Near the station it may be so oriented as to pick up the A more strongly than the N even though you are flying in the N sector; the reverse is also true. In addition, the cone of a loop range can't be detected properly with the loop antenna.

Trailing Antenna. Severe static, such as that encountered in snow flurries, can be relieved by using the trailing antenna as a static discharger. You can restore some degree of readability by reeling out the trailing antenna and grounding it to some metallic part of the aircraft. However, this has two disadvantages: first, the discharge from the trailing wire is often quite noisy and, secondly, in or near thunderstorm areas, the trailing wire may attract a lightning stroke.

Reducing Speed. Sometimes, you can make it possible to establish radio communications or use radio navigational aids in severe precipitation static by merely reducing the speed of the aircraft. Do this by reducing power. Don't try to decrease speed by dropping the landing gear because, with many types of aircraft, this will simply provide additional areas for corona discharge.

Audio Filter. When static is caused by the periodic discharge of high-intensity electrostatic energy such as lightning, the audio filter can help. Switch it to the RANGE position, and all frequencies except the narrow 1,020-cycle band will be rejected. This provides a reduction of the undesirable noise and will often leave range signals distinguishable.

PRECAUTIONS IN USING RADIO RANGES

In using radio ranges, be alert for difficulties and problems you may encounter. Here are some things you should be careful about.

1. Be alert for irregularities due to sky wave reflection on any loop-type radio station at night.

2. Before using unfamiliar ranges, check the latest NOTAMS and note any range irregularities. Temporary irregularities may be reported on the scheduled broadcasts of the various range stations.

3. Avoid setting the volume too high. Every radio receiver has an overload point at which the signal intensity no longer increases as the volume control is advanced. In fact, the signal will begin

to drop as the volume control is further advanced. When this point is reached, the weaker signal entering the receiver may actually sound louder than the stronger signal, which is producing the overload. If a strong N overloads the receiver substantially, the weaker A signal, which is not overloading the receiver, may sound louder. You will then be hearing the signals in reverse strength and interpreting them erroneously.

4. Some aircraft radio receivers and certain components of all aircraft receivers have a selector position which provides a constant volume level in the headset without manual volume adjustment. This is true, for example, of the COMPASS position of the radio compass equipment. Be sure, therefore, not to try to solve problems involving build or fade in signal volume while using the automatic volume control features.

5. Above all, when you use a range station, be sure you tune it in and identify it properly.

DETUNING

When tuning a station that has simultaneous voice and range transmission, you can provide for either maximum voice or range reception. You can do this by "detuning." There is a frequency difference of 1.02 kc between the voice and range transmission. If the range signal is tuned for maximum volume, the voice transmissions will not be comfortably audible because the range signal is 1.02 kc higher. Therefore, if you tune the signal to maximum reception with a moderate volume setting and turn the tuning handle to the right (reducing the frequency) until the range signal is barely audible, you will get the carrier frequency. Then, when you return the volume to normal with the volume control, both range and voice transmissions will be received clearly.

THE FILTER BOX

A filter box in the aircraft enables you to select either voice or range signals. The filter box provides three selective positions marked BOTH, VOICE, and RANGE. No filtering is introduced on the BOTH position. On the RANGE position all tones except the 1,020-cycle tone are filtered out. On the VOICE position, *only* the 1,020-cycle tone is filtered out.

RADIO FACILITIES CLASS DESIGNATORS

A series of letters have been designated to describe the class of ranges by antenna, frequency, and power. In addition, the available facilities of the individual station are described by use of the following letters as applicable:

RL	Loop range with power of over 150 watts.
MRL	Loop range with power of 50 to 150 watts.
ML	Loop range with power of less than 50 watts.
RA	Adcock range with power of over 150 watts.
MRA	Adcock range with power of 50 to 150 watts.
S	Simultaneous homing and range facilities; also voice unless suffix W follows.
B	Scheduled broadcast includes latest weather, NOTAMS, etc. At CAA-operated stations it comes at 15 minutes and 45 minutes after hour. At Navy and AF stations it comes at 29 minutes past.
W	Without voice communications.
Z	A Z-marker is installed.
VOR	Omni Range.
VOR—E	Omni Range with DME.
TVOR	Low power VOR—no standby equipment on airport.
LVOR	Low power VOR with standby equipment.

These designations are subject to change, of course. Look at the first few pages of Radio Facility Charts to find those currently used. They are used in the "Class Power" column of the Tabulation Pages throughout the book.

VISUAL-AURAL RANGES (VAR)

As pointed out before, the 4-course, low-frequency range just discussed is subject to various

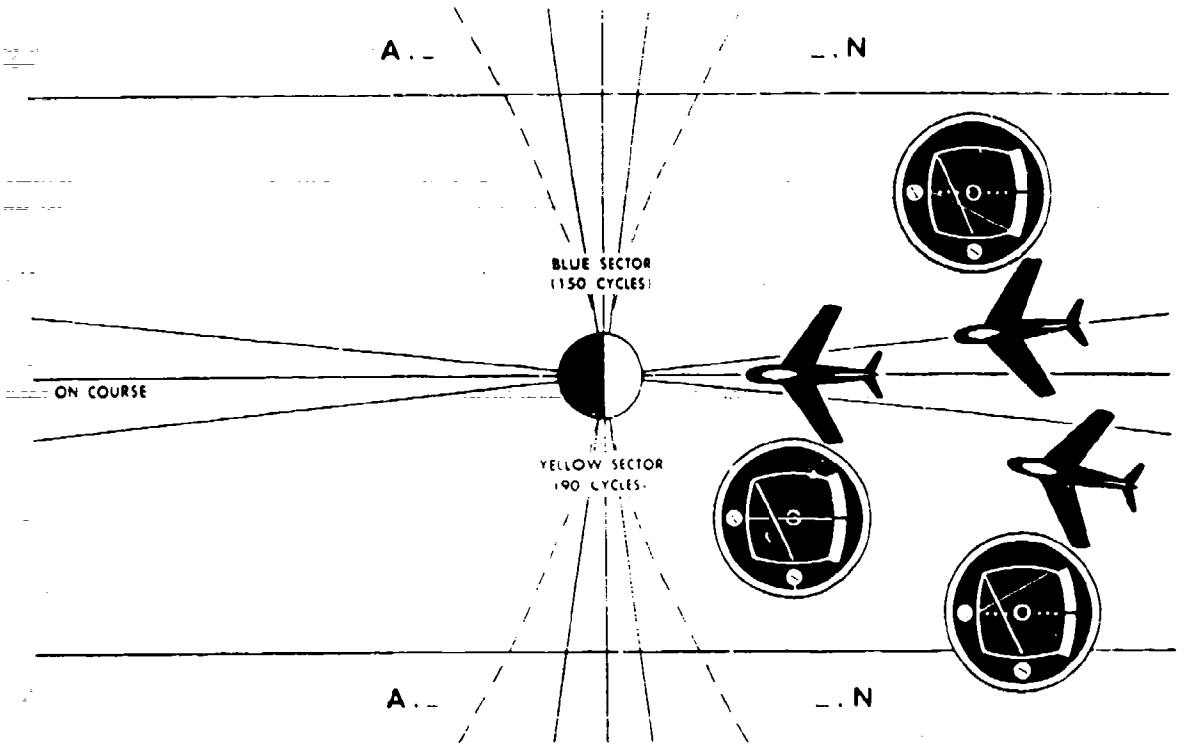


Figure 15-11. Visual aural range

limitations and problems. During periods of heavy precipitation or static, it is difficult to receive and interpret. In addition, it may be misleading as a result of bent legs, multiple beams and the like.

To overcome these difficulties, the visual-aural (VAR) range was developed. It embodies the same features as the low-frequency range, but adds the advantages of a visual signal and a very high frequency of transmission. As a result, visual-aural ranges provide easier sector identification, easier orientation to the station, and reliable reception even under conditions that would render an LF MF range unreliable.

The main disadvantage of VAR is that the range legs cannot be bent to match airways. They are always at right angles to each other. This is due to the method used in getting four quadrants with different identifications.

Flight procedures with the VAR are essentially the same as those for the LF MF range; however, a small amount of practice is required by most pilots who have not had experience with the visual indicator.

Operation

The VAR station is usually located on the highest terrain available in a position which provides a clear line of sight to the horizon, for the distance at which you can receive the range signals depends on the altitude of the aircraft and any intervening terrain features. You can receive the signals properly only if there is a direct "line of sight" between the transmitter and the aircraft. This is a distinct disadvantage for flight conducted at relatively low altitudes or over mountainous terrain.

Part of the antenna array transmits an aural pattern—a radio wave keyed with the letter N on one side of the station and a radio wave keyed with the letter A on the opposite side. This produces two signal sectors with an equisignal zone between

them where the A and N signals overlap to form the solid on-course tone. There is a bisignal zone on either side of the on-course leg which is very similar to the bisignal zone of an LF/MF range. Coded station identification signals are transmitted at 30-second intervals, first in the N sector and then in the A sector.

In addition to the aural pattern, there is a two-sector visual pattern produced by the "visual" transmitter. One sector is modulated with a 90 cps signal and the other with a 150 cps signal. The two-signal sectors overlap in such a manner as to produce an on-course or an area of equal signal intensity.

The aural and the visual signal patterns combine to produce a four-course range. (See Figure 15-11.) Each quadrant is separately identifiable by an aural signal and a visual indication.

Receiver Equipment

Radio Receiving Set RC-103-A is used to fly the VAR. This is the same set that is used to fly the ILS (SCS-51). The volume of the aural signal is controlled either at the jack-box or at the ILS control box. Reception of the 90-cycle signal is indicated as a deflection of the vertical needle into the yellow field. Reception of the 150-cycle signal causes the needle to indicate in the blue. In the area of the on-course, where both signals are equal, the needle is centered.

If your aircraft has the AN/ARN-14 receiver with the ID-249 Course Indicator (Figure 15-12),

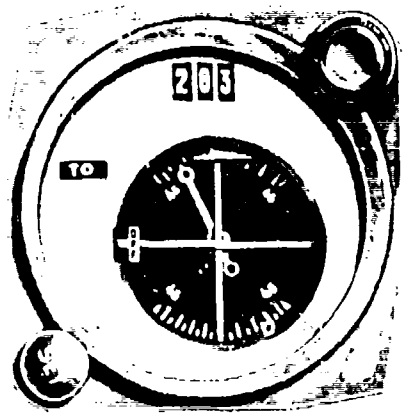


Figure 15-12. ID-249 course indicator for ARN-14

previously discussed in Chapter 7, set the TONE PHASE switch on the control box to TONE. In the blue sector, the vertical needle will deviate to the left; in the yellow sector, it will deviate to the right. If your aircraft is equipped with an AN/ARN-30 receiver, set the switch marked OMNI-VAR LOC to VAR LOC, tune to the station, and you will get the same course indications on the Deviation Indicator that you would on the AN/ARN-14.

Designation of Sectors

Since the visual course of the VAR is the easier to fly, the signal pattern is always oriented so that the visual legs lie along the airway. On Green and Red airways the blue sector is north of the visual course and the N sector is east of the aural course. On Amber and Blue airways, the blue sector is west of the visual course and the N sector is to the north of the aural course. Naturally, you should check the Radio Facility Charts to be sure in each case.

Figure 15-13 shows a VAR range from the Radio Facility Charts. There is an LF/MF range just to the left of it. The visual course 021°-201° M. is a single line with blue and yellow on the appropriate sides. The aural courses are shown like legs of an LF/MF range. Since the solid line of the aural legs is north of the aural legs, N here lies north of the east-west aural legs. Note also in this picture that another line runs in a northeasterly-southwesterly direction through the airport, marked 045°-225° which has a blue/yellow (B and Y) indication on either side. This is not VAR but is the localizer for ILS at the airport.

Flight Procedures for VAR Ranges

In Radfacs, check for the frequency and characteristics of the VAR range and identify the quadrants on the chart. Tune the receiver to the channel used. VAR normally uses one of three channels: U-108.8 mc; V-108.7; W-109.1. The localizer shows the color of the sector by the vertical needle deflection. On some indicators, the horizontal needle remains tilted upwards and is inoperative, while on others it is centered when inoperative.

In following the beam on a visual leg, you use the same techniques as in following a localizer

course. On the aural leg, you proceed as on an LF/MF range leg. On a visual leg, station passage is shown by a full deflection of the vertical needle from one color to the other. On an aural leg, you will hear the A or N change and the vertical needle may oscillate rapidly.

ADDITIONAL RADIO AIDS

Since the radio range system does not, in itself, provide a definite fix except over the range station or at an intersection of two range legs, additional radio aids to navigation have been provided. These additional radio aids include non-directional homing devices and various marker beacons.

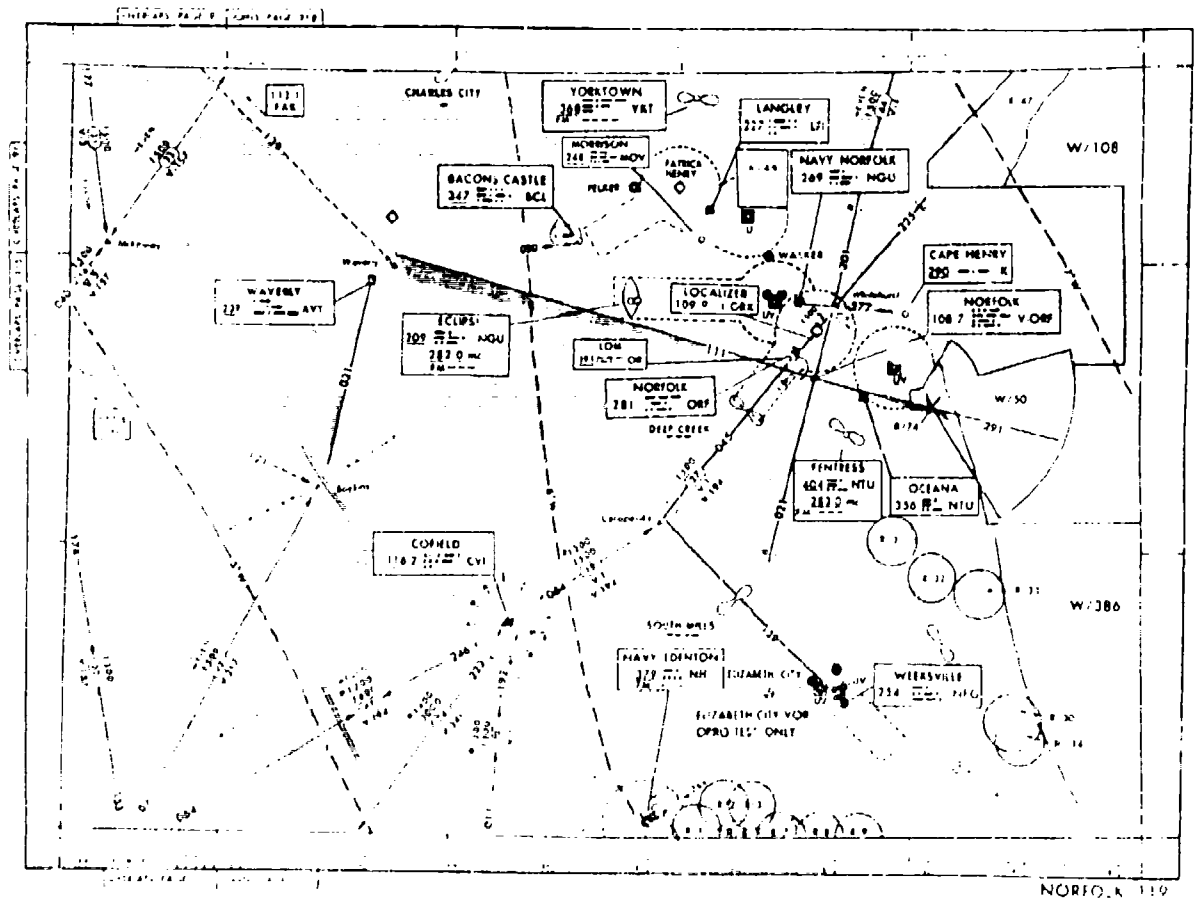
Z-Markers

The Z-marker is a station location marker which is used for positive station identification. Having a normal power output of 5 watts, it is located directly over the station, and has a signal pattern in the form of an inverted cone. It is modulated with a 3,000-cps tone and can be received on the Marker Beacon Receiver—the same 75-mc receiver that is used for the fan marker. It can be received both aurally and visually. Its zone of best reception extends above the station to 10,000 feet. The presence of a Z-marker is shown by the Class/Power designation in Radfacs for that station.

Fan Markers

A fan marker is a positive fix for traffic regulation and spacing, holding and stacking, and it

Figure 15-13. VAR range from Radio Facility Charts



provides a definite fix for checking ground speed. It is normally located on the approach leg, but it can be located at any position on any range leg. It is normally placed between 10 and 12 miles from the station, or between 20 and 25 miles from the station. The busier airports have fan markers at both locations.

The fan marker uses VHF transmitter of 75-mc and a normal power output of 100 watts. It transmits a 3,000-cycle signal which can be received only on a 75-mc receiver. The signal can be received aurally or it may be used to turn on a light on the pilot's instrument panel. The signal is transmitted in a definite pattern. On the older fan markers, this is an ellipse 10 miles long and 3 miles wide. In more recent installations, the transmission pattern is bone (or dumbbell) shaped rather than elliptical. This provides a more definite holding fix because the pattern is 1½ miles wide at the center instead of 3 as in the elliptical fan markers. Once in a while, especially with ILS, smaller 5-watt fan markers are used and these appear on the charts as a much smaller ellipse.

Fan markers are identified by a definite system of dashes and dots. The number of dashes corresponds to the number of the range leg on which the fan marker is located. Thus, a fan marker on the number 2 course of the range would transmits a series of two dashes (— —, — —, — —). If there are two or more fan markers on the same range leg, the identification signals of the farther markers are preceded by an increasing number of dots. Thus, on the number 2 course of the range the closest fan marker would be identified by two dashes — —; — —; the next fan marker out on the same course would be identified by two dashes preceded by two dots . . — —, . . — —, . . — —; the next fan marker on the same course would be identified by two dashes preceded by three dots . . . — —, . . . — —, . . . — —; etc. The transmitted signal, consisting of a continuous repetition of the identification signal, can be identified as such both aurally and visually. (See Figure 15-14.)

For positive identification of either fan markers of Z-markers, you must check both the aural and visual signals. The visual signal of the 75-mc receiver can be actuated by lightning and/or high tension wires.

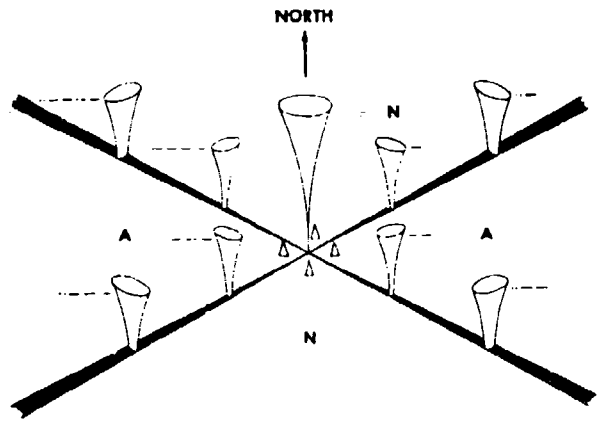


Figure 15-14. Normal fan marker identification system

Non-Directional Radio Beacon (Homer)

The non-directional radio beacon is an omni-directional homer which broadcasts a continuous series of coded identification letters on a frequency between 200 and 415 kc. It is of no value for navigation without direction-finding equipment in the aircraft. Non-directional radio beacons are located:

1. In areas with limited range facilities. Here they are used as navigational aids across long distances over which radio range signals would be of minimum intensity and use.

2. At airports whose associated range station is at such a distance that accurate let-down from the station would be difficult.

3. At some fan marker sites to help pilots maintain precise holding pattern when holding is required.

4. Occasionally as obstruction or distance-limit indicators.

5. As fixes from which arrivals can start final straight-in approaches.

Non-directional radio beacons of less than 50 watts power are designated in airways publications by the letters "MH." Those from 50 watts to 2,000 are designated by the letter "H." Those over 2,000 watts are designated "HH."

SUMMARY

As a summary of the information in this chapter, check the information in the facility chart

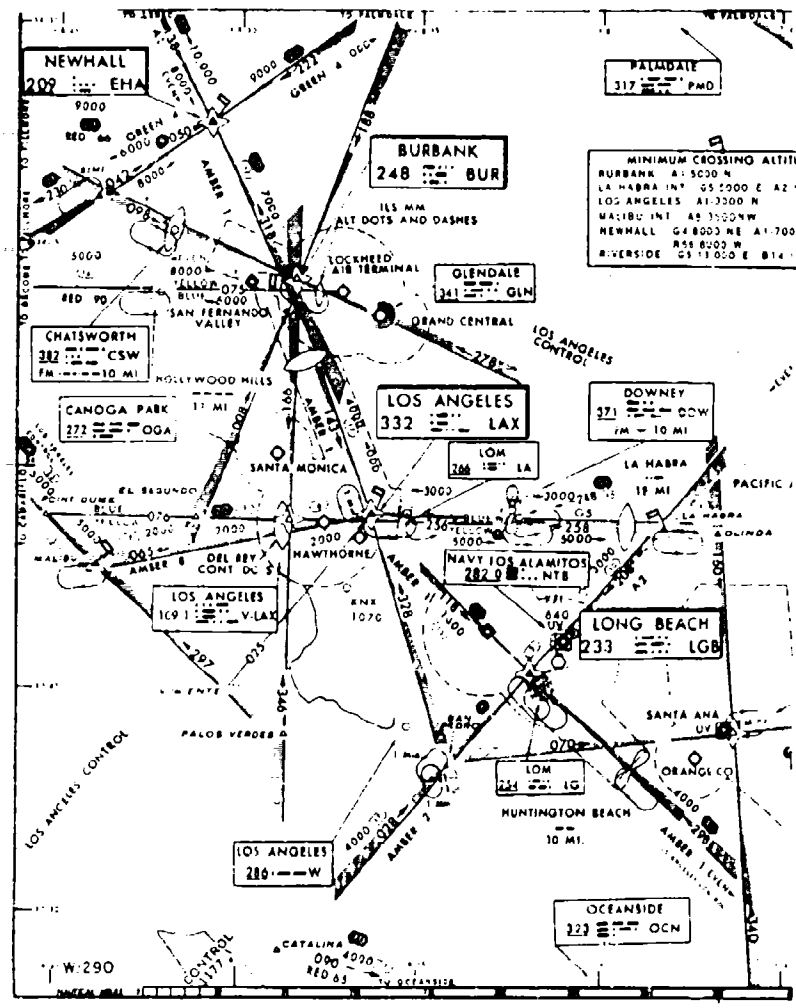


Figure 15–15. Los Angeles facility chart

and its tabular page for the Los Angeles area as shown in Figure 15-15 as you read the following discussion. The discussion covers the facilities at Los Angeles and Burbank. (Remember, of course, that the chart shown here may be partially obsolete when you read this manual. For actual flight planning, refer to the latest edition of Radfacs.)

Los Angeles

The CAA operates the LF/MF range on 332 kc. It is designated SBRAZ. This means it is a high-power, Adcock range (RA) with simultaneous range, homing, and voice signals (S) and scheduled weather broadcasts (B) on 332 kc, its location marked by a Z-marker. On the east leg (256° M. inbound) there are two fan markers. The inner fan marker, Downey, is identified by a single dash because, counting from north clockwise, it is on the first leg. This is a bone-shaped marker to give a precise position check when flying the "on course" inbound, and for holding. The outer fan marker, La Habra, is marked . . — to show it is the outer marker on the first leg. Downey is 10 miles and La Habra 18 miles from the airport. There is no fan marker needed on leg number 2,328° M. inbound as inbound traffic can determine position and hold as required at the intersection with the SW leg of Long Beach. The fan marker, Del Rey, on the number 3 leg, 065° M. inbound, is 6 miles out and is identified by con-

tinuous dots. The fan marker at Hollywood Hills, 11 miles out on the fourth leg, 143° M. inbound uses the normal 4-dash identification. Notice, however, that on the NW or number 4 leg of Burbank (098° M. inbound), the marker at Chatsworth emits . — — — — rather than just four dashes in order to avoid possible confusion with the Hollywood Hills marker.

Before passing to other stations, note the data about Radiobeacons (Rbn) and Radar Beacons (Racon) around L. A. At Downey, the table shows there is DOW, a radiobeacon on 371 kc. This homer appears on the chart at the same place as the inner fan marker but the table locates it more exactly at 9.5 miles out on the east leg. The radar beacon emits a signal "2" on 9,310 megacycles and appears on the chart as a white "T" in a black circle. The table shows that it is operated intermittently. Its precise location is found in the special table of radar beacons to be 33°55′ N. and 118°08′ W. Another homer in the area, listed under L. A. in the table, is near the San Pedro intersection on the south leg, identified "W" on 286 kc. and shown in the table to operate 1 min. on and 2 min. off. Both this and the Downey homer are designed "HW" (medium power; no voice facility). Another aid at Los Angeles is a VAR range, V-LAX on 109.1 mc. The N sector is east of the aural legs (the solid line side of legs). Looking in the table, however, you find important data about this range. It is designated BVAR, meaning a VAR range with weather broadcasts scheduled, but a note states its visual courses are not usable. Whether this is temporary or not, you can at least know that it should not now be relied on for east-west flight (the visual courses). Note that it is west of the field; the table states 1.6 miles and 083° from range to station. The LF/MF range, however, is even farther, being 3.4 miles on 245° M to station from the range. Note how the VAR range is shown on the chart. Note that ILS is available at Los Angeles. The localizer outer marker is designated as usual "LOM" and has a call LA on 266 kc for the radiobeacon marking its location, just east of the LF range. Such localizers only appear on the chart when used as reporting points.

Burbank

Burbank is designated SBML (low power loop range (ML)) with simultaneous homing, voice, and range (s) with scheduled weather broadcasts (B). There is no field there, the range being used primarily for transient aircraft and to approach to Lockheed Air Terminal. Note the little fan marker identified "ILS MM" just east of the range station. This is an ILS middle marker. The localizer course, 075° M., with its yellow and blue sides marked, is seen running eastward into Lockheed. Find these radiobeacons (homers): Glendale (at Grand Central field) Chatsworth, Canoga Park. Note that Burbank is within the Los Angeles Control Area.

As practice for yourself, examine the charts for all the above items in the ex[illegible]tion for the Los Angeles area, and determ[illegible]ies have been changed since this bo[illegible]d, and what changes, if any, have [illegible] the Radfacs presentation.

CHAPTER 16

RADIO RANGE PROCEDURE (CONVENTIONAL AIRCRAFT)

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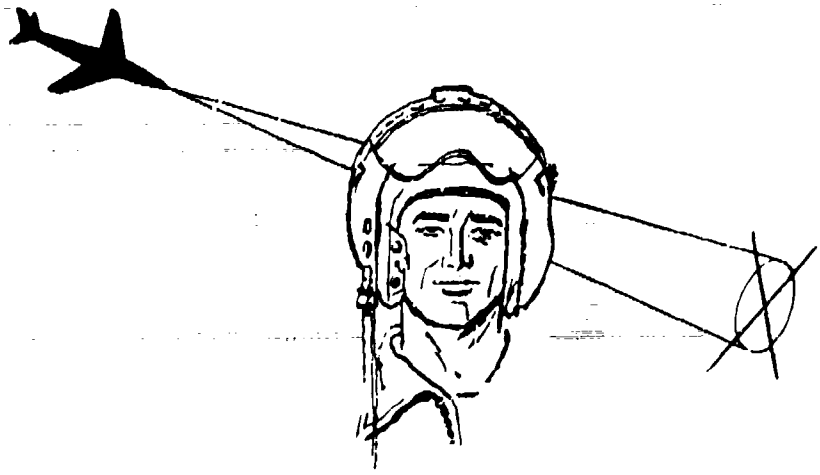


CHAPTER 16

RADIO RANGE PROCEDURE (CONVENTIONAL AIRCRAFT)

THIS chapter discusses the LF/MF radio range procedures for conventional aircraft from range leg interception to letdown, including holding and emergency procedures. As an aid to clear understanding of the discussion, it is well to start with some of the basic terms used.

Interception refers to the method of intercepting a known range leg when flying in a clear signal quadrant.

Tracking is a method of following a range leg on course by flying the published heading until the aircraft drifts off, correcting back to on-course, flying a new heading which makes some allowance for wind until the aircraft drifts off again, and so on, until a heading is held from which the aircraft does not drift to off-course.

Following refers to any method of flying along a beam leg so as to stay approximately in the on-course signal zone regardless of the wind.

Orientation is a procedure used when a pilot is in some range quadrant or intercepts some range leg, but does not know which way to turn to head toward the station. In this day of D/F equipment of many kinds, such a situation is not common. However, since the need for orientation is often the result of an equipment failure or extreme weather, such procedures must be known and practiced before they are needed.

Procedure Turn is any specified turn for the purpose of reversing course on a range leg as a part of any standardized procedure. It is usually a standard rate turn.

INTERCEPTION

The interception of inbound and outbound beam legs is identical. In this section, therefore, only the inbound interception is discussed.

When approaching a range leg from a clear quadrant, make the interception at a large enough angle to be sure that the leg will definitely be intercepted well before reaching the station; however, do not make it so large that the on-course might be missed or that a long turn might be required.

You can use any angle of interception, but an angle of 45° is recommended since it is large enough to counteract any probable drift and will still give you an expeditious flight path toward the station. The way to reduce this angle to prevent overshooting as you approach the beam is explained later in this section.

In Figure 16-1, the angle of interception would be 90° if you maintained the original course of the aircraft. However, a 45° angle of interception is most desirable: so as soon as the signal definitely indicates the bi-signal zone, turn the aircraft so as to intercept the desired beam at a 45° angle. As you approach the beam, the background signal grows stronger, and the two station identification signals approach an equal level of intensity.

The width of the on-course is directly proportional to the distance from the station. If you are more than three minutes from the station, it is not usually necessary to lead the turn. Remember that an aircraft has a larger radius of turn at high altitude. Therefore, if you are intercepting a beam at high altitude, it may be necessary to reduce the angle of interception to 30° as the signals approach an equal level of intensity. On the other hand, decreasing the angle of interception will sometimes slow up the interception considerably, when there is a strong wind. If you do not intercept the beam in a reasonable time, you must use the full 45° angle.

If you are less than three minutes from the station, start the turn slightly before receiving the on-course so that you won't pass through the beam into the opposite quadrant. The rate of build in the background signal will enable you to estimate the approximate lead for the turn to the beam heading. In this example, no lead is necessary. Therefore, as soon as you hear the on-course, or when both station identification signals are of equal intensity, turn the aircraft to the published beam heading. During this turn, ignore the aural signals and execute a normal basic instrument turn to a heading. If you don't know the wind, turn to the published beam heading. Then, as soon

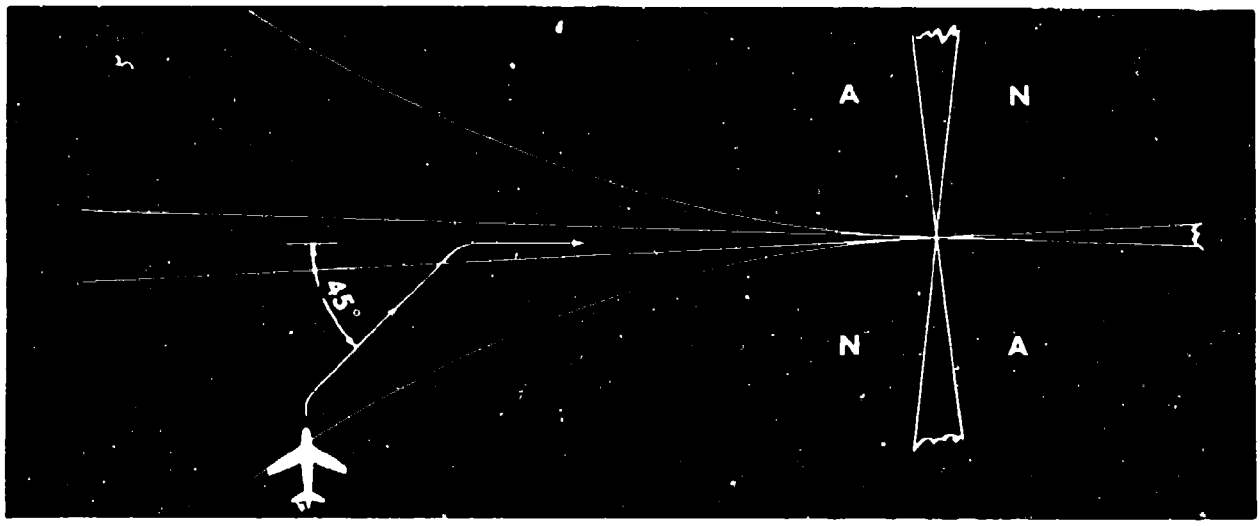


Figure 16-1. Beam Interception

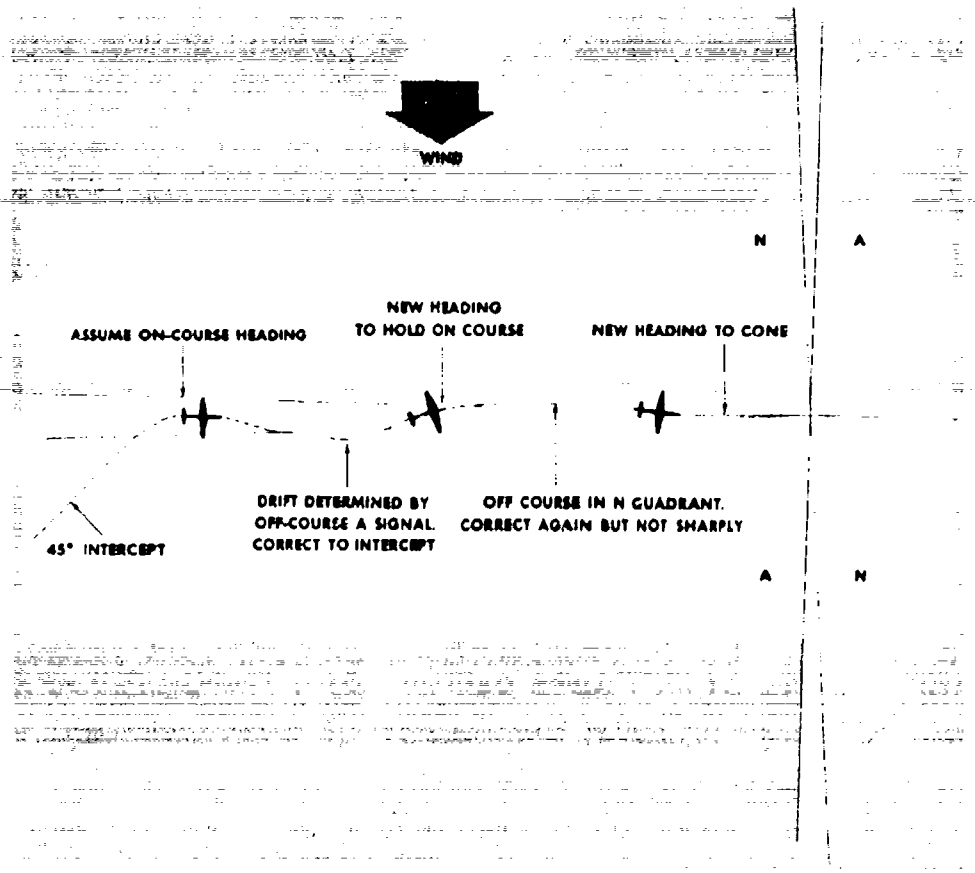


Figure 16–2. Beam following

as the wings are level, monitor the aural signals closely to determine the position of the aircraft relative to the beam.

The volume increases as the aircraft approaches the station. Counteract the increase of volume by adjusting the volume control to maintain a constant level. Flying from a clear-quadrant signal, through the bi-signal zone, to the on-course results in an apparent fade in signal strength. This is due to the fact that the background signal, a monotone, becomes predominant and is not as audible as the clear-quadrant A or N signal.

During an interception, the station identification signals might be transmitted just as you enter the on-course. A comparison of the intensity of the two signals provides the means for recognizing the on-course.

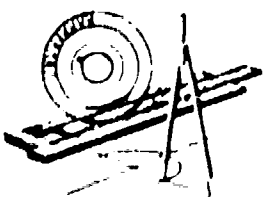
BEAM FOLLOWING

After you complete the turn to the published beam heading, follow the beam to the station. In following the beam, you control the flight path of the aircraft along the track determined by the aural signals. Assuming the heading indicator to be correct, the only factor that will cause the aircraft to leave the beam is wind. You can use the winds-aloft report for the particular cruising altitude as the basis for initial correction and planning. Often the easiest method is to set the probable or forecast wind on the computer and determine anticipated drift. However, since this may be impractical, especially in single-place airplanes, you can make a rule of thumb correction based on the wind.

During the initial interception, if you know

the wind, turn the aircraft to the beam heading corrected for the wind. If you don't know the wind, make the turn to the published beam heading and monitor the radio signal closely. Memorize the position of the N and A quadrants relative to the on-course so that you can make corrective turns in the proper direction as soon as you recognize the first off-course signal. If the signal indicates that the aircraft overshot or undershot the beam during the intercepting turn, turn to a new heading which will return the aircraft to the beam. This correction should be big enough to re-intercept the beam (10° to 40°), in order to get back on course as soon as possible. (See Figure 16-2.) After applying the correction, you must interpret the signal closely to observe the results of the correction. The signal should indicate that you are approaching the beam. If not, excessive winds are present and additional correction is necessary. As soon as you hear the on-course, turn the aircraft either to the published beam heading or the heading which will counteract the known wind.

After turning to the beam heading, if you hear the on-course signal, hold the heading constant. However, as soon as you hear an off-course signal, make a correction for the wind. Make this correction toward the beam. The amount of correction needed will depend on the distance from the station and the rate at which the aircraft drifts off course. After you make the correction, note the time required to re enter the on course so that you can get an estimate of the wind velocity. As soon as you hear the on-course signal, turn the aircraft toward the beam heading. Stop the roll-out short of the published beam heading by the number of degrees you estimate will be required to counteract the wind drift. For example, if you estimate that a wind correction of 5° to the right is necessary when flying inbound on a wind heading of 90°, make the roll-out on a heading of 95° after re-entering the on-course.



Maintain the new heading until the signal again indicates the aircraft is drifting off-course. If that happens, consider both the time you were on course and the direction of drift. The length of time you stay on course is an indication of the amount of correction needed. If you were on course for a comparatively long time, you need only a small correction. The direction of drift indicates whether your original correction was insufficient or too large. If the aircraft enters the downwind bi-signal zone, the correction was not enough. If it enters the upwind bi-signal zone, the original drift correction was too large. In this case, turn the aircraft to the published beam heading or a few degrees downwind, let the aircraft drift back to the beam, and when you hear the on-course signal, turn to a heading which will decrease the original drift correction by a few degrees.

Repeat this kind of procedure whenever the aircraft leaves the beam, reducing the size of each correction systematically until you can stay on course by a correction of less than 5°. Very close to the station, the beam is very narrow and you can't hear the bi-signal. An off-course is indicated by a clear A or N signal.

Beam following, like all instrument maneuvers, requires the proper use of the controls to insure coordinated flight. Making changes in heading by slipping or skidding is very poor technique and prevents precise beam following.

As you approach the station, the volume will build at an ever increasing rate. Adjust the volume control to counteract this buildup, for constant volume is necessary for accurate beam following. The more frequently you have to adjust the volume, the closer you are to the station. When you are close to the station, keep the volume down so you can easily recognize station passage.

Generally you should fly nearer the right hand side of a beam leg, as this may help you avoid large corrections near the station. As you get very close, you should make no corrections larger than 5° even though that causes you to miss flying right over the cone. You can still determine station passage.

Be careful to avoid steep banks, particularly

close to the station. The aircraft receiving antenna is directional and will pick up the signal from the high-wind side of the turn. This will give an erroneous indication of position. Furthermore, confusion may result from large correction angles if you should pass the station at that time. An excellent rule of thumb for banking on corrections is to keep the degree of bank at or below the desired amount of turn—that is, for a 20° turn, use 20° of bank or less; for a 10° turn, use 10° of bank or less, etc.

ORIENTATION PROCEDURES

The range procedures just discussed are for situations when you know your initial position in relation to the range station. Now consider the orientation procedures to be used when you don't know your position in relation to the range station. Obviously, you should be thoroughly familiar with these procedures. The time when you will need them most will normally occur during periods of strong mental strain, probably when weather conditions are adverse, impairing radio reception and making control of the aircraft difficult. Mechanical failure in the aircraft could also be a contributing reason for your need to use them. Under such conditions, orienting yourself in the shortest possible time may be imperative because of a lack of fuel or mechanical difficulties, or both. Your complete familiarity with orientation procedures can then make all the difference in the world.

The recommended orientation procedures are the Fade 90, the Parallel Close-In and the On-Course Orientation. Before orientation or during the first part of it, establish communication with the nearest controlling activity and convey to them pertinent information as to your situation (general position and altitude). ATC will then assign an altitude at which to perform the orientation. Before proceeding to your ultimate destination, you will generally have to revise your flight plan or file a completely new plan.

THE FADE 90

The Fade 90 system is one of many orientation methods that can be used by aircraft equipped

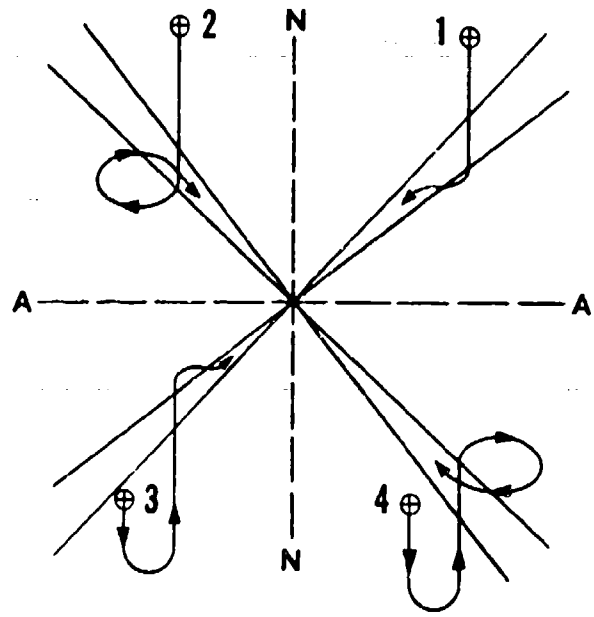


Figure 16–3. The fade 90 orientation

with non-directional receiving antennas. However, experience has proven that it has advantages over other methods and that if you know this system thoroughly, you can use it for any situation. In general, here is how this system works. In Figure 16-3 you see the case of a pilot who finds himself in the N sector of the range. Positions 1, 2, 3, and 4 represent typical positions at which he may be, and from which he may intercept a range leg. In flying from any one of these starting points, the first step is to determine whether the signal is fading or building. If it is fading, he is at 3 or 4. He executes a 180° turn so that he will again approach the range leg. After making this reversal of course, he is in the same sort of position as if he had been at 1 or 2—that is, he is approaching a range leg which he will identify after making a 90° right turn upon intereception. By flying a bisector heading he will intercept at approximately 45° (actually 45° on a square range, and more or less than that on another shaped range). If he turns out to be at position 5 (or its equivalent from the opposite sector), he changes to the Close-In Orientation as soon as he recognizes the situation.

Now, consider the procedure more specifically. Here is what you do.

1. Select, properly tune, and identify the radio facility being used.

2. Refer to the proper chart and determine the average bisector heading of the quadrant signal being received. Turn the aircraft to the bisector heading nearest the present heading. Note the time. Now you know that the aircraft can intersect only one of two possible beam courses which bound the quadrant the aircraft is in.

3. While flying this heading, carefully analyze the signal. Assume, for example, that you are in an absolutley clear quadrant. Turn the volume relatively low. This is best accomplished by turning the volume to an inaudible level, then carefully increasing the volume to a minimum distinguishable level. This will help you recognize a change in signal strength. If you get a fade in signal, reverse course without changing the volume, and check the fade with a build (#3 and 4 in Figure 16–3). In this case, you should backtrack, at least the length of time you flew to establish a fade, before expecting much build. If, on establishing the initial course, you get a build, reduce the volume again (#1 and 2). Continue on course and check with another build. When you have done this, you have established the identity of the quadrant in which you are flying.

If, on initial orientation, you find yourself in a bi-signal zone, the procedure for selecting a bisector heading in the same; however, you should set the volume so that the weaker signal is at its lowest audible level. This situation will permit you to determine more readily whether you're going toward or away from a range course. You remember that in flying away from a beam, the station identification from the opposite quadrant becomes weaker. When flying toward a beam, the opposite quadrant station identification becomes stronger. On entering the on course beam, the two identification signals become equal. In addition to this, you should also analyze the relative change of the background on-course signal in relation to the quadrant signal being received. Don't fail to notice whether the over-all signal is building or fading. In all instances, then, you can tell when you are inbound. The next phase of the problem is to determine which of the two possible courses you will cross.

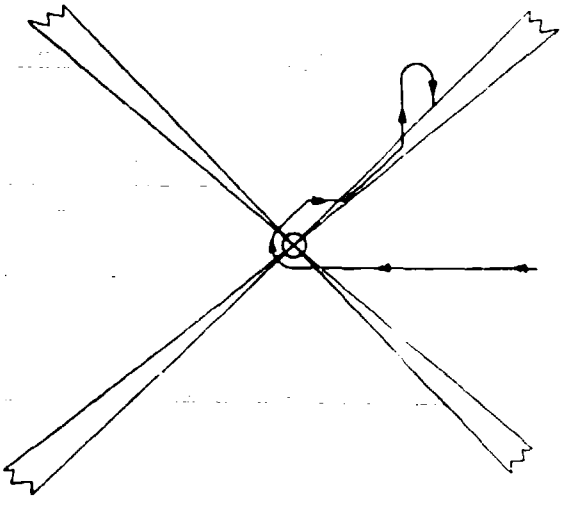


Figure 16–4. Close-in procedure

4. Continue the proper bisector heading until you have intersected one of the two possible beams. (See Figure 16–3.)

5. At the first off-course signal after passing through the beam, make a 90° turn to the right. If you are inbound from the north N sector and you re-intercept the beam when you cross it and turn right, you know that you are on the northeast course (#1). However, if you make the 90° right turn and then get a fade in background on-course signal and an increasingly predominant A signal, you have established your position as having crossed the northwest course (#2). After you identify the course, the next step is to return to it inbound toward the station. Upon recognizing the northwest course, however, you should continue on your heading for approximately one minute before attempting to re-intercept the inbound course.

Advantages

1. The system will work on any range pattern.

2. Quadrant ambiguity is solved largely by signal change and not by total volume. Signal analysis is simpler and quicker. The system is advantageous when static interferes with radio reception.

3. It is always completed with aircraft headed toward station.

4. Except on extreme range patterns, all headings are bi-sector headings. They are printed on the charts in the "Pilot's Handbook" series of publications for that station.

Disadvantages

1. It may take too long to recognize build or fade if the starting point is in the clear signal zone.

2. Apparent range pattern distortion due to high winds may cause confusion, particularly on a scissors range.

3. In quadrants of 120° or more, high winds may cause confusion on the turn to identify leg. (Such circumstances, however, would probably be known and allowance made for them.)

4. When interception is close to station, close-in procedure is preferable.

CLOSE-IN PROCEDURE

If the orientation terminates close to the station or if the initial interception of a range course is made too close to the station to permit normal beam interception, and the pilot knows it, the close-in procedure should be used to place the aircraft on the desired course of the range. In either case, turn to the outbound heading of the desired leg and hold this heading until the signal fade gives assurance that the station is behind. Then make correction to put the aircraft on course, and follow normal procedures for the rest of the initial approach.

The need to use the close-in procedure must be determined before any interception of the on-course is made. If you have been flying a clear quadrant, the signals you receive before on-course interception will indicate how close to the station you will be when you make the interception. If you have remained within the clear signal area for an appreciable time while making several adjustments for volume builds, you should know that you will intercept the on-course close to the station. The longer you spend in the clear quadrant and the greater the number of volume adjustments you make, the closer you will be to the station when interception is made. In determining that the aircraft will pass close to the station (that is, if you enter an on-course from a clear signal zone with little or no bi-signal, pass through 2 beams before completing the 90° turn, or receive a clear opposite quadrant signal right after crossing the cone of silence), you should consider yourself "close in" and immediately turn to a heading parallel to the desired course. (See Figure 16-4.)

Once you have established a heading parallel to the desired course, you normally don't have to fly outbound longer than one minute before turning to intercept the on-course. The interception angle should be great enough to make progress toward the desired course. Normally 45° will suffice. After interception, but not less than two minutes from the station, make a procedure turn and proceed to the station. Remember that the time spent performing a close-in procedure will prolong your approach; therefore, try to use sound techniques and good judgment in this procedure to eliminate the possibility of taking too long.

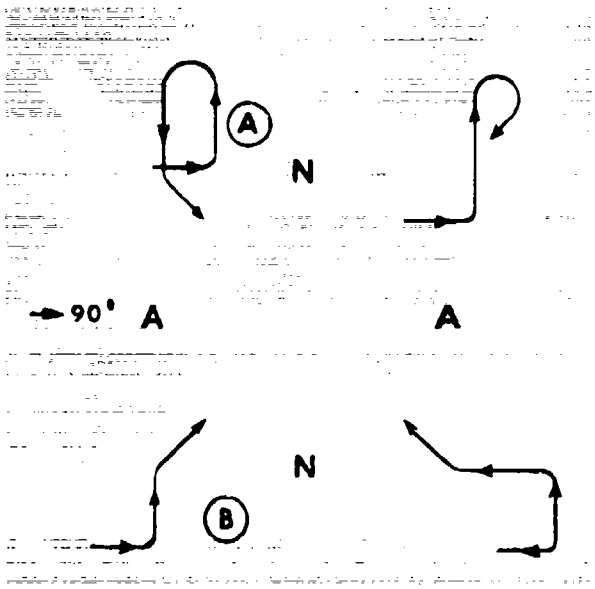


Figure 16-5. On-course orientation

ON-COURSE ORIENTATION

If the aircraft is in the "on-course" when you tune in the range, perform an "on-the-beam" orientation. (See Figure 16-5.)

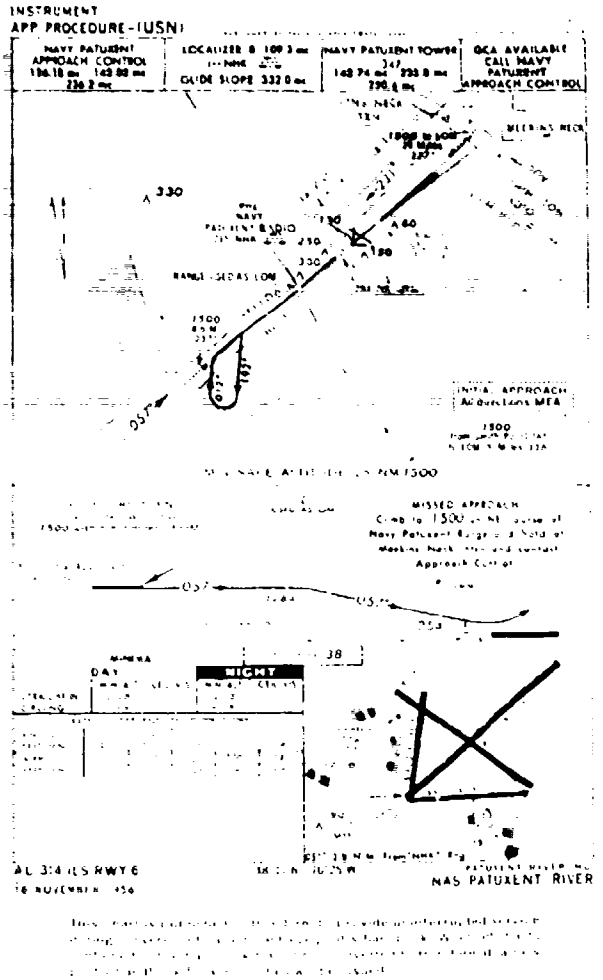


Figure 16–6. Standard instrument approach procedure

Make a turn immediately to the closest bisector heading of any quadrant. When you receive the first off-course signal, you can eliminate two legs of the range. Then make a 90° turn to the left and you will positively identify the leg. For example, suppose you find that the closest bisector heading is 90°, make the turn, and receive an N signal, as shown in Figure 16-5. The only two places where an aircraft could fly off the beam on a 90° heading into an N quadrant are positions A or B. This immediately eliminates the northeast and the southeast legs. A 90° turn to the left then identifies the leg. The four examples in Figure 16-5 show you the proper turns to make after you identify the leg.

LF/MF RANGE APPROACHES

Before considering LF/MF range approaches, check the following rundown of basic terms.

An Initial Approach to the airport is made over specified legs or routes from a reliable fix within 25 miles of the facility. It may include letdown from minimum en route altitude to a specified level (high cone).

Shuttle is a letdown procedure between two fixes or flying a pattern similar to the race-track holding pattern at a distance from the station while letting down before initial approach.

Holding and Stacking involve flying a race-track pattern at a certain altitude. Stacking is nothing but holding while waiting to be cleared to hold ready for an approach. Both are waiting maneuvers.

A Letdown from initial approach altitude to final approach usually consists of intercepting a prescribed range leg, flying outbound to a certain point, making a procedure turn, and heading back toward the station.

A Final Approach begins at the end of the procedure turn and ends when the aircraft is landed or missed approach procedures are begun. If an aircraft reaches the minimum altitude for the field and the landing cannot be completed, a missed approach procedure is prescribed.

Standard Instrument Approach Procedures are prescribed for every field. These are found in the USAF-USN *Instrument Approach Procedure Charts* booklets, where the altitudes and courses for the procedures applicable to the particular field are shown. You must have this data in your aircraft for your destination.

Station Location and Initial Approach

The initial approach to the station is made over specified courses, usually range legs. Generally, the initial approach is completed at the en route altitude, though sometimes some amount of letdown may precede initial approach. There are three elements to the initial approach.

1. Ten minutes out, send a message giving position, time, altitude, estimated time over the high cone, and requesting clearance for approach and existing weather.

2. Bracket or follow the range leg to the cone. If you do this carefully, you will learn a lot about the wind during this process which may help in later stages.

3. Locate and identify the station at station passage.

After you complete this process and are cleared, you will begin the letdown to final approach. If a clearance cannot be given, you may be directed to hold or to proceed to an alternate.

The principal item in the initial approach procedure not yet discussed is the location of the station by recognition of the cone.

Cone Recognition

The only definite geographical location on the radio range installation is the cone of silence. The cone of silence, which extends vertically above the radio transmitter, is a zone in which no signal is received. Certain definite characteristics indicate its proximity. In the vicinity of the station, there is a rapid increase in volume. (See Figure 16-7.) The on-course zone becomes extremely narrow (50 feet) as do the twilight and bi-signal areas. Because of the narrow signal zone, the signal changes rapidly.

Here is the sequence of events during station passage. Within approximately one minute of the station, you note a rapid signal build. The rate at which the signal builds increases as the station is approached. During this period, you keep one hand on the volume control to maintain a constant volume level. Right at the cone, there is a surge of volume, then the signal fades out completely. The signal returns again with a surge, then fades rather rapidly.

This sequence of events assumes passing directly through the cone of silence. This is some-

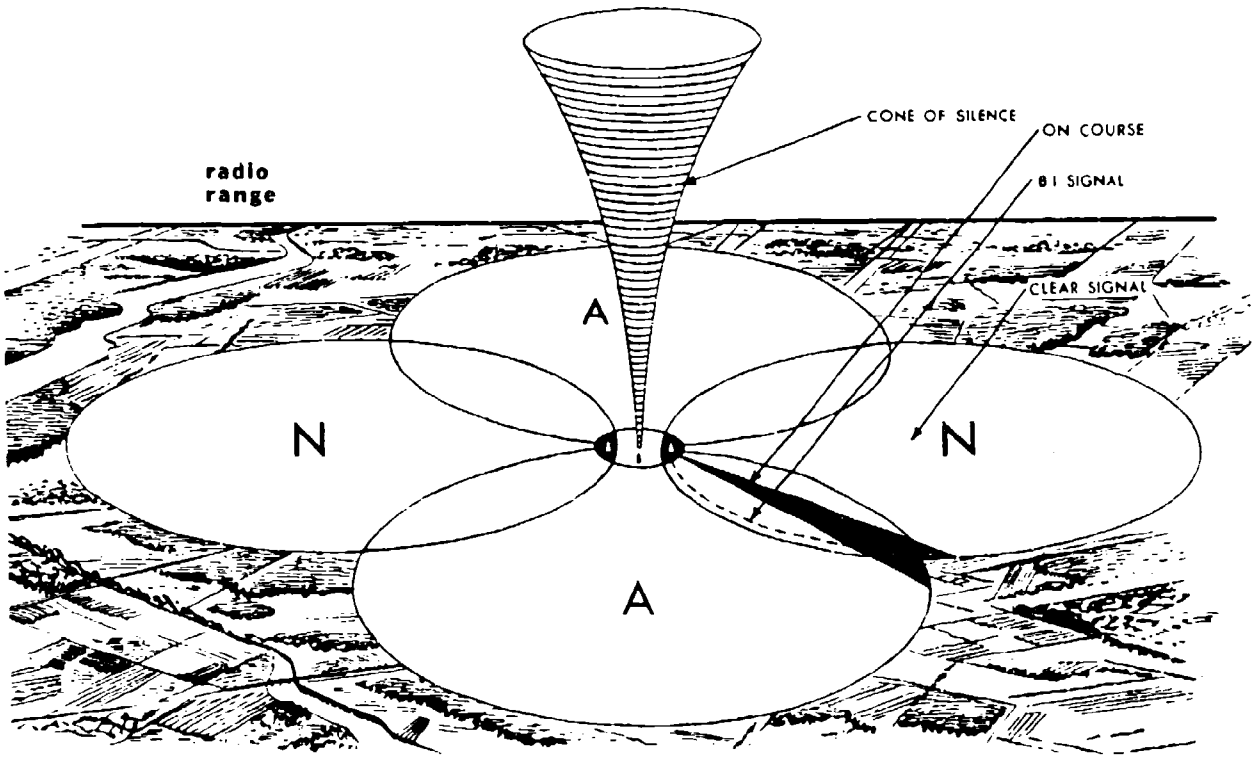


Figure 16-7. Cone of silence

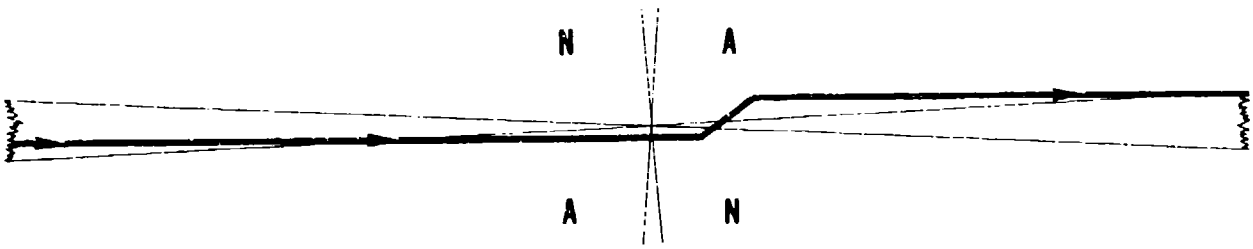


Figure 16-8. Determining station passage without passing through the cone

thing that you should make every effort to do and that you can do if you use proper technique and judgment in bracketing before station passage. However, positive station identification is possible without passing through the cone. (See Figure 16-8.) A rapid signal build, an increase in clearness of the clear signal, and very narrow bi-signal and on-course signal zones are indications of close proximity to the station. If you are nearly parallel to the beam heading in a clear zone and get a very brief (1 or 2 second) on-course signal followed by a reversal of the clear signal, you have probably passed the station. Check it by making a check turn and analyzing the signal change.

On passing the cone, there is a reversal in signal. You can check the cone by making a turn and determining if the proper signal change results. One of the most important contributing factors to successful cone location is proper volume control. The apparent size of the cone depends directly on the amount of volume used (see Figure 16-9), so don't allow the volume to build up when close to the station, as this will narrow the cone and make it difficult to recognize. In addition, after you pass the station, the fade is harder to detect if the volume is high. On the other hand, don't turn the volume too low. Low volume can be misleading when approaching the cone because any false fade will appear to be a station passage, and beam following will be more difficult.

The altitude at which you are flying also makes a difference in cone recognition. In Figure 16-7, note the shape of the cone of silence at higher altitudes. The width of the cone of silence at high altitudes makes recognition of station passage easy. At 20,000 feet it may take up to one minute to fly through the cone of silence. At 40,000 feet it may take two or more minutes to pass through the cone, assuming you keep the volume at a comfortable level until you recognize a fade in volume indicating station passage. For precision navigation you must use some method of station passage so that you can obtain an exact time over the station. One method is to note the time when the fade starts and then again when you hear the signal. Divide the elapsed time by two to determine the center of the cone. Another method is to keep the volume at a comfortable level by gradually increasing it as you enter the cone of silence. Remember that it may take up to three minutes after station passage before you can recognize a fade in volume. To save time, make station passage definite and you will need no final check.

Another method of recognizing station passage utilizes the station Z-marker. If the aircraft is equipped with a Marker Beacon Receiver, the marker beacon light goes on when the aircraft is within the zone of the Z-marker signal. In most marker beacon installations there is also an aural Z-marker signal. You can recognize it by a high-pitched hum, which increases in volume as the aircraft approaches the station. However, you still cannot rely on it to give a pin point position as being directly over the station.

Preparation for Letdown

If the range station is associated with your destination, you must prepare for the letdown. Timing starts from the high cone. Check the time, adjust mixtures rich, reduce power, and start a turn to intercept the letdown leg. Call the station and give your position report (position, time, and altitude). Intercept the approach leg and bracket

outbound. Finally, you make the letdown, as discussed later.

VOICE REPORTS

The increasing amount of traffic on the radio range network has made correct voice procedure imperative. Since the location of all aircraft must be accurately reported, there is a tremendous burden on communication facilities. You can ease this burden by using correct voice procedures and making voice reports promptly. Decide what to include in the report before commencing transmission. Follow the specified sequence of position reports—position, time, altitude. Don't initiate unnecessary calls for information available from other sources.

Here are some of the more important voice reports. Failure to make them may add to the communications load, increase traffic delays, and result in disciplinary action against the offenders.

1 Position reports over compulsory reporting points, or points named in the clearance.

2. When the estimated time of arrival over the reporting point changes more than three minutes.

3. When a change in flight plan is anticipated or desired.

4. When directed to report.

5. When unexpected or unusual flight conditions are encountered—conditions such as severe icing, turbulence, or loss of an engine.

6. When entering and departing from holding points.

7. When pulling up on a missed approach.

8. When leaving an assigned altitude.

HOLDING

One of the disadvantages inherent in the LF/MF range network is the limited number of beams, or navigation channels. During instrument conditions, there are not enough navigation and letdown channels to handle all the traffic, so holding is used. Holding is a procedure for methodically delaying aircraft until the range facilities are available for use. Holding en route is often necessary to provide aircraft separation. Holding at the destination while awaiting turn for letdown is known as *stacking*. *The holding point* must be a definite fix. Holding points, therefore, are limited to (1) the station or cone, (2) fan markers, and (3) range intersections.

Holding Pattern

The standard holding pattern is to follow the specified course inbound to the holding fix, make a 180° standard rate turn to the right, fly straight course outbound from the holding fix for two minutes, parallel to the range leg, make another 180°

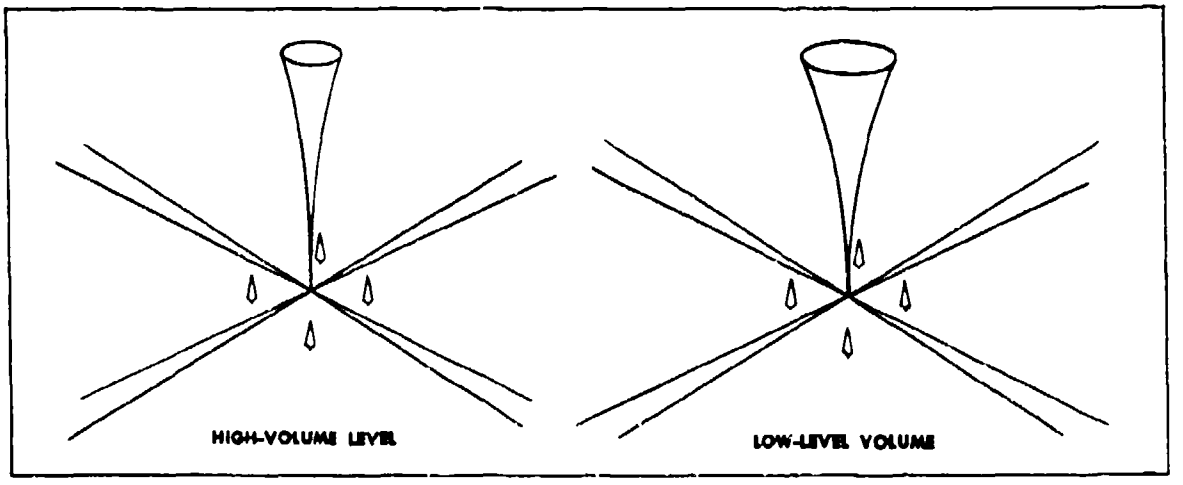


Figure 16-9. Volume control affects the apparent size of the cone

standard rate turn to the right, and again follow the specified course inbound. When you're holding at a fan marker and receive instructions from approach control specifying the time of departure from the holding point, adjust your flight path to depart from the marker, inbound, at the exact time specified. You can do this by shortening or lengthening the holding pattern within the limits of the holding clearance. All turns required in connection with entry or exit from the holding pattern should be made on the same side of the range leg on which the pattern is to be established.

Because of geographical or traffic restrictions, the standard holding pattern is not always feasible in certain locations. Any variation from the pattern will result in a non-standard holding pattern. Normally all non-standard holding patterns are shown in the Radio Facility Charts. On blow-up charts both standard and non-standard are shown. Always follow a standard holding pattern unless instructed otherwise. The variations will be in time of legs or direction of turns.

Entering Holding Pattern

If you are inbound to the station on the holding course, simply commence the first turn of the holding pattern when over the station. If you are on another heading, fly inbound on the range leg from the holding fix specified. Then proceed outbound on the range course from the holding fix for one minute, make a procedure turn, follow the specified course inbound, and commence holding pattern over the station. (See Figure 16-10.)

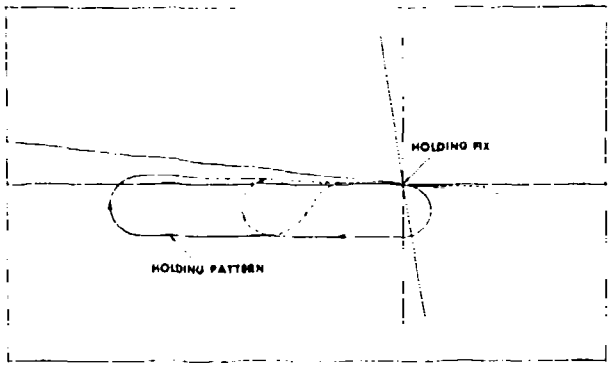


Figure 16-10. Entering holding pattern

Direction Finding

Holding procedures involving radio direction finding equipment are often used. They are covered in Chapter 18.

Timing the Holding Pattern

The normal holding pattern, as stated, involves two-minute courses in each direction. With standard rate (3°/sec.) turns, each turn takes 1 minute. Therefore the entire pattern takes 6 minutes with standard turns. In order to depart from the holding pattern at the proper time and place, adjust this time by shortening or lengthening the straight courses. This standard pattern is called a two-minute pattern in the holding instructions. A one-minute pattern uses one-minute straight courses.

THE SHUTTLE

A shuttle is a holding pattern used for the purpose of losing altitude before descent on the final approach leg. Where specified in a procedure, the shuttle leg is designated and so is the altitude to be reached before crossing the station and proceeding out the final approach leg. When a shuttle is necessary but not specified, aircraft may shuttle on the final approach leg.

The shuttle pattern normally is a descending (500 feet per minute) standard holding pattern. Three thousand feet of altitude is the maximum that can be lost in one complete pattern. You can shorten the shuttle if the altitude to be lost is less than 3,000 feet, or you can repeat it until the desired altitude loss is effected. When you have reached the desired altitude, proceed to the station and make a standard instrument letdown.

LETDOWN

The letdown must be made in accordance with the clearance given and the minimums established. After locating the station, check the time over the station, adjust mixtures (rich), reduce power, start the turn to intercept the letdown leg, and give your position report to the radio station. The check-off list is normally executed at this time. Take up a 30° intercept angle to the letdown leg, intercept the leg, turn to the published leg head-

ing and bracket outbound, letting down as necessary and as cleared. Check minimums and *do not* let down below them. The letdown outbound depends on the wind and the amount of altitude you have to lose.

PROCEDURE TURNS

After a letdown outbound, you have to reverse course to return to the station and to the field. You can do this most satisfactorily by means of a procedure turn. This involves getting far enough off the on-course to effect a 180° standard rate turn, returning to the leg, and bracketing inbound. With no wind, a turn of 45° from the on-course heading, held for 1 minute, will allow sufficient room to complete the 180° turn and to turn inbound on the let-down leg. *The entire procedure turn should be modified for the effect of the wind.* It is desirable to make the procedure turn in level flight.

The procedure turn just described is called the 60-second or one-minute type, and is shown in Figure 16-11. Another type which is sometimes used is the 80° reversement type shown in Figure 16-12. Here are the characteristics and uses of both these types.

60-Second Type: Turn 45° left or right, hold 60 seconds after "off course" before starting 3°/sec.-turn away from station for 180°; then fly to intercept range leg. Uses: All-purpose, especially good if wind or position are unknown uncertain. Disadvantages: time consuming.

80° Reversement Type: Turn 80° off the course and immediately reverse the turn for 260° around to the reverse of the original course. This procedure turn is particularly useful in low-visibility approaches. Sometimes pilots prefer to turn 90° and then reverse into a 270° turn, but the 80°/260° version gets the same result with less turning. Advantage: Rapid course reversal. Disadvantage: Too much turning and inability to monitor aural signal during banked flight.

Direction of Procedure Turns

A procedure turn must be made in the direction shown for that maneuver in the procedure chart for that station. Usually procedure turns are made to the left from the outbound range course, but terrain or other considerations may require right turns to be specified at some stations. The procedure turn must be accomplished within the distance from the range station and not below the altitude specified on the approach plate.

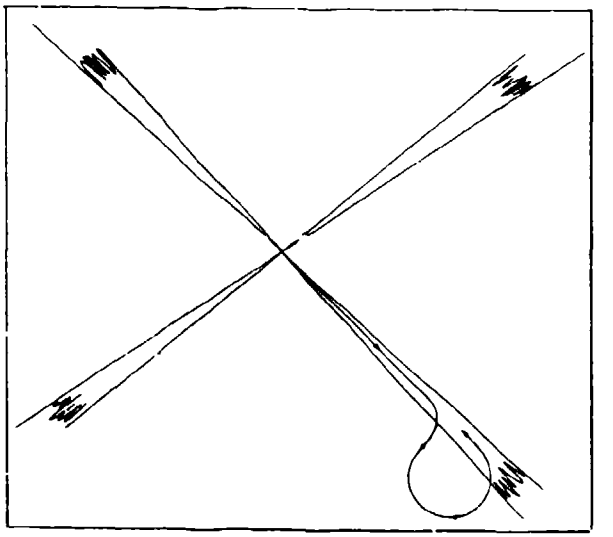


Figure 16-11. 60 second or one-minute type of turn

THE FINAL APPROACH

When you have completed the procedure turn and are heading inbound to the low cone, you have started the final approach. The aircraft should be completely set up for landing before you start the final approach. Check the time carefully so that you can determine the effective wind for maximum station-to-field timing by comparing the time outbound with the time inbound. Check the altimeter setting and try to reach the minimum low cone altitude as rapidly as safety and terrain clearance permit. The low cone will be of minimum size and you should make every effort to pass through it for positive recognition of station passage. This will require exact bracketing. For the same reason, watch the volume control carefully. Failure to identify station passage

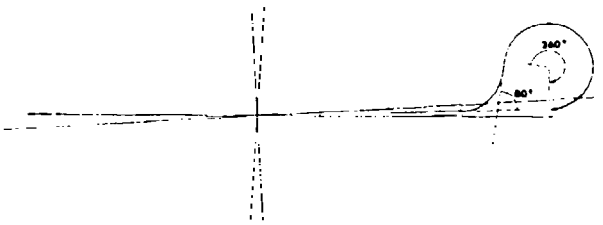


Figure 16-12. 80° reversement procedure turn

will result, at best, in a pull-up for another letdown, and valuable time will be lost.

Station to Field

Station-to-field legs, being of low altitudes, require precision instrument flying. Your altimeter setting must be correct and you must not go below the minimums. Be careful to make sure you follow the on-course to the field. Do not exceed the station-to-field time which should be corrected for wind. If the associated airport is on the range leg, maintain the on-course carefully until contact, or until a pull-up is necessary. This will minimize the possibility of not seeing the field as a result of reduced visibility. Check the time over the low cone. The minimum descent altitude must be reached as soon as possible consistent with safety. At the letdown minimum, you must not exceed the maximum safe distance from the station. When the time is up, pull up and try again or proceed to an alternate.

Many airports are not located on the range leg. In such cases a station-to-field bearing is available, but no aural check is available to determine how closely the bearing is being followed. You must identify the station positively to turn to the field bearing and you must correct for wind to determine the heading necessary to fly this bearing. In fact, the success of the approach may well depend on the accuracy with which you determine the wind during previous stages of the approach. You can use the radio compass to track outbound to the airport.

Multiple Airports

In congested metropolitan areas, there are often several airports connected with a single range station. Obviously, only one station can be on the range leg. In such cases, station-to-field bearings are usually given in the instrument approach procedure chart along with the station-to-field distances and field minimum altitudes. Often the airports off the range are equipped with non-directional radio beacons and you can use the direction finding gear to complete the approach to them.

The Missed Approach

The distance from the station to field (that is, to the nearest usable portion of the field) is given in the procedure charts booklet. You must determine the time required to cover this distance after consideration of airspeed and wind. If you don't see the field, a pull-up is necessary in accordance with the pull-up procedure given. The pull-up may be due only to failure to recognize station passage. Regardless of the reason, however, do not hesitate to start the pull-up in accordance with established procedure, report your intentions, and request further clearance. Certain procedures of turning to identify legs, waiting for a fade, and the like, where mentioned before as ways to determine whether station passage had been made when passing the high cone. Do not use such devices if you are not sure of station passage at low cone. If low cone passage is doubtful, execute the missed approach procedure at once.

Low-Visibility Approaches

If low visibility prevents you from executing a visual straight-in or circling approach to landing, follow the procedures which have been established to align the aircraft with the service runway.

Here is the recommended low-visibility approach. Turn directly downwind over the service runway; on passing the end of the runway, turn 90° (preferably right); after reaching the 90° change of heading, start immediately on a 270° turn in the opposite direction. Both turns should be standard rate. By making the first turn to the right, the pilot of dual aircraft will be on the inside of the turn during the 270° turn and have better visibility. The entire maneuver should be executed by reference to instruments until the aircraft is definitely lined up on the landing approach or until the approach can be continued entirely contact. (See Figure 16-13.)

The Straight-In or Fan Marker Approach

When existing traffic and facilities permit, a straight-in approach may be authorized. The straight-in approach is feasible only at those airports where the final approach course of the associated range station coincides with the station to field course, where the missed approach procedure does not involve a reversal of course, and where an additional radio aid is available. When cleared for a straight-in approach, the pilot is cleared to descend to the minimum en route altitude for that portion of the route. The initial approach is to an additional radio facility, usually a fan marker, on the final approach leg. The final approach is that part of the approach from the last radio fix to the low cone. This last radio fix is crossed at the specified altitude and the aircraft is set up for a landing. When the fix is crossed, descent is immediately established to the low cone minimum, the low cone is crossed, and a descent to the approach minimum made. If contact is established at or above the minimums, the landing is completed.

THE STACK

When aircraft are holding on a radio fix, awaiting turn for instrument letdown, the holding group becomes a stack. When instrument approaches are necessary, several aircraft may desire to use the range for letdown at the same time. Since this is obviously impossible, aircraft are assigned altitudes separation on the holding fix, all altitudes below the lowest plane are cleared, and an instrument approach is made by the lowest aircraft. As the planes depart the stack and complete their approaches, the other aircraft are cleared to the next lower level.

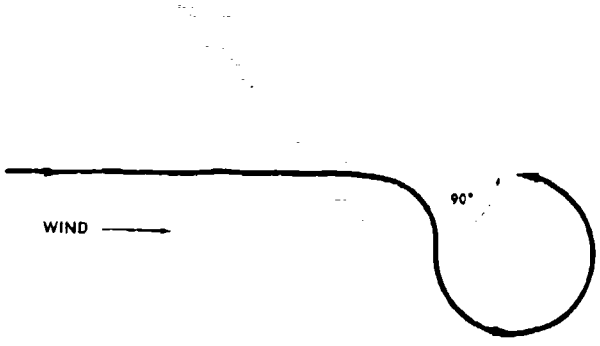


Figure 16–13. Low visibility approach

Approach Control Stack

When approach control operates the stack, it is usually established over a fan marker on the letdown leg. This method allows straight-in approaches to the airport, expediting the handling of aircraft by minimizing the approach time.

Since approach is operated by the tower, the frequency on which the pilot receives instructions is one of the tower frequencies or the frequency of the associated range station.

Clearance to an approach control stack includes holding instructions and an *expected approach time*. The expected approach time is the time at which an aircraft would start a standard instrument approach in case of two-way radio failure.

Each pilot in an approach sequence is given advance notice of the time he should leave the holding marker on his approach to the airport. When you have received the departure time, adjust your flight path to leave the marker as closely to the designated time as possible. The "Depart Inbound" time is not a final clearance; when you use standard approach procedures, you must maintain your last assigned altitude until you receive a final clearance. The final clearance is usually "Cleared for straight-in approach," or "Cleared to land." Upon receiving final clearance, start your descent to the low cone altitude, report leaving your last assigned altitude, and go over the landing cockpit check-off list. The approach from this point on is the same as the final approach of the standard instrument approach.

Range Station Stack

Clearance to a range station stack includes holding instructions and an expected approach time. It is the time that a standard instrument approach will be started if two-way radio failure occurs. Clearance for an approach is given before the expected approach time or the expected approach time will be revised.

EMERGENCY DESCENT BY AIRCRAFT HOLDING ABOVE OTHER TRAFFIC

If, while holding, you should have to make an emergency descent through other traffic, you should so advise Air Traffic Control or Approach Control through existing communication facilities. On receipt of advice that an aircraft is making an emergency descent through traffic at assigned altitudes over the airport, the controlling agency will immediately broadcast, or cause to be broadcast, the following message on the radio range and/or approach control frequencies:

"EMERGENCY TO ALL CONCERNED: EMERGENCY LANDING AT (name of) AIRPORT. ALL AIRCRAFT BELOW (number of) FEET WITHIN (number of) MILES OF (name of radio facility) LEAVE (location) COURSE(S) IMMEDIATELY."

It is then expected that pilots receiving such a broadcast will clear the specified areas, maintain the last assigned altitude, and stand by on the appropriate radio frequency for further instructions from the tower or center.

Immediately after such a broadcast, the tower or center will issue further instructions to all aircraft involved on additional procedures to be followed during and subsequent to the emergency.

TWO-WAY RADIO FAILURE

In case of two-way radio failure between aircraft and the ground under VFR conditions, regardless of the type of flight plan, the pilot should proceed under VFR and land as soon as practicable, or proceed according to the last acknowledged air traffic clearance, whichever the pilot deems necessary.

In case of two-way radio failure between the aircraft and the ground while under IFR conditions, the pilot should proceed according to the last received and acknowledged air traffic clearance at the specified altitude or the minimum instrument altitude, whichever is higher, to the clearance limit. If the last received and acknowledged

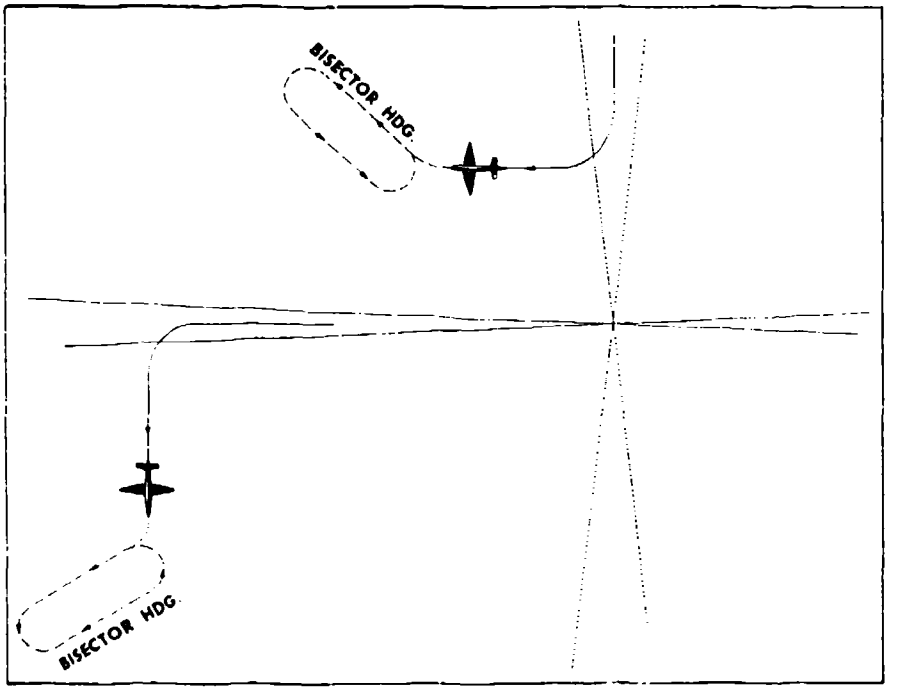


Figure 16-14. Vacating a range

clearance was to hold until a specified time and expect further clearance, the pilot should start his approach at the specified time or as soon thereafter as possible. If the clearance limit was to the designated airport or facility serving such airport with instructions to contact approach control over a specified point, the pilot should start his approach at the last estimated time of arrival specified in the flight plan or as soon thereafter as possible. If the clearance was to a point other than the destination airport, the pilot should proceed to the specified point, maintaining the specified altitude or the minimum instrument altitude, whichever is higher, to the clearance limit, then to the designated airport and commence his approach at the estimated time of arrival specified in the flight plan or as soon thereafter as possible. If a pilot maintains an assigned clearance altitude which is higher than the approach altitude to a radio facility serving the destination airport, the descent from the higher altitude should be on the final approach course and should start at the expected approach time last received. If no expected approach time was received, descent should be started at the last estimated arrival time specified by the pilot, or as soon as possible thereafter. A full standard instrument approach should be executed unless a VFR approach can be made.

If a clearance to the tower at the airport of intended landing has been received and acknowledged, the pilot is expected to comply with any special instructions contained in the clearance and make a normal descent for landing.

Air Traffic Control may issue appropriate instructions to be broadcast "blind" over air carrier radio facilities (for air carrier aircraft), and over suitable radio range facilities.

ENGINE FAILURE

If engine failure occurs, control of the aircraft is of prime importance. The procedures involved will depend, of course, on the type of aircraft and its limitations. Upon completion of measures necessary to control the attitude and flight path of the aircraft safely, it is the pilot's responsibility, if on an IFR flight plan, to call the nearest control activity and advise them of his situation and his intentions relating to the approach and landing of the aircraft. This situation normally requires a change in flight plan because of the resultant change of airspeed (usually in excess of 10 miles per hour) and/or destination.

LOSS OF LF/MF RECEIVERS

If the loss of LF MF receivers prevents the use of the LF/MF range in an aircraft not equipped with VOR or UHF/DF gear, contact the nearest station with VHF/DF or UHF/DF services and request a steer. If GCA or other landing aid will be needed, select a station with that facility and advise that it is desired. ATC should be advised of the emergency and clearance obtained, of course. In addition, don't fail to take advantage of the various radar services available to the lost pilot, as described in the Radio Facility Charts.

VACATING A RANGE

Sometimes Approach Control must order all traffic off all legs of the range because of an airplane working a descent under emergency conditions. If so instructed, leave the range immediately and await further instructions. It is suggested that, pending further instructions, the pilot flying inbound on a range leg at such times should turn 90° right (terrain permitting) or turn left outbound, and hold that course until he can obtain a corrected clearance or specific instructions, or until far enough to begin a holding pattern in the clear signal quadrant. This will avoid collisions which might occur if every aircraft left the range on different courses at random. Of course, as in the case of the emergency descent instructions, maintain your last assigned altitude or minimum instrument altitude, whichever is higher, until otherwise instructed. Do not proceed so far out from the range leg that terrain obstructions become a hazard. Use the ADF to hold in the area without entering the range legs. (See Figure 16-14.)

CHAPTER 17

RADIO RANGE PROCEDURE (JET AIRCRAFT)

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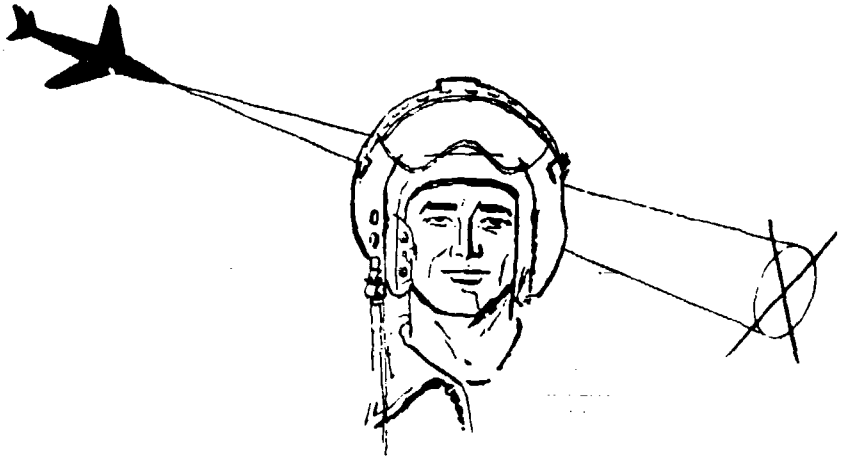


CHAPTER 17

RADIO RANGE PROCEDURE (JET AIRCRAFT)

THERE is no tremendous difference between jet procedures and conventional procedures in flying the LF/MF range. The difference is big enough, though, to necessitate your learning a number of new things. The difference is caused by four factors:

1. High altitude en route—Before the jet can make an approach, it must reduce altitude for transition to final approach and to conserve fuel, it must do this quickly. The maneuver is called a penetration.

2. High speed—The jet covers a lot of ground very quickly. In an SNB, a two-minute holding pattern with 3°/sec. turns is about a 15 mile racetrack. In a jet which has a 200-knot true air speed at low altitude, a two minute holding pattern with 1½°/sec. turns is about a 24-mile racetrack.

3. Rate of turn—Using 1½°/sec. (half standard rate) turns makes any given turn take twice as long, and the higher speed means a greater increase in turning radius.

4. Fuel consumption at low altitude—Since the jet at low altitudes uses fuel at very high rates, the jet cannot be asked to hold for very long once it descends. Furthermore, many jets have rather limited fuel endurance. Therefore, some procedures have had to be streamlined for rapid handling of the jets in a low altitude traffic pattern. This same problem makes it unwise to plan jet flights in IFR weather into terminals with high-density commercial traffic operations.

BEAM INTERCEPTION AND FOLLOWING

Intercepting a beam leg in jet aircraft is the same as in conventional aircraft in almost every respect. The initial angle of interception is 45°. However, the large turning radius of jet aircraft makes some lead necessary as the on-course is approached. Therefore, in the bi-signal zone, as signals approach equal intensity, reduce the angle to about 30°. When you receive the on-course, or the range station identifications signals reach equal intensity, turn to the published course, correcting for wind if you know it.

Of course, decreasing the interception angle delays full interception. Therefore, if the wind is blowing you away from the beam leg as you try to intercept and if the wind velocity approaches half the TAS, it may be necessary to maintain the 45° angle of interception in order to intercept at all. Consequently, if interception does not occur within a reasonable time after you enter the bi-signal zone, return from the 30° to the 45° interception angle.

On reaching the on-course or equal identification signal area, start to roll out on the leg course. The amount of lead required varies with the altitude. At 20,000 feet, for example, the lead to roll out on a heading must be greater than at lower altitudes because the increased TAS at the higher altitude makes the turning radius large.

Do not make your interception "free-hand." Use the heading indicator to determine headings and angles. After picking up the on-course, note the heading you are flying and maintain it accurately until it becomes time for correction. Failure to fly headings makes beam following haphazard.

After reaching the on-course, fly a heading which is adjusted for known winds aloft; if you don't know the wind, fly the published beam heading. Maintain that heading until you hear the first off-course. The off-course signal (A or N) will tell you whether you have drifted to the right or left of the leg. Correct back promptly to the on-course (turn 25° to 45° toward the range leg), then assume the same heading as before but modified to allow for the drift you encountered. If you have drifted off the original heading quickly, a fairly larger correction for wind drift is needed. If it took a while to drift off, a smaller correction is needed. Fly this new heading until drift again takes you off course, and repeat the process. Corrections to return to on-course should be reduced as you approach the station and should not exceed 5° in close proximity to the range. This is to avoid passing the station abeam while correcting. Another thing to avoid is trying to interpret aural range signals when the plane is in a turn.

As a rule of thumb, remember that 10° drift correction will compensate for a beam wind of 1/6 the TAS; 20° drift correction will compensate for a beam wind 1/3 the TAS; and 30° drift correction will compensate for a beam wind half the TAS. If the wind is less than abeam, drift is less. A wind 45° off the beam produces about two-thirds the above amounts of drift. Therefore, a 10° drift correction is usually more than ample for normal wind velocity and airspeed relationship at any altitude.

Rigid bracketing of beams in jet aircraft is usually impossible. Wide-radius turns and high speed prevent the pilot from making precise corrections to stay on course. At best, the jet *follows* the beam. Furthermore, the high-altitude aircraft is more troubled by beam irregularities; and leaning cones and ice crystal static tend to make navigation by LF/MF ranges inaccurate at high altitudes.

ORIENTATION

Jet orientation procedures are exactly the same as those for prop aircraft. Any orientation is time consuming, however, and orientation is a serious problem to a jet at destination with fuel exhaustion imminent. Therefore, try to avoid the need for orientation procedures. Use your Tacan, VOR, ADF, UHF DF, or other navigational equipment, to try to determine your position. Do not hesitate to ask the ground station to give you a bearing to the station by taking a UHF bearing on you or by using radar to determine your position.

In the situation where orientation is necessary, the aircraft is in effect "lost" and, before the or-

ientation can be performed, clearance must be obtained. Therefore, it is no more admitting to being "lost" to request a steer or position from the ground facilities than it is to ask for clearance to perform an orientation. In fact, the jet fuel-consumption problem makes the orientation least desirable of these alternatives. So don't be so proud of your ability to find yourself by orientation on a range that you fail to reach your destination because of fuel use. Jets have very little navigational gear, and it is expected that they must ask for ground assistance under IFR conditions. On the other hand, if the orientation does become necessary, have enough advance practice so you know how to do it quickly and accurately.

As a jet pilot, you need only the three principal orientation described in Chapter 16 Fade 90, Close-In, and On-Course.

STATION PASSAGE

In the case of station passage, again, the jet pilot has no special problems which the pilot of prop aircraft does not also have. One point, though, is worth emphasizing. The section of Chapter 16 in which this subject was treated discussed the large width of the cone of silence at high altitude. As the volume begins to drop off, indicating the cone, boost the volume control one time and consider that you are entering the cone when this new volume adjustment begins to fall off to silence. This method makes possible certain

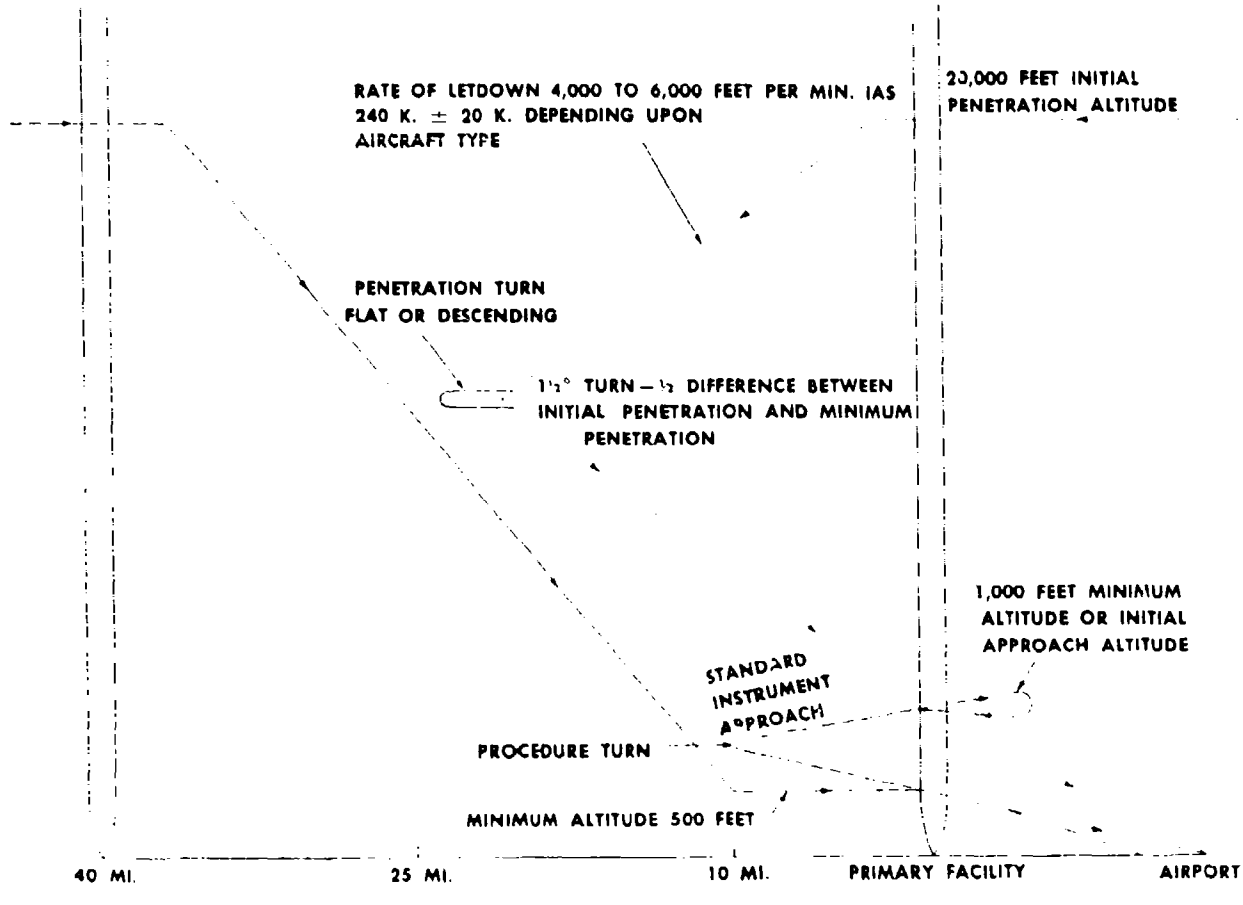


Figure 17-1A. Example of jet penetration procedure, profile view

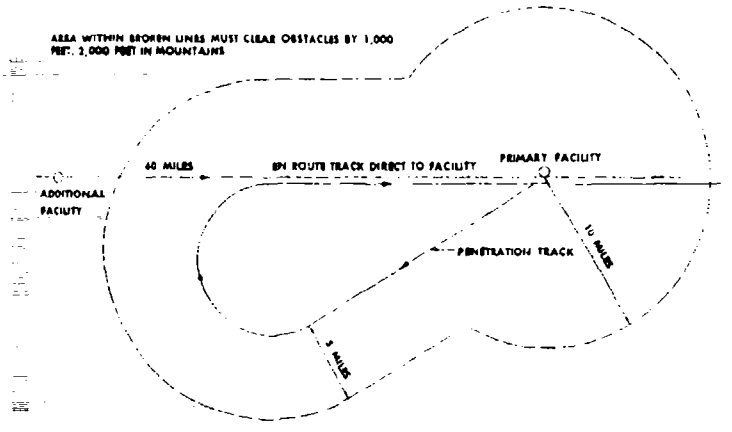


Figure 17-1B. Example of jet penetration procedure, plan view

identification of the cone or the crossing of a beam leg if the center of the cone is missed by a little amount.

PENETRATIONS

The word penetration has been loosely used to describe the entire letdown and instrument approach for jet aircraft. Properly a penetration begins at high altitude (usually at or over 20,000 feet) and ends when the jet has reached a minimum penetration altitude or initial approach altitude for the standard instrument approach at the station. From this altitude, the jet makes a standard instrument approach or straight-in approach, as may be directed.

The instrument approach procedure charts for high-altitude aircraft show official penetration procedures where established. At other fields, no standard penetrations are provided and you may use any type of penetration for which you may obtain clearance. However, there are certain standards which govern the establishment of official penetration procedures, and you are restricted to penetrations which meet such criteria.

Penetration and Approach Criteria

Here are the policies used by the United States Navy, United States Air Force, and the United States Coast Guard in formulating and approving all jet penetration and approach procedures. Although currently recognized by the Civil Aeronautics Administration, these policies are applicable to military operations only.

For purposes of formulating penetration and approach procedures in accordance with this criterion, penetration is defined as the maneuver involved in descending an aircraft from an en route altitude or other specified initial penetration altitude to a minimum altitude from which transition to final approach can be made.

Initial-Penetration Altitude. The altitude at which the aircraft crosses the radio facility for beginning the penetration and approach procedure is called the initial-penetration altitude. This altitude is established for each procedure and is normally specified as 20,000 feet mean sea level or 1,000 feet on top. Air Traffic Control may deviate from this specified penetration altitude to permit initial penetration from en route altitudes providing air traffic conditions and terrain do not prevent such action.

Penetration Turn. A penetration turn is made during the jet penetration procedure to return the aircraft to an inbound heading to the radio facility being used for the penetration procedure. The procedure indicates whether the penetration turn is a descending or flat turn.

Minimum Penetration Altitude. The minimum altitude over the radio facility before transition to final approach is called the minimum penetration altitude. Arrival at this altitude must

be reported to the controlling agency. This altitude provides a clearance of at least 1,000 feet above all obstructions within a radius of 10 miles of the radio facility, and five miles to either side of all penetration courses for a distance of 25 miles from the radio facility. In those areas designated as mountainous areas, a clearance of at least 2000 feet must be provided. Where this clearance altitude proves to be impracticable for any reason, deviations may be authorized, but never is a clearance of less than 500 feet provided in an area like this—and such a clearance is allowed only when there is some radio fix along the penetration course within 12 miles of the radio facility.

It is permissible to make a straight-in penetration without first crossing the radio facility, provided that a satisfactory radio fix on which to start descent is available within 40 miles. Descent at distances greater than this are considered en route operation, and en route operation clearance is provided until you are within 12 miles of the radio facility at which time reduction is as outlined before by use of an additional radio fix.

Initial Approach Altitude. The initial approach altitude, when applicable, will be that established for the standard instrument approach procedure.

Emergency Altitude. The emergency altitude is one which will clear all obstructions within a radius of 100 nautical miles of the radio facility by 1,000 feet except in mountainous areas, where clearance will be 2,000 feet.

Standard Penetration. (See Figure 17-1.) Normally the standard penetration procedure starts over the radio facility at the initial penetration altitude. The penetration procedure is established in the direction from the radio facility which is most acceptable, considering controlled airspace and terrain features. The aircraft starts the penetration when it is over the radio facility or at a given distance after passing the radio facility and continues until reaching the minimum penetration altitude or the intial approach altitude, whichever is applicable.

The penetration turn is normally started when one-half of the difference between initial penetration altitude and minimum penetration altitude or initial approach altitude is lost. When the penetration turn is completed, the aircraft either tracks on the specified heading to the radio facility or intercepts a specified radio range course, depending on the procedure specified. In either case, the minimum penetration altitude or initial approach altitude, whichever is applicable, must be reached before arrival over radio facility.

The penetration procedure terminates over the radio facility on which a procedure is based, at the minimum penetration altitude or initial approach altitude. If visual contact is not established on reaching the minimum penetration altitude for the jet procedure when over the radio facility, then a straight-in approach to the airport may be started, provided:

1. The bearing from the facility to the end of the runway to be used does not diverge more than 30° from the direction of that runway; and

2. The descent to the authorized minimum altitude involves no vertical rate of descent greater than 1,000 feet per minute and the minimum altitude provides a minimum clearance in accordance with regulations.

If this is not practical, a standard instrument approach procedure should be executed.

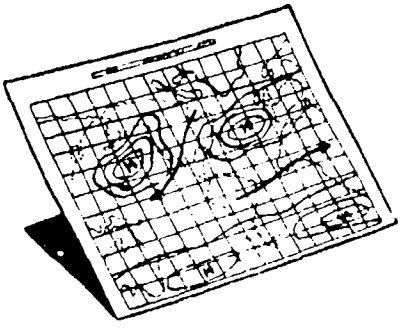
Missed-Approach Procedure. A missed-approach procedure is formulated for each approach procedure. The recovery is normally made on a course which most nearly approximates a continuation of the final approach course after due consideration of obstructions, terrain, and other factors influencing the safety of the operation.

A missed approach is initiated:

1. At the point where the aircraft has descended to authorized landing minimums at a specified distance from the facility and has not established visual contact.

2. If the landing has not been accomplished.

3. When directed by Air Traffic Control.



The altitude to which the aircraft proceeds in the execution of a missed approach provides at least 1,000 feet clearance above all obstructions within 5 miles on each side of a specified course for a distance of 25 miles or to a specified fix within 25 miles of the facility. Obstruction clearance during climb is at least equal to that required for take-off.

Alternate missed approach procedures are established whenever they are required for Air Traffic Control purposes. They are included in the space provided for a missed approach procedure.

Types of Penetration

The criteria just described gives you information on the terms used and the minimums employed in planning a penetration. Actual penetrations, however, may vary. We shall now consider some of the common types of penetration. These are illustrated with the first letdown and penetration turn shown as dotted lines, and the lower level part of the letdown and approach as solid lines to conform to usage in the approach procedure charts booklets for high-altitude aircraft.

The penetration procedure shown in Figure

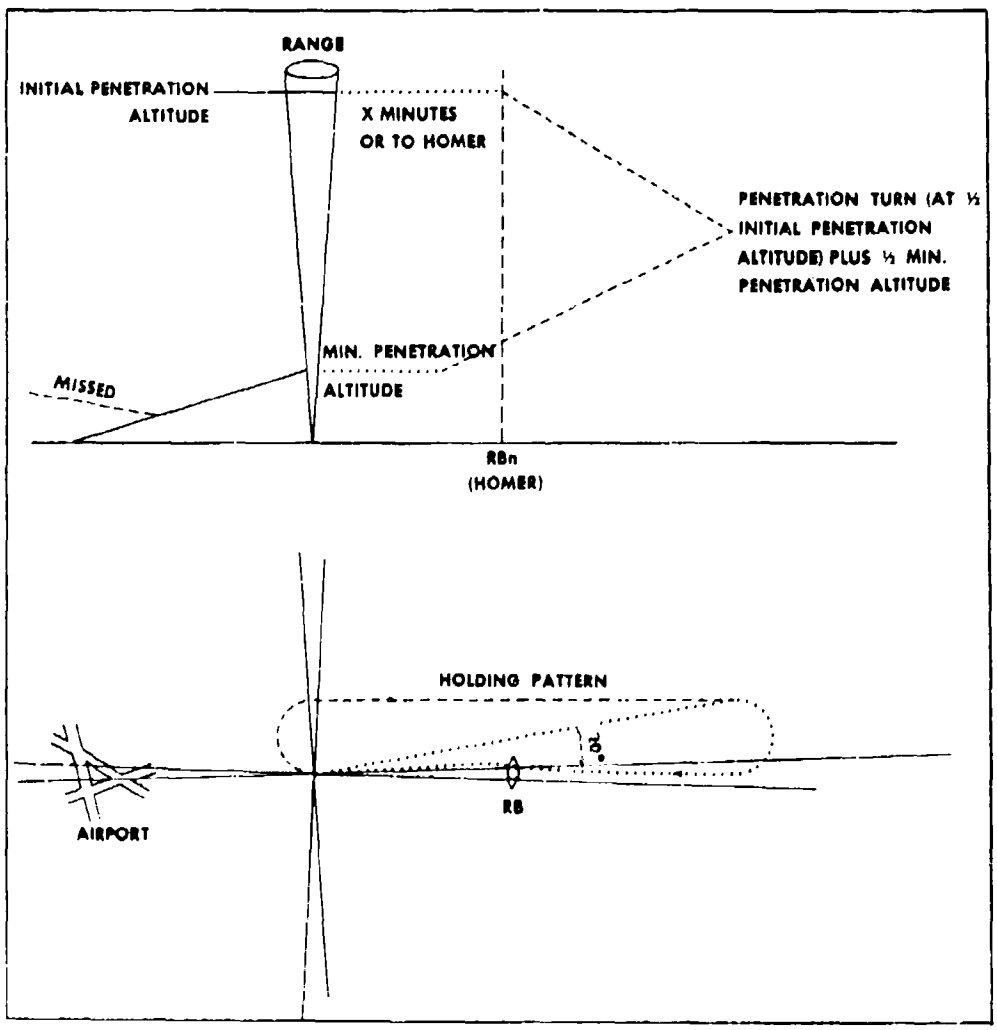


Figure 17–2. Unrestricted tear-drop penetration at homer, fan marker, or X minutes from high cone

17–2 on page 17–6 is of the type called *unrestricted* or *single tear-drop*. The name tear drop comes from the appearance of the penetration turn in the plan view. The "primary facility" in that illustration might be a radio range, a radio-beacon (homer), or a fan marker. It is not necessarily on a range leg.

Usually, the jet is cleared for a straight-in approach from the fix position at the minimum penetration altitude. If not, the standard instrument approach (letdown, procedure turn, low cone, station-to-field, landing or missed approach) as published for the station is commenced at initial approach altitude.

In the penetration illustrated in Figure 17–2, if the pilot arrives at the radio range and is required to hold, he can enter the holding pattern at the initial penetration altitude (20,000 feet or higher) and avoid the loss of fuel he would have when holding at low levels. When cleared to descend, he begins his descent outbound, and makes a back turn to the station when he has lost half the altitude between the initial penetration altitude and the minimum penetration altitude. The turn pictured is a descending turn, as is usual. The letdown begins at the radio beacon (or a fan marker); before reaching the primary facility (the range in Figure 17–2), the aircraft must be at the minimum penetration altitude.

Whether the pilot may pass the low cone into a direct or straight-in approach depends on his clearance. Usually a jet is cleared to do so.

The penetration descent is performed in either a clean or dirty condition. Airspeed is held constant and rate of descent is maintained at 4,000 fpm. In the TV-2 this descent is normally made for high-speed 68% to 75% power, 250-knot airspeed, speed brake extended, 4,000 fpm down. The penetration turn is made at the same airspeed, with 30° bank. The cut away from the inbound beam heading is made 20° toward the procedure turn side of the leg. About 1,000 feet above level off, start to bring the aircraft into level flight. After the speed drops below 190 knots, extend the landing gear. If it's a long way into the station, retract the speed brakes. Reduce the airspeed at station passage to 150 to 160 K and the power to 80%.

If you performed this in a dirty condition

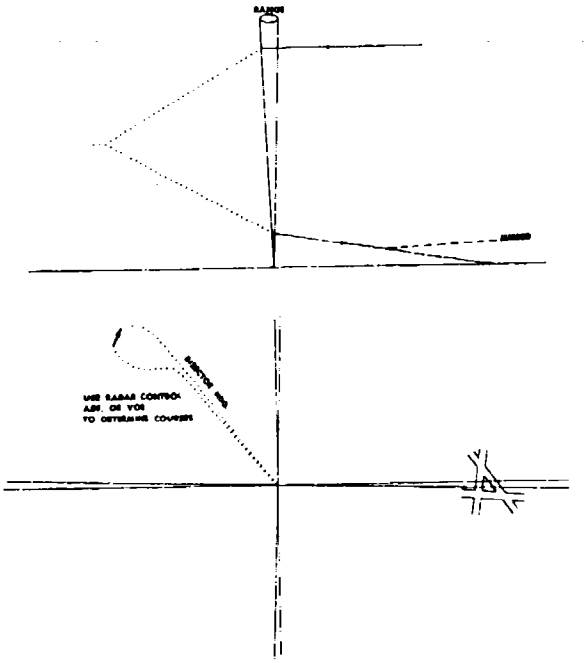


Figure 17–3. Unrestricted penetration, open quadrant type, with procedure-turn course reversal

(flaps, brakes, and gear down), descent at 152 to 170 K and start the level off 400 feet above the minimum penetration altitude.

If holding at low altitude is necessary, adjust power to hold the fuel pressure at 60 psi (65% power) for maximum economy.

In Figure 17–3 you see another version of the same procedure. The only difference here is that the descent or penetration is made in the clear quadrant of the range. To avoid getting lost, the ADF or VOR equipment is used to maintain heading on the approximate bisector of the quadrant. A regular type of procedure turn is preferable to the tear-drop penetration turn because it permits the outbound and inbound reciprocal courses to be the same. Some fields, however, provide for a tear drop pattern usually with 20° between the outbound and inbound courses. The tear-drop pattern is easier and quicker to fly but possibly harder to control the course. The unrestricted penetration is best because it takes only 60 to 70 gallons of fuel (TV 2) and 10 to 11 minutes.

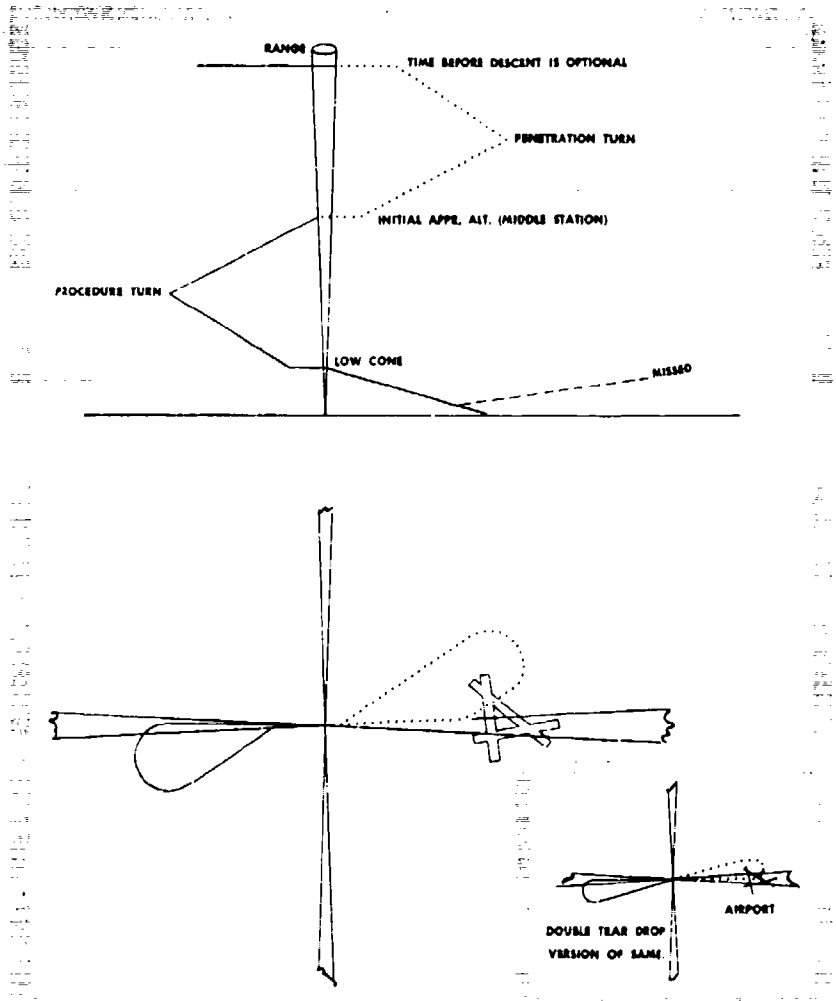


Figure 17–4. "Over-and-under" penetration with procedure-turn course reversals

Sometimes it is preferred to bring jets in from their rapid penetration descent at the same altitude that is used for initial approach by conventional aircraft. The advantage gained is that all aircraft, jet or prop, below that level are subject to the same general approach procedure. The disadvantage is that such an approach uses more fuel. This type of approach is frequently called an over-and-under penetration, a middle station penetration, or a shuttle leg penetration. It may also involve initial descent in a clear quadrant or on a range leg. (See Figures 17-4 and 17-5.)

In this procedure, the radio facility or range is crossed three times. The first time is at the initial penetration altitude. The second is at the initial approach altitude and is sometimes referred to as the "Middle Station." The third is at the low cone and is the same as for conventional aircraft.

The penetration or descent to middle station is sometimes called a shuttle leg. This name is derived from the conventional race-track descent pattern known as a shuttle—a procedure, by the way, which is not normally used for jets. The turn on the shuttle leg is, of course, the "penetration turn," and the turn on the low approach is

the "procedure turn." These turns may be either of the tear-drop type or the usual procedure turn forms. While the tear-drop is fairly common for the shuttle leg, it is not usual in the low approach procedure turn stage.

The middle station penetration is often prescribed at Air Force Bases. It may be ordered at other airports to bring jets in by directing the jet to let down on a shuttle leg opposite the holding leg where other aircraft are stacked. When the shuttle or penetration phase of the letdown is in a clear quadrant on a bearing, it may be called the shuttle bearing.

The penetration to initial approach altitude is performed in the same way as was described for the unrestricted penetrations. Descent is commenced over the fix or at a given time or distance after passing the fix.

Standard Instrument Approach is commenced at the initial approach altitude over the fix with the letdown and procedure turn being the same as that established for conventional aircraft. Descend from the initial approach altitude to low cone at 65% to 80% (TV-2) and 160 to 180 knots IAS. Some pilots prefer to descend clean to the procedure turn, but most prefer to use speed brakes throughout. Do not exceed the published distance limits from the station for the precedure turn. In fact, you should try to reach the procedure turn altitude as soon as reasonably possible. Raise the speed brakes in the turn. In the final, lower the speed brakes, landing gear, and landing flaps at low cone or two minutes from the field, whichever is sooner. Hold the power at 74% to 80% and the airspeed at 139 to 150 knots in the final.

In case of a missed approach in a TV-2, apply 100% power and clean up the aircraft, reducing power to 85% after airspeed is up to 180 K.

The middle station penetration procedure takes 100 to 110 gallons of fuel and 14 to 17 minutes in a TV-2. A GCA or ILS approach may add some 4 or 5 minutes and about 25 gallons of fuel to the requirement for any of these penetration procedures.

The middle station approach with the penetration descent in an open quadrant (see Figure 17-5) is performed in the same way. It is used when all legs of the range are occupied by through or holding traffic which must be by-passed in the descent. Often it is a good idea to request GCA to take over and guide you to a straight-in approach from the procedure turn or low station.

En Route Descent

In the interest of saving time and fuel, you should descend to the initial penetration altitude before reaching the destination facility. Establish radio contact with the appropriate range station or approach control in sufficient time to execute an en route letdown to arrive over the facility at the initial penetration altitude (which is usually 20,000 feet) or as assigned by ATC. At this time also, you may receive holding instructions, if necessary.

We have previously noted that an en route penetration descent may be authorized all the way

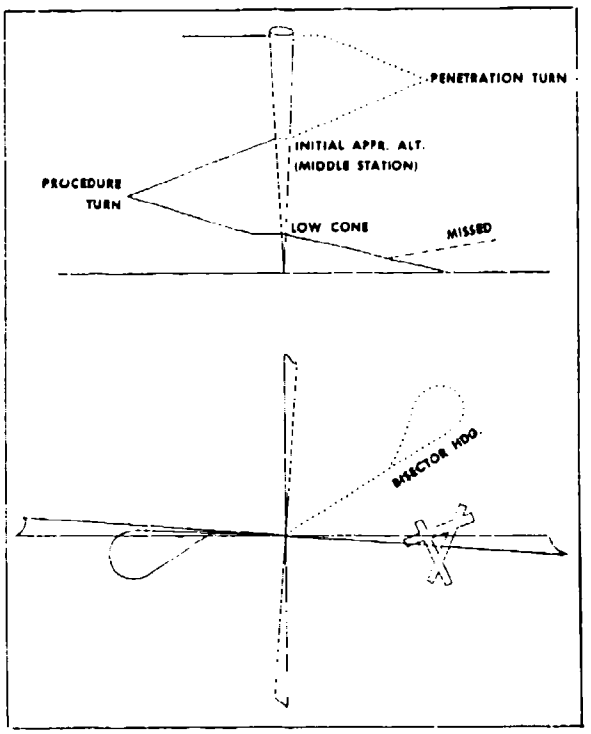


Figure 17-5. "Over-and-under" penetration with shuttle leg in open quadrant and procedure turns. (Tear-drop turns may be used at some stations.)

from the en route altitude to low station passage, provided there is a radio fix obtainable within 40 miles of the station from which to begin the descent below the initial penetration altitude. When the en route altitude exceeds the initial penetration altitude, you may obtain clearance, if traffic permits, within 100 miles of the station, but you must not go below the initial penetration altitude unless you obtain a positive position check at the secondary facility within 40 miles of station.

En route penetration procedures terminate at the initial approach altitude over the radio facility for the airport. If visual contact is not established over the radio facility at the initial approach altitude, an instrument approach must be executed. It is strongly recommended that you accept en route descent clearances only after ascertaining that no delay is to be expected upon reaching the initial penetration altitude over the approach fix.

REVERSAL

The chief reversement turn you will be interested in here is the 210° Reversal, shown in Figure 17-6. This turn is used to reverse course when directed to climb on a leg or heading and to reverse course at a specific altitude or position. This turn has one important difference from all other procedure turns: the aircraft remains on the outbound heading to a certain point and then turns back inbound to intercept. All the other turns are made away from the station with interception beyond the original turning point.

A constant climb is maintained during the reversal. It uses less fuel and time than a 80°/260° reversal. Because the aircraft is in a climb, the turn should always be made into the wind if terrain allows. This permits easier climbing and also prevents failure to reintercept the course by reason of drifting downwind away from the desired inbound leg. The wind will blow the aircraft back onto the inbound course early.

Use a 1½°/sec. turn, and certain dimensions will prevail in a no-wind situation. Hold this turn through 210°, thus attaining a 30° intercept heading. The turn will take 2 min. 20 sec. at 1½°/sec.; after rolling out of the turn, it will take 2 min. 35 sec. with no wind (or less time if you turned into a wind of any force) to intercept the reciprocal of the previous course. Thus, for example, if you wish to make the entire turn on the far side of a fan marker, leaving a station, travel outbound from the fan marker 2 min. 35 sec. before starting your turn, and you will then be sure of interception at or before your return to the marker. The entire turn from any point and back

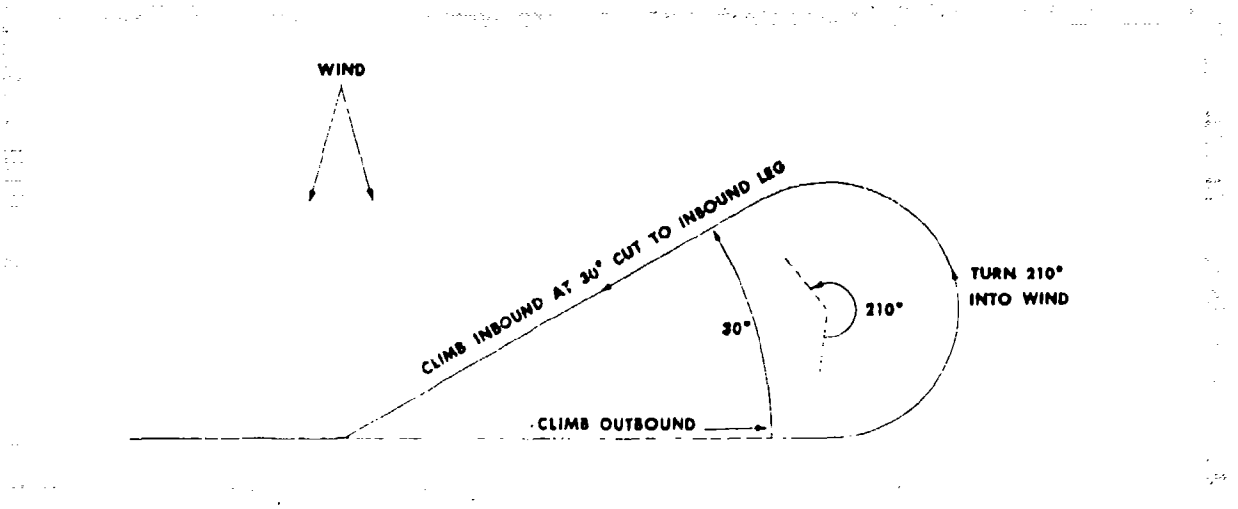


Figure 17-6. 210° reversal

to that point takes 7 min. 30 sec. if you use 1½°/sec. turns. Before you can begin such a reversal, however, you must determine wind drift well enough to be sure the turn is made upwind. It is not necessary to know the exact amount of wind or drift—only the direction of the drift.

MISSED APPROACH

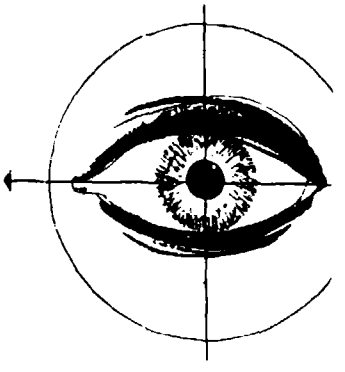
As you pass the station, note the exact time and begin a descent immediately so that you can reach the minimum altitude before reaching the field. Frequently, when good visibility and broken or ragged ceilings exist, you can proceed visually from a point near the range station. If the ground is not visible when you reach the minimum altitude, maintain the minimum altitude until the station-to-field time has elapsed. If the ground is still not visible at this time, immediately follow the missed approach procedure for that station.

The missed-approach procedure for each station with a published let-down is listed in the *Instrument Approach Procedure Charts*. You must use correct voice procedures and monitor the proper radio frequency continuously. Always carry out instructions immediately and acknowledge radio transmissions promptly.

If you see the landing field while on the low approach, make a landing "straight-in" on the runway most nearly aligned with the aircraft unless exceptionally high tail winds or cross winds make this impossible. Frequently, you may lose sight of the field while attempting to maneuver the aircraft for landing on a more desirable runway.

LOW VISIBILITY APPROACH

If a straight-in landing is impossible because of extremely high winds, obstructions on the runway, and the like, it may be necessary to make a low-visibility approach in order to line up with the desired runway. Do this by flying downwind directly over the landing runway, and as you pass the end of the runway, make either a 40-second, or a 90° type procedure turn. The turn can be made in either direction, depending on obstructions. Maintain precise control of the aircraft by reference to the flight instruments and by bringing the ground into the scan as another "instrument." Unless strong cross winds exist, the aircraft will be aligned with the runway when the procedure turn is completed.



If you use the 40-second type of procedure turn, the aircraft will be approximately one mile from the end of the runway after completing the turn. If it is desirable to have the aircraft closer to the end of the landing runway after completing the turn, you must start the procedure when approximately ½ to ¾ mile from the downwind end. This will put the aircraft ¼ to ½ mile from the end of the landing runway upon completion of the turn.

You may also start the 90° type of turn slightly before reaching the downwind end of the runway in order to keep the aircraft close to the end of the landing runway at all times. You can't start the low-visibility approach before passing the downwind end of the landing runway, use the 90° turn since it saves time and puts the aircraft closer to the field after completing the turn.

Be extremely careful when making a low-visibility approach. If the ceiling is very low or the visibility extremely poor, and if you don't know the terrain features or obstructions positively, you had better comply with the missed-approach procedure and proceed to the alternate airport.

HOLDING

In general there is no difference between jet and conventional procedures for holding and stacking. If possible, the jet should hold at the highest possible altitude to conserve fuel. Furthermore, when requesting clearance to penetrate or when ordered to hold, the pilot should inform

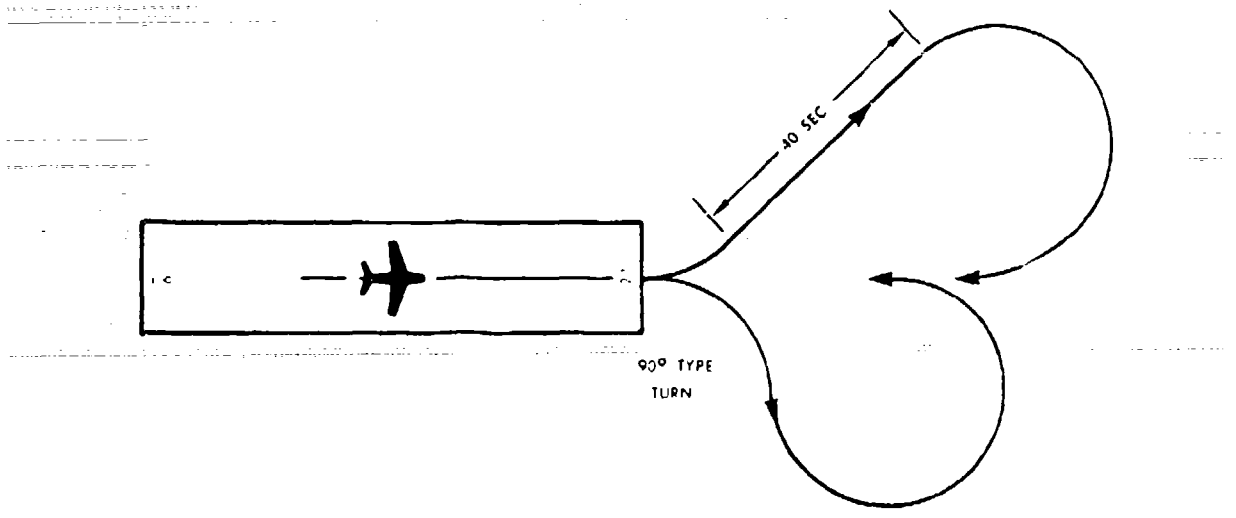


Figure 17–7. Low-visibility approach

Approach Control of the amount of fuel in terms of minutes remaining on board. Request an expected approach time, if it is not given, in order to plan whether you will have to go to an alternate at any future time because of impending fuel exhaustion.

The method of entering an elliptical holding pattern should be left mostly to the discretion of the pilot. The turning diameter is so great at high altitudes that it is impractical and time consuming to proceed out-bound on the holding leg and then to execute a procedure turn when entering the pattern from other than the holding leg. At 20,000 feet and 180 knots IAS the turning diameter is about 5 miles. The pilot should enter the pattern by tear-drop reversal, 90° turn, 80°–260°, or other method at his discretion so long as he remains within the dimensions of the holding pattern airspace area as set forth in the Flight Information Manual (June 15, 1955, p. 63). No deviation from the right hand turn, 2-minute leg pattern is permitted unless it is published or you are specifically directed to deviate.

Correcting for wind drift in the elliptical holding pattern at high altitudes with high wind velocities and slow rates of turn is more of a problem than is normal at lower altitudes. Using one-half standard rate turns causes the aircraft to be in a turn during half the time of the entire holding pattern. To counteract the effects of the wind during the turns in the pattern, use a one-half standard rate turn when turning into the wind. If, during the turn inbound, the range signals indicate that improper wind correction will cause the aircraft to be off course at the end of the turn, follow the same procedure for compensating for the error as that described for the 1 min. 15 sec. procedure turn.

You can also correct for a head or tailwind in a holding pattern. Regulate the time you fly on the outbound leg of the pattern so as to insure a maximum of two minutes inbound flying time to the station.

This pattern, which is very flexible, enables you to maneuver the aircraft in such a way as to be able to depart from the holding fix at any time the control agency may designate. For example, if you receive the approach clearance after making the 180° turn at the holding point, making another turn of 180° will place the aircraft inbound on the

final approach. You may decrease the time of straight flight away from the station as necessary to make good the expected approach time.

EMERGENCY PROCEDURES

There is no difference between the jet and conventional emergency procedures on the radio range. However, the jet pilot does have a problem of watching his fuel. Careful flight planning will help eliminate the need for an emergency descent. In the early days of jet aircraft, some air controllers did not seem to appreciate the fuel consumption problem of the jet aircraft. Now, most controllers are well aware of this problem. Still, you must be sure that you are not asked to hold at unreasonable altitudes or for long periods. You must also check your clearance to approach to be sure you have enough fuel to make such approach and letdown. Advising Approach Control of fuel time remaining in connection with requests for clearance or holding instructions may help prevent trouble from developing.

SUMMARY

As a jet pilot you will generally follow the same procedures on the LF/MF radio range as the conventional aircraft pilot except for the rapid descent to initial approach or to minimum penetration altitude, as applicable, and the use of simpler forms of procedure turns. In many cases there will be no prescribed penetration for the destination airport. In such cases, you should be able to plan a suitable penetration that will meet the standard criteria outlined at the beginning of this chapter and that will not unduly conflict with other traffic; then request such penetration be approved. Depending on terminal conditions, this should either bring you out just before the low cone, oriented for straight-in final approach, or at initial approach altitude on a suitable course to begin letdown to the procedure turn and standard instrument approach procedure. IFR approaches in jet aircraft require careful planning and judgment to avoid excessive use of fuel or a missed approach.

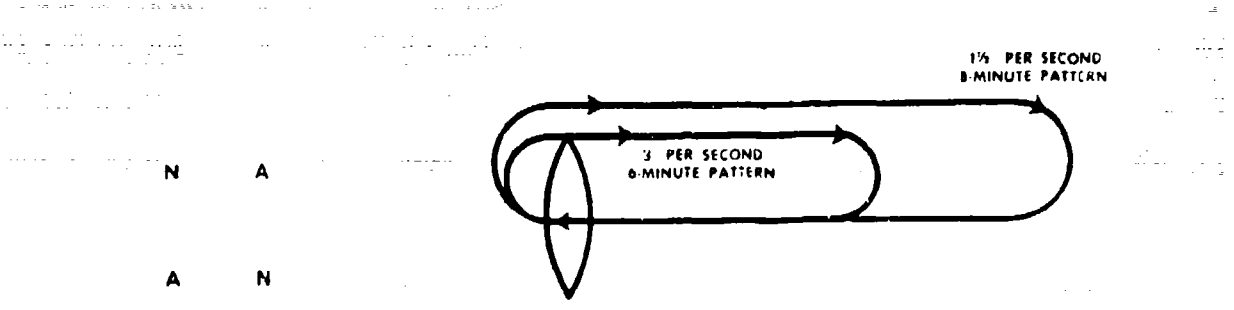


Figure 17–8. Elliptical holding pattern

CHAPTER 18

RADIO COMPASS PROCEDURES

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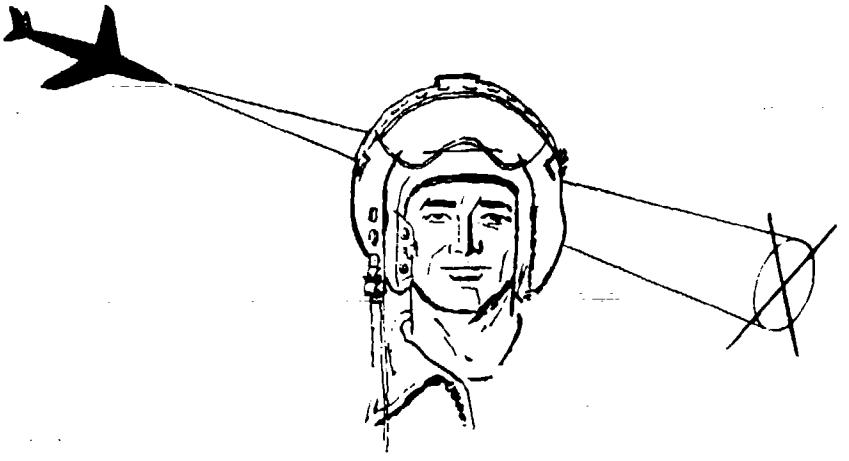


CHAPTER 18

RADIO COMPASS PROCEDURES

ALTHOUGH many new types of direction finding and homing equipment are coming into more and more widespread use, the radio compass still remains a basic and important piece of equipment for homing, tracking, intercepting courses, and similar purposes.

So far as these purposes are concerned, there is no important difference between the two radio compasses in use today—the AN/ARN-6 and the AN/ARN-7. They are both referred to in this chapter as the radio compass or automatic direction finder (ADF), and you use both in just the same way. Either compass will serve you as an excellent piece of navigational equipment if you use it properly. It is desirable, therefore, to consider the operation of this equipment before going into the procedures.

OPERATION OF THE RADIO COMPASS

Switches and Indicators

Here is how the radio compass switches and indicators are used and interpreted. These points apply to both the AN/ARN-6 and the AN/ARN-7. (See Figures 18-1 and 18-2.)

The *function switch* has four positions:

1. OFF—The set is inoperative in this position.

2. COMP.—In this position both the loop and

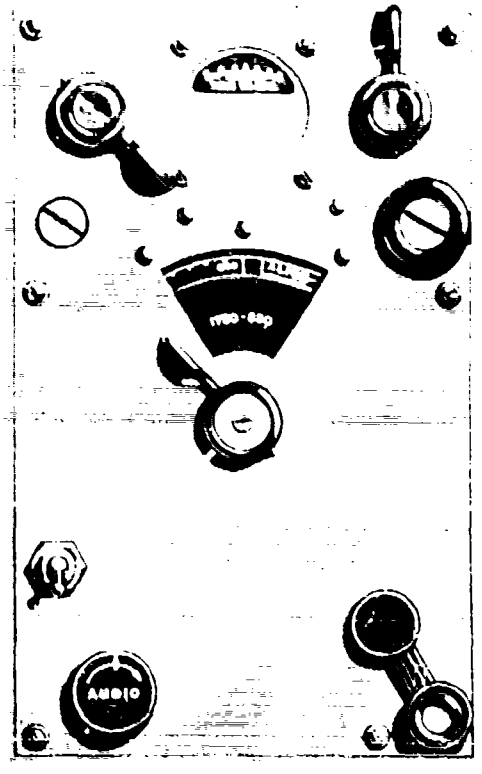


Figure 18–1. Control box AN/ARN 6

the sensing antennas are used, and the set operates as an automatic direction finder.

3. ANT.—In this position, only the sensing antenna is used, and the set functions in the same way as the command set receiver.

4. LOOP.—In this position only the electrostatically shielded loop is used and serves as a shielded antenna.

The band selector switch selects any one of the four available frequency bands:

1. 100–200 kc.
2. 200 to 410 kc.
3. 410 to 850 kc.
4. 850 to 1750 kc.

The tuning crank rotates the chosen band to the desired frequency.

The maximum signal indicator indicates the signal intensity of the carrier wave.

The LEFT–RIGHT *switch* rotates the loop to the right or left by means of a small motor.

The CW-VOICE *Switch* is set on CW to modulate the carrier wave and give it a steady, audible hum; is set on VOICE for regular broadcast reception.

The bearing or azimuth indicator indicates the position of the loop antenna in relation to the longitudinal axis of the aircraft.

Tuning Procedure

It is important to tune in a new station only in the ANT position due to the fact that the servo motor will be easily damaged by the action of the sensing antenna as you swing past numerous stations when tuning. For every individual station, follow this same procedure:

1. *If the interphone system is used, set the interphone jackbox or junction box to* COMP *and set the junction box volume to maximum.*

2. *If the function switch is* OFF, *turn it to* ANT *and wait for warm-up. With the function switch on* ANT *and the* VOICE/CW *switch on* VOICE, *select the frequency band and tune in the station.* Adjust the tuning crank position until a maximum needle deflection shows on the signal indicator. Listen to identify the station.

3. *Turn to the desired function:*

To ride a radio range by listening to the signals, use the ANT *position.* Only in this position do you get complete, accurate aural (audible) signals. In the COMP position, the AVC (automatic volume control) feature causes the on-course

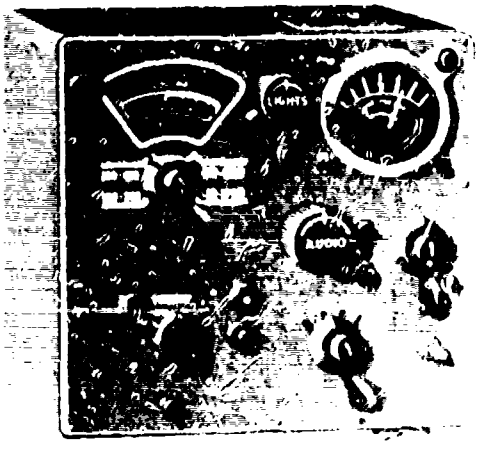


Figure 18–2. Control box AN/ARN 7

signals to be broadened. In the LOOP position, the loop antenna may be so positioned that it is at the null (that is, the hole of the loop points toward the station) and, unless you rotate the loop for maximum, you may get poor signals. The only time to use the LOOP position for radio range is during periods of extreme static when better reception may be obtained in LOOP position because the loop is shielded. To use the loop this way, rotate the loop to maximum by the LEFT-RIGHT (L-R) switch. In flying a loop range on LOOP position, you may find the A and N signals reversed and may have to discontinue using the LOOP antenna close to the station.

To use the Automatic Direction Finding (ADF) *feature of the radio compass, set the function switch to* COMP. If the station is an Adcock or simultaneous loop range, retune for maximum nondirectional homing signal. The head of the needle points to the bearing of the radio station from the aircraft. On the usual ADF indicator this is a relative bearing, and the top center of the indicator is the zero or nose position. On some sets the indicator may have a VAR adjustment knob and if the true or magnetic heading is cranked in, the indicator will indicate true or magnetic bearing, respectively. Such indicators (Fig. 18-3) are uncommon, and usually found only at the navigator's stations in large aircraft. If the aircraft has the RMI type of indicator (aircraft with the RMI usually also have VOR, Tacan or UHF DF equipment), the ADF may indicate bearings on one of the two needles of the RMI. In this case, the angle of the needle shows the relative bearing, but the dial numerals at the needle indicate actual magnetic bearing. This is because magnetic (or true) bearing equals magnetic (or true) heading plus relative bearing. Since the dial rotates to the magnetic heading automatically and the needle points in the direction of the relative bearing, the needle points at a numeral which is magnetic heading plus relative bearing, in other words, at the magnetic bearing. (Fig. 18-4.)

To use the radio compass for Manual Direction Finding (MDF) or Aural Null procedures, turn the function switch to LOOP and set the VOICE CW switch to CW. Then rotate loop with the L-R switch to maximum signal and retune for desired beat frequency in the earphones, not necessarily for maximum signal strength. A high beat frequency tone usually comes through background noise and static better than a lower tone. The tuner may have to be adjusted from time to time as the distance from the station changes, in order to maintain the most desirable beat tone in the earphones. Now rotate the loop antenna with the L-R switch to the *minimum* or null signal. One end of the needle now points toward the station and the other end away from it, but you don't know which is which. You can solve this 180° ambiguity by using the aural null procedures described later in this chapter.

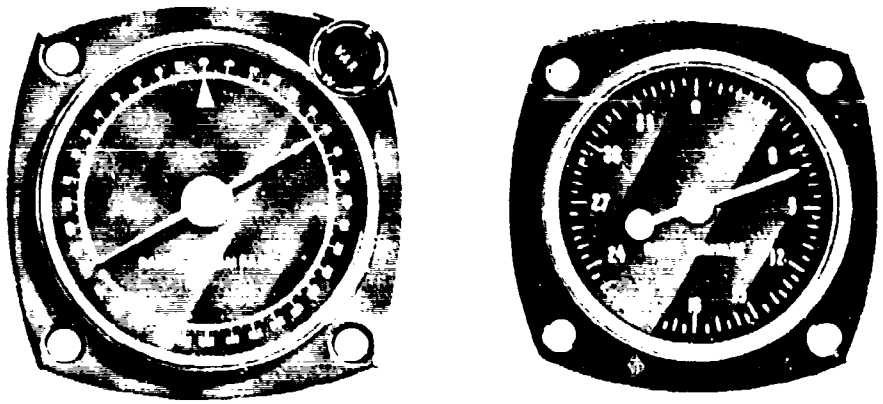


Figure 18-3. Indicator I-81 (left) and Indicator I-82 (right)

IRREGULARITIES OF THE RADIO COMPASS

Mountain Effect

When you use the ADF, ore deposits will sometimes cause the needle to deflect off course. The reflection of radio waves from mountains may also cause erroneous or fluctuating bearings. For this reason, be careful in using bearings taken in the vicinity of mountainous terrain.

Twilight Effect

Sky waves reflected by the ionosphere come back to the earth at some point beyond 30 to 60 miles from the station and may cause the needle to fluctuate. This effect, which is sometimes called night effect, is most prevalent during periods just before and after sunrise and sunset. Generally, the greater the distance from the station, the more pronounced these irregularities are. There is little or no remedy for it, but you can minimize the error by using an average value of the fluctuations, or by resorting to aural null procedures. You will encounter maximum night effect in commercial stations in frequency ranges above 1000 kc; the frequencies below 1000 kc are generally less subject to this irregularity. Adcock radio ranges seem to be least affected by this phenomenon as they radiate fewer sky waves because of antenna design.

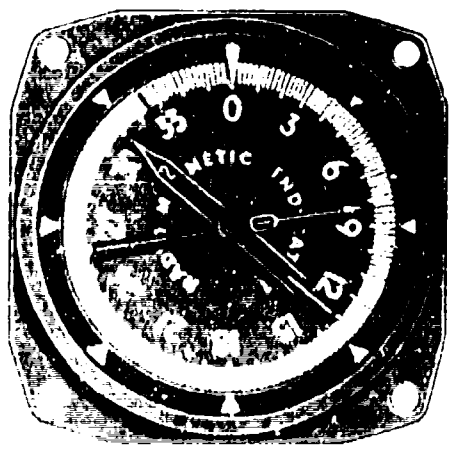


Figure 18-4. Radio Magnetic Indicator

Shoreline Effect

As radio waves pass from land to water, their direction of travel is changed. This is known as shoreline effect. (See Figure 18-5.) Because of shoreline effect, a bearing taken on an inland station from an aircraft over water is inaccurate if it makes an angle of less than 30° with the shoreline. At greater angles, bending is negligible. When taking bearings over water, therefore, choose either stations right on the shore, such as marine stations, or stations so located that bearings on them make angles greater than 30° with the shoreline.

Mercator Distortion

Over land, a pilot or navigator seldom takes radio bearings on a distant radio station. Over water, however, a distant radio station, especially a commercial broadcast station of high power, may be the only available aid. In this situation you must consider another factor in the process of plotting bearings to find position. Radio signals follow a great circle course, which is the shortest distance over the curved surface of the earth to the receiver. This bearing will not form a straight line on a Mercator chart which is normally used for ocean navigation. However, you can find the angular difference, measured either at the aircraft or station, between the observed great circle bearing and the line to draw to plot it on the chart. Use the correction shown in the table (Figure 18-6). This correction is not required for north-south bearings because it is the difference of longitude which causes the error to appear. If you are in north latitude, add the correction to the bearing if the aircraft is west of the station and substract it if the aircraft is east of the station. In south latitude, signs (plus or minus) are reversed. It makes no difference whether the correction is applied to the true bearing from the aircraft or its reciprocal from the station.

Inaccurate Heading Determination

If the ADF indicator is the RMI, the magnetic bearing (relative bearing plus magnetic heading) is mechanically shown. In the conventional ADF, however, you must take the heading from the compass (corrected for deviation if necessary) at the same time you read the relative

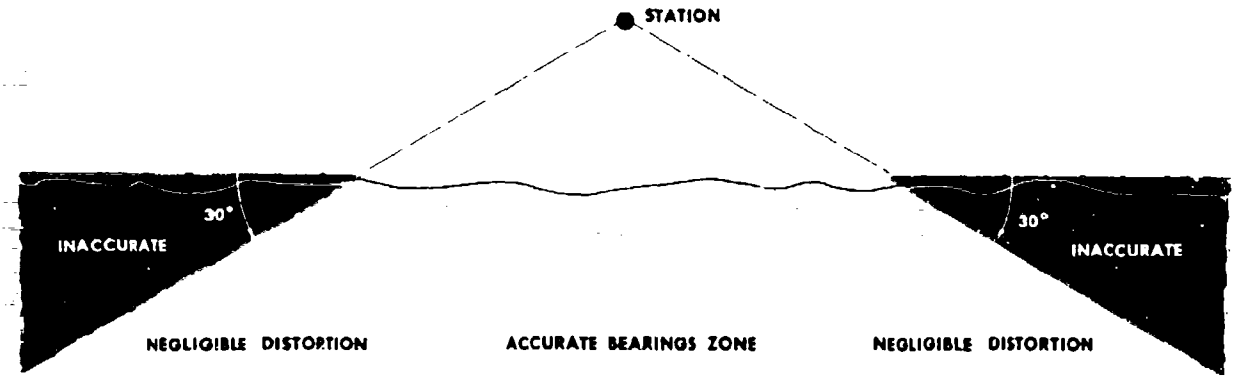


Figure 18–5. Shoreline effect. In the zones marked "inaccurate," distortion cannot be calculated

bearing from the ADF needle. You can make significant errors in position determination, particularly in taking a bearing on a distant station, if you don't determine the heading accurately. Remember, too, that in tracking you must follow headings accurately followed to make a quick and accurate drift determination.

Precautions in Use of DF

When you home on a very powerful non-directional radio station, the volume may appear to remain constant for several miles before the station is reached and often after it is passed. This makes it take much longer to determine that the station has been passed.

When you use a single frequency loop station, the needle will tend to oscillate within approximately 20 miles of the station, the oscillation becoming more pronounced as you come closer to the station. When you are on or near the range leg, the average of the oscillation will be the correct bearing. When you are in the middle of the quadrant, one of the extremes will be correct, and it is best to switch to loop and use aural null procedures. The construction and antennas used in a loop station are responsible for these irregularities, and you should avoid single frequency loop stations if other stations are available in the area.

Simultaneous loop range will give practically the same ADF *compass* results as Adcock ranges. Radio should be tuned to the non-directional homing frequency, as when using the Adcock range. That is, the published frequency which is 1020 cycles lower than the range frequency.

Remember that the automatic features of the radio compass are absolutely reliable *only* when used in conjunction with all equipment at your disposal. In the absence of more advanced navigational aids, you must continually verify your position with reference to radio ranges and beacons with the automatic feature of the radio compass. Use the aural null procedures set forth here only when there is an emergency due to the lack of range facilities or when precipitation static prevents the identification of range signals.

MIDDLE LATITUDE	Difference of longitude of plane and station													
	2°	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°
66	0.9	1.8	2.8	3.7	4.6	5.5	6.4	7.3	8.2	9.1	10.0	11.0	11.9	12.8	13.7
63	0.9	1.8	2.7	3.6	4.5	5.4	6.3	7.1	8.0	8.9	9.8	10.7	11.6	12.5	13.3
60	0.9	1.7	2.6	3.5	4.3	5.2	6.1	6.9	7.8	8.6	9.5	10.4	11.2	12.1	12.9
57	0.8	1.7	2.5	3.4	4.2	5.0	5.9	6.7	7.5	8.4	9.2	10.0	10.9	11.7	12.5
54	0.8	1.6	2.4	3.3	4.1	4.9	5.7	6.5	7.3	8.1	8.9	9.7	10.5	11.3	12.1
51	0.8	1.6	2.3	3.1	3.9	4.7	5.5	6.2	7.0	7.8	8.5	9.3	10.1	10.8	11.6
48	0.8	1.5	2.2	3.0	3.7	4.5	5.2	5.9	6.7	7.4	8.2	8.9	9.6	10.4	11.1
45	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.1	7.8	8.5	9.2	9.9	10.6
42	0.7	1.4	2.0	2.7	3.4	4.0	4.7	5.4	6.0	6.7	7.4	8.0	8.7	9.4	10.0
39	0.6	1.3	1.9	2.5	3.2	3.8	4.4	5.0	5.7	6.3	6.9	7.5	8.1	8.8	9.4
36	0.6	1.2	1.8	2.4	3.0	3.5	4.1	4.7	5.3	5.9	6.4	7.0	7.6	8.2	8.7
33	0.5	1.1	1.6	2.2	2.7	3.3	3.8	4.4	4.9	5.4	6.0	6.5	7.1	7.6	8.1
30	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.4
27	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.6	4.1	4.5	5.0	5.4	5.9	6.3	6.8
24	0.4	0.8	1.2	1.6	2.1	2.4	2.9	3.3	3.6	4.0	4.4	4.8	5.2	5.6	6.0
21	0.3	0.7	1.1	1.4	1.8	2.2	2.5	2.9	3.2	3.6	3.9	4.3	4.6	5.0	5.3
18	0.3	0.6	0.9	1.2	1.6	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3	4.6
15	0.3	0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.3	2.6	2.8	3.1	3.3	3.6	3.8
12	0.2	0.4	0.6	0.8	1.0	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1
9	0.2	0.3	0.5	0.6	0.8	1.0	1.1	1.2	1.4	1.6	1.7	1.9	2.0	2.2	2.3
6	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.6
3	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8

Figure 18–6. Correction to convert great circle bearing to mercator bearing

USES OF RADIO BEARINGS

The bearings you get from the radio compass, whether in ADF or MDF, may provide many kinds of navigational information. The following outline may help you visualize the abilities of the radio compass: each procedure is discussed later in the chapter.

A. *Pilotage* (Navigational procedures without plotting position on a chart):

1. *Homing:* Following the null or nose position to the ADF needle into a station. If there is any cross wind, this results in a curved track, with the curvature increasing as the station is approached.

2. *Tracking:* Flying a series of headings toward or away from a station, making corrections for drift as it is determined. This results in a series of straight-line tracks, but ends up with a straighter and more direct track than homing. It is considered better pilot technique than homing.

3. *Intercepting Desired Bearings:* This is a simple technique by which you intercept a specific inbound (or outbound) bearing to a radio facility and, after interception, tracks on that bearing.

4. *Time/Distance Checks:* Using the radio compass to establish distance from a radio facility in order to establish an ETA if that facility will be approached or to determine position as it passes a beam.

5. *Holding, Letdown, or Approach by Use of ADF:* Using radio bearing to maintain proper course during radio range or emergency procedures.

B. *Navigation* (use of radio bearings plotted on a chart):

1. Plotting lines of position.

2. Fixes from single radio station passed abeam.

3. Fixes from two or more radio stations.

4. Fixes from radio bearings and other lines of position.

ADF METHODS AND PROCEDURES

The first step in any radio compass procedure is proper station tuning. Follow the method described before. In aircraft which have dual radio compass control boxes, make sure your unit has control of the receiver before you tune the station. On the ARN-7, the box in control shows a green light. Another way to find out whether your box is in control is to turn the function switch to LOOP and try the L-R switch. If the loop rotates, your box is in control. If not, depress the control button on the box. Depressing the button on either control box shifts control from whichever box is then in control over to the other box. This procedure, of course, is unnecessary in aircraft with only one control box.

> NOTE: On the ground, or when you are flying VFR in a known area, check the indication of the azimuth needle for accuracy against the known direction to the station.

Homing

Homing is flying the aircraft on any heading required to keep the azimuth needle on 0° until the selected station has been reached. (See Figure 18-7). To head the aircraft toward the station, you make a turn to zero the azimuth needle. All turns during ADF work are made to a predetermined heading because of an inherent dip error in the radio compass during turns. You determine the heading required to center the azimuth needle on 0° by checking the position of the azimuth needle relative to 0° on the azimuth scale while flying level; for example, if the needle is 20° to the left of 0°, make a turn of 20° to the left.

After you make the turn, check the azimuth needle again and make small corrections, if necessary, to zero the azimuth needle.

If there is no wind, merely flying the gyro heading that originally placed the azimuth needle on 0° will take the aircraft to the station. If there is a cross wind, it is necessary to make small corrections from time to time in order to keep a reading of 0° on the azimuth scale. As you maintain a constant gyro heading, the direction and magnitude of the azimuth needle deviation indicates the direction and number of degrees of turn necessary to return the azimuth needle to 0°. For example, if you maintained a constant gyro heading and, after a little while, the azimuth needle was dis-

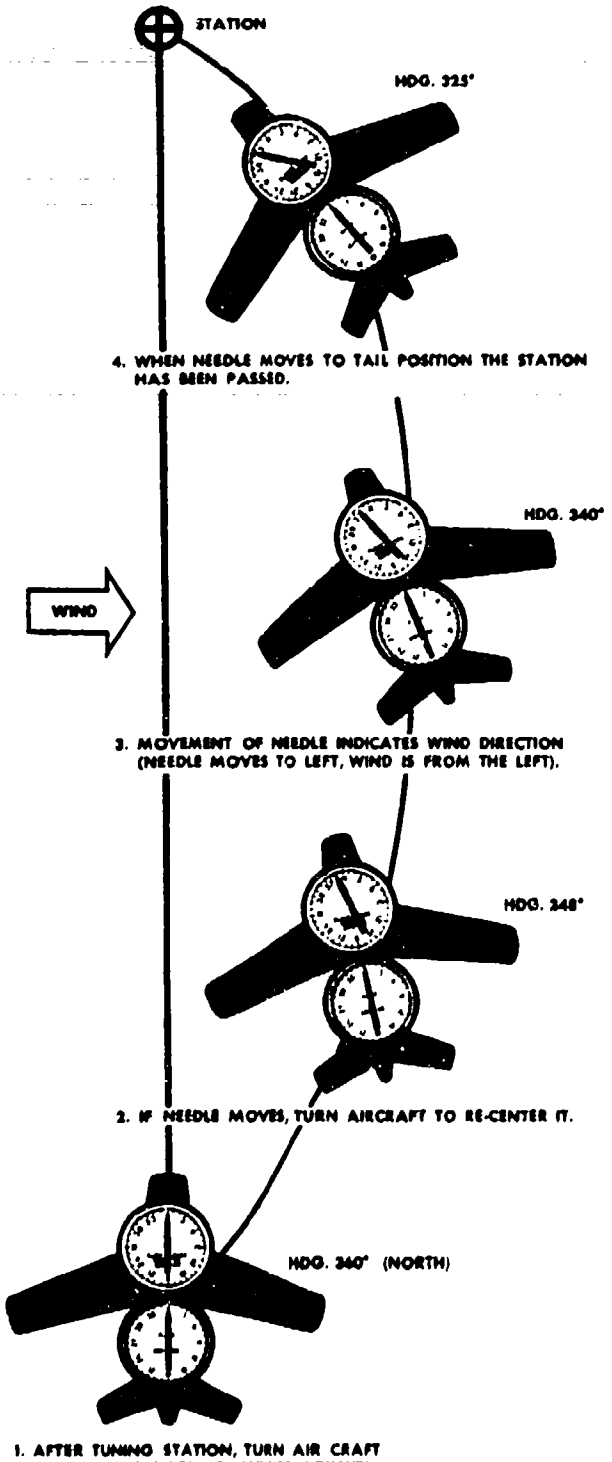


Figure 18–7. Homing on ADF

placed 2° to the left of 0°, you should make a 2° change in gyro heading to the left. When you complete this turn to the left, the azimuth needle will again indicate 0°. Similarly, a displacement of the azimuth needle 5° to the right requires a turn of 5° to the right to return the azimuth needle to 0°. Thus, when a cross wind exists, the resultant flight path is curved downwind.

This curvature increases as the station is approached, as shown in Figure 18–7. The closer the aircraft gets to the station, the more rapidly wind drift causes the needle to move to one side.

For this reason, homing is considered sloppy flying. It is easy but not precise. In addition, station passage is not made on a good course for continuation in the same direction outbound. Tracking is a better procedure because it allows for drift as the station is approached so that, by the time station passage occurs, you have found a heading which allows for drift and which you can usually continue outbound without alteration. Actually, many N[illegible] use the word "homing" to describe the tracking procedure.

Tracking

ARTC instructions, terrain, or restricted areas may make it necessary or advisable to make good a desired geographic flight path. This is known as tracking. "Desired track" is synonymous with "desired magnetic bearing."

Tracking and beam following are very similar. When you follow a radio beam, you hear the aural signal, and that indicates the position of the aircraft in relation to the beam. When you track, you look at the azimuth needle, and that indicates the position of the aircraft in relation to the desired track. The problem in both tracking and beam following is to establish a heading that will keep the aircraft on the desired track or range leg regardless of wind direction or velocity. The technique developed for beam following is applicable to tracking.

To track inbound, turn the aircraft to the gyro heading that places the azimuth needle on 0°. If you maintain this heading, a cross wind is clearly indicated when the azimuth needles move to the left or right of 0°. (See Figure 18-8.) When you see a distinct change in the azimuth indication (2° to 5°), make a corrective turn in the direc-

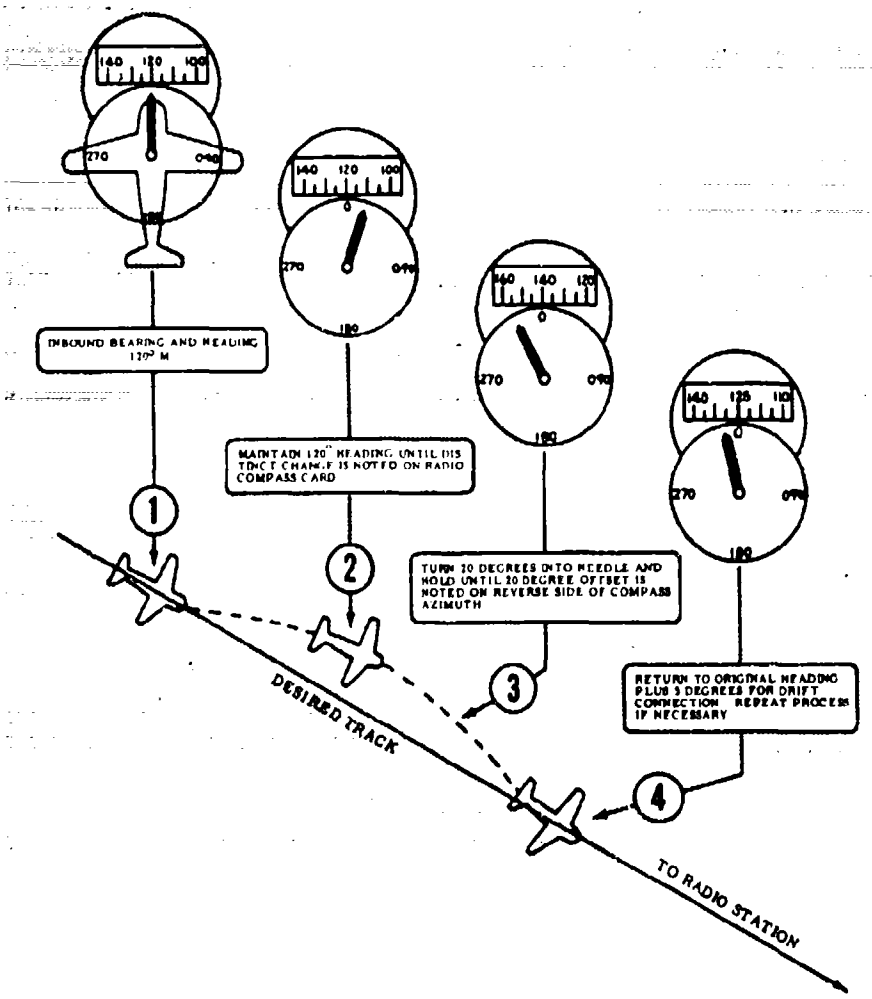


Figure 18–8. Tracking inbound to station

tion in which the needle is moving in order to reintercept the desired track. If the azimuth needle moves right, the intercepting turn is to the right; if the needle moves left, the intercepting turn is to the left. The angle of interception should be sufficient to return the aircraft to the desired track and *must always be greater than the number of degrees of drift.*

The magnitude of this intercepting turn depends on the distance from the station, the true airspeed, the existing wind, and how quickly you want to return to course. For example, if an aircraft is 5° off track, 60 miles from the station, it is 5 miles from the desired position; use a large angle of interception because this will return the aircraft to the desired track quickly and allow more time for determining drift correction. If the aircraft is only 5 miles from the station, however, and the azimuth needle of the radio compass indicates a 5° departure from the desired track, the aircraft is less than one-half mile from the desired track; therefore, a small angle of interception is advisable to prevent overshooting.

A rapid departure from the desired track indicates a strong cross wind when the aircraft is 60 miles from the station; however, if the aircraft is only 30 miles from the station, this same rate of departure from the desired track indicates only half that amount of cross wind. As you double the true airspeed, you double the effectiveness of a drift correction, and the necessary drift correction for a given wind is cut in half.

After estimating the angle of interception necessary to return to the desired track (and that

angle must always be greater than the number of degrees of drift), turn the aircraft toward the track by that amount, using the RMI or Heading Indicator as the primary instrument for directional control. When you complete the turn toward the desired track, the azimuth needle will indicate the angle of deflection of the station to be on the opposite side of the zero point.

When the deflection of the azimuth needle from 0° becomes the same as the angle of interception originally selected, the aircraft is back on the desired track. You then make a turn to the magnetic bearing of the desired track plus or minus an estimated correction for wind drift. It is necessary to lead or start the turn to the magnetic bearing of the track before the track has been reached because of the radius of turn of the aircraft. The amount of lead necessary depends on the distance from the station, the existing wind, the number of degrees to be turned, the true airspeed, and the rate of turn being used. Since there is no rule of thumb, that is applicable to all cases, you must use your judgment as to the amount of lead necessary, based on the rate at which the aircraft is returning to track.

If, after regaining the desired track and making an estimated correction for wind drift, you find that the radio compass needle moves toward the nose, the correction is insufficient. In this case, make a correction to regain the track, and when on track, establish a large correction into the wind. If the needle moves farther away from the nose when you are holding a drift correction, the correction is too large. If you have overcorrected, simply alter heading to fly the no-wind heading of the desired course until the wind blows you back to the course; this will be shown by the ADF needle returning to zero. Then take up a new heading which allows a smaller drift correction.

Station Passage While Homing or Tracking

The indications of proximity and passage of the station are similar whether you are homing or tracking. In homing, the needle tends to drift off the zero more quickly and more often when you are close to, or passing, the station. In tracking, the slightest error in drift correction is indicated considerably sooner than when you are further out. Aural monitoring of the signal is necessary as an aid to detecting this proximity during the approach to station.

If you're tuned into a low-frequency range station, a surge in volume is apparent as you approach the station despite the automatic volume control of the radio compass. This is the first indication of the proximity of the station. You may not notice a surge in volume as you approach a high-powered broadcasting station; the volume level often remains unchanged within a large radius of this type of station.

When you are very close to the station, even a slight departure from the desired course causes a large deviation of the azimuth needle. It is desirable, therefore, to make a correction in heading as soon as the compass needle deviates slightly, until it begins steady movement toward the wingtip. This can best be explained by considering the difference in width of a 5° angle at varying distances from the station. An azimuth needle deflection of 5° when the aircraft is 10 miles from the station means that the aircraft has departed from the desired course approximately 4,400 feet while the same 5° displacement at 1 mile would represent a distance of only 440 feet.

Don't try to zero the azimuth needle when it starts moving rapidly to the side; maintain a constant gyro heading since the station is very near. In the immediate vicinity of the station, the azimuth needle action may be erratic, swinging as much as 30° to either side of 0°. As the aircraft passes over or slightly to either side of the station, the azimuth needle swings and oscillates; when the station has definitely been passed, it settles near the 180° position on the azimuth scale. When the azimuth needle swings from 90° to 270°, assume that the aircraft is over the station and begin timing at that instant regardless of further oscillations. From one to three minutes may elapse at high altitude from the time the azimuth needle starts to rotate until it stabilizes at or near 180°.

To summarize the rules for tracking:

1. When on course, zero the ADF.
2. Hold that heading until drifted off by wind.
3. Turn into the needle to correct. The amount of correction is determined by:

   a. Distance from station. When far out, use a larger correction; 45° is almost always

plenty. Near the station, keep the correction small (not over 5°).

b. Speed with which the aircraft drifted off on the previous heading.

4. Hold the corrected heading until the needle has progressed to a point on opposite side of 0° equal to amount of turn made to correct. (If you resumed the desired course heading, ADF would show zero, but drift would again occur to take you off course.)

5. Assume a new heading which is toward the wind enough to offset for the drift encountered.

6. Hold that heading until drift again occurs on one side or other, and repeat the process, each time making a smaller adjustment to original drift correction.

7. Before reaching the station, you can find a heading at which the aircraft stays on course and the ADF needle stays constant at the drift correction angle.

Tracking Outbound

Tracking away from a station is basically the same as tracking toward a station. Make corrections for drift in the same way when tracking outbound as when tracking inbound. By visualizing the 0° to 180° line on the azimuth scale as the longitudinal axis of the aircraft, you can apply the same rules for tracking toward and away from the station. If the azimuth needle moves to the right, make the corrective turn to the right; if the azimuth needle moves to the left, make the corrective turn to the left. When you are flying away from the station, determine this movement in relation to the 180° point on the azimuth scale. (See Figure 18-9.)

NOTE: When you use the radio compass needle in conjunction with the radio magnetic indicator of the VOR, the 0° to 180° positions, as described in the procedures just discussed, will be the top and bottom of the instrument, respectively.

A difference between tracking inbound and outbound is the reaction of the needle. Inbound to the station, a turn toward the desired track causes the needle to move toward 0° on the azimuth scale. When you are flying away from the station, a turn in the direction of displacement causes the azimuth needle to be deflected further from the 180° point.

When you are tracking outbound, the amount of deviation from the desired track is indicated in degrees to the left or right of the 180° point. To get back on track, make an intercepting turn toward the desired track. The azimuth needle will then indicate the original angle of deviation, plus the angle of interception. The azimuth needle will move toward the tail position as you approach the track. When the deflection of the azimuth needle equals the angle of interception, the aircraft is on track. Now make a turn toward the magnetic heading of the desired track, corrected for the estimated wind drift. Again you will find a lead is sometimes necessary.

When you are on track and holding the proper drift correction, the azimuth needle will be deflected from the 180° point a number of degrees

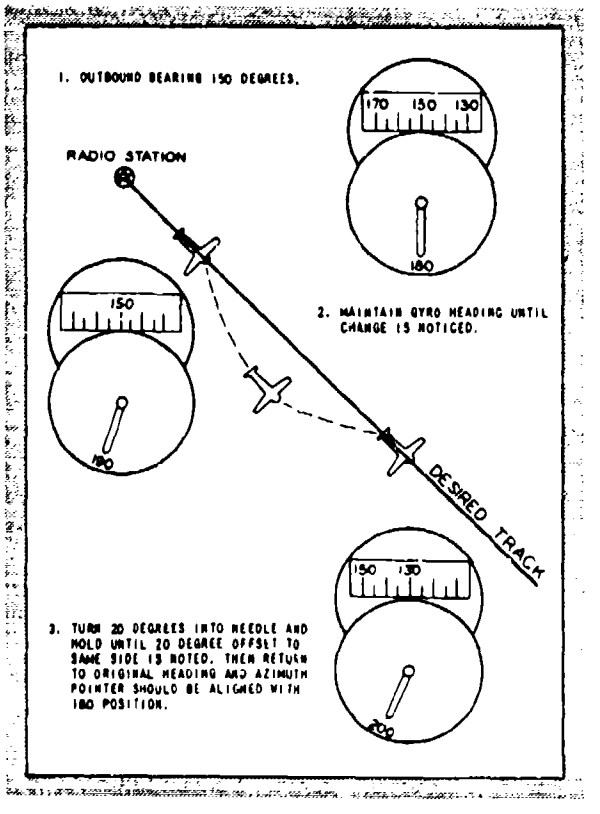


Figure 18-9. Tracking outbound

equal to the drift correction and to the same side as the correction. A movement of the azimuth needle further away from the 180° point indicates too little drift correction. Make any necessary corrections as previously described.

Precision instrument flight is necessary in tracking. Turns to headings must be accurate, and desired headings must be maintained. Any deviation in heading causes an equal deviation in the reading of the azimuth needle. Therefore, when you notice a change on the azimuth needle, immediately check the heading indicator to determine that it is not the result of a change in heading.

Interception of Pre-Determined Magnetic Bearings

To accelerate the movement of air traffic, ARTC often issues a clearance to track into or away from a radio fix on a definite magnetic bearing. Usually the aircraft is not on the desired track, so it becomes necessary to intercept the specified magnetic bearing (the desired track) and then continue to track on course. The procedure for intercepting a desired magnetic bearing is the same as simple tracking, except that the angle of interception required (to get on track) is usually greater.

To intercept a magnetic bearing, you must determine the position of the aircraft in relation to the station and to the magnetic bearing. To accomplish this, turn the aircraft to the magnetic heading of the desired bearing, and note the indications of the radio compass needle. Now determine whether the station and the desired magnetic bearing are to the left or right of the aircraft. If the needle is to the left of the 0° position of the azimuth scale, the station and desired bearing are to the left of the aircraft; if the needle is to the right, the station and desired bearing are to the right. Note the number of degrees the needle is deflected from the 0° position. Now, if you turn the aircraft this number of degrees toward the desired magnetic bearing, the aircraft will follow a course toward the station, in a no-wind condition. However, to intercept the magnetic bearing before reaching the station, you must turn a greater number of degrees than the original angle of deviation indicated by the deflection of the needle.

There are two methods generally used to intercept a desired bearing:

1. Double the Angle on the Bow, which may be used when the angle of interception is found to be between 10 and 45°. This method of interception is preferred because it gives the distance from the station at time of interception, and therefore an ETA.

2. 30° intercept method, which may be used to intercept a bearing when the angle of interception is not over 90°. Neither of these methods will serve to intercept a bearing which is more than a 90° angle of interception.

Double the Angle on the Bow

With this method, you first determine the angle of interception toward the station as just described, by reading how much and in what direction off zero the ADF needle indicates when you fly the desired heading. As an example, see Figure 18-10, where this angle is 38° right. As soon as this is done turn the aircraft so the ADF needle will indicate an equal and opposite deflection from zero (in this case 38° left, or 322° relative bearing). Note the new heading (in this case, 045° M), and fly that heading. Continue to fly that heading until the needle moves aft to a point equal to double the angle of interception (in this case 76° to the left) and turning that amount will place you on the desired course. The time between the turns, in a no-wind situation, will equal the time from the last turn to the station. Even with a wind, the error will usually be negligible because drift on the two headings will usually be almost the same since they do not differ by more than 45°.

Factors introduced by drift, error in heading determination, or inaccuracy of the ADF may cause inaccurate time/distance determination by this method in cases in which the angle of interception was less than 10°, but will not affect the validity of the interception procedure. Remember, too, that a strong crosswind blowing from the direction to which you turn may cause you to miss the station if the angle of interception is less than about 10°. To avoid this latter difficulty, apply wind to all headings if you know the wind. Then, after turning to intercept, watch the ADF needle. If it does not move toward the wing-tip, increase

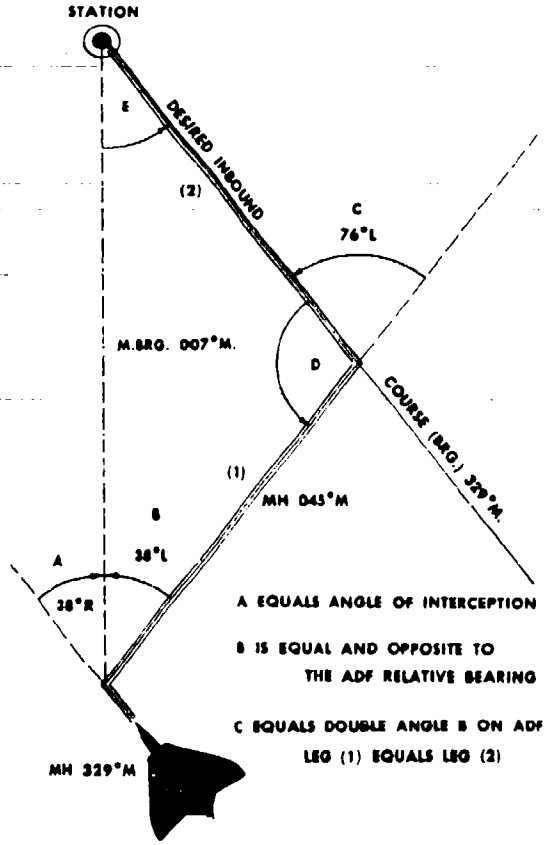


Figure 18–10. Intercepting desired course by doubling angle on the bow

the turn considerably (say, 30°) to insure interception. You will be on desired course when the magnetic bearing of station from the aircraft (M. H. plus relative bearing on ADF) equals the desired course. If there is any reason to expect strong, unknown winds, do not use this method if the angle of interception is less than 15°.

30° Intercept Method

This method begins in the same way as the method just discussed, that is, by determination of the angle of interception. Turn the aircraft to the heading of the desired bearing and read the ADF. The needle deflection is the angle of interception, and its direction right or left of zero is the direction to turn to intercept. Turn in that direction that many degrees plus 30° more. Using the same bearings as in the previous example, this means a turn of 68° right. (See Figure 18–11.)

If the turn is to the left, the azimuth needle will then read 30°; if the turn is to the right, it will read 330°. Fly the aircraft on this new heading until the azimuth needle is deflected the same number of degrees from the 0° position as the angle of turn to intercept. This is the number of degrees the aircraft is off the heading of the desired track. When you obtain this reading (68° L or 292° relative in our example), the aircraft has intercepted the desired bearing. Now turn to the desired bearing, and begin normal tracking.

If ARTC insists you intercept a specific course or bearing inbound whose angle of interception exceeds 90°, visualize the relative positions of the bearing of the station from the aircraft and that of the desired course to decide whether to track around the station clockwise or counterclockwise. If clockwise, turn to put the station at 090° relative on the ADF and fly in such a

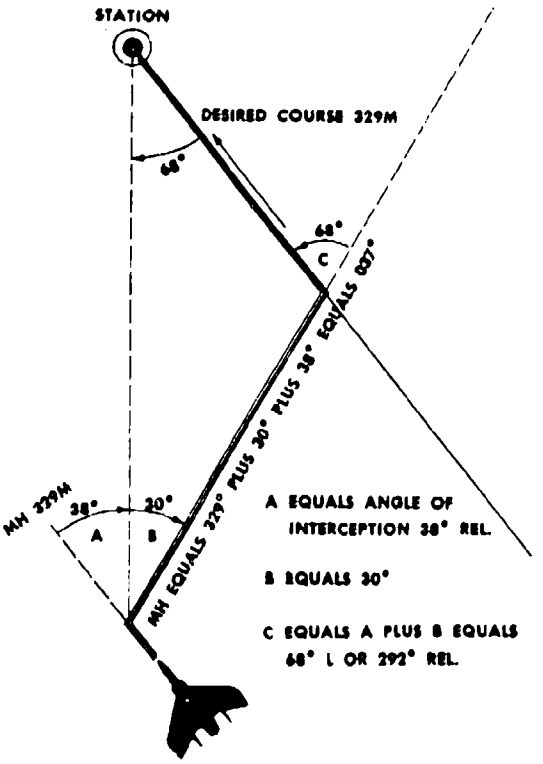


Figure 18–11. Thirty-degree intercept method for intercepting a desired inbound course

direction as to hold it at 090° (gradual right turn) until the heading of your aircraft plus 90° (or 85° if you are within 10 minutes of the station) equal the desired bearing: at this time, turn right. In a jet, you need more lead than that: hold the turn until the heading of your aircraft plus 80° (or 65° to 70° if you are within 6 minutes of the station) equal the desired bearing, then turn right. If you are tracking clockwise, use 270° relative on the ADF (instead of 090°) and turn left to get on the desired bearing.

Interception Outbound is very simple. If you turn to the desired outbound course heading, the needle will be in the right or left quarter. If left, then a left turn will intercept the outbound course. The sharper the turn, the sooner you will intercept it. You may be as close or closer to the course than to the station. Therefore, if you are quite close to the station, make a gentle turn in the proper direction. If the needle is nearly at 180° relative, you are near the desired course; if it is near 090 or 270° relative, the station is abeam and you are almost as far from the desired course as from the station. The maximum practical turn to intercept is 30° plus the number of degrees the needle was from 180° relative when the direction to intercept was determined. After turning, continue on that heading (see Figure 18–12) until the needle is again off 180° relative by the same number of degrees as you turn to intercept. Never turn over 45°. The desired course will be intercepted at too sharp an angle if you do.

When intercepting a bearing, you must start a turn to that magnetic heading before intercepting the bearing; otherwise, the radius of this turn will carry the aircraft past the desired magnetic bearing. The number of degrees of lead necessary depends on the true airspeed of the aircraft, the existing wind, the distance from the station, and the rate of turn used. Use the greatest amount of lead when you intercept the bearing at an angle of 90°. For any angle of interception, and any distance from the station, you can approximate the number of degrees of lead to use by interpreting the rate at which the azimuth needle is approaching the desired indication. Practice will enable you to determine the amount of lead to use.

TIME-AND-DISTANCE CALCULATION

When using the radio compass for instrument navigation, in both the automatic and the manual positions, you can calculate the time or the distance from the station.

Calculation Time From Station

After tuning to the station, note the position of the radio compass needle. The position of the needle indicates the magnitude and direction of

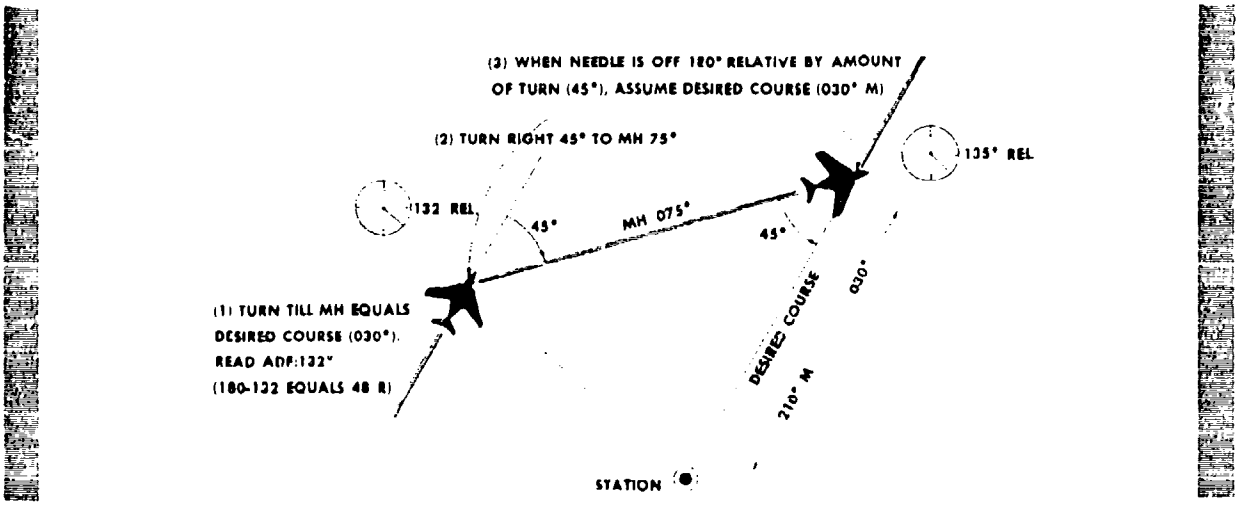


Figure 18–12. Intercepting outbound leg. Turn any number of degrees up to 45 degrees to intercept, letting distance and angle to station determine the turn angle

the turn required to place the needle on 90° or 270°. After you complete the turn on the heading indicator, note the position of the radio compass needle and make any necessary correction. Note the time, and fly a constant magnetic heading until there is a change of bearing of 5° to 10° as indicated by the radio compass. (See Figure 18-13.) After you notice a definite change in bearing, check the time again and apply the following formula:

$$\text{Min. to Station} = \frac{\text{60 times Min. between Bearings}}{\text{Degree of Bearing Change}}$$

Thus, if it took 3 minutes to fly a bearing change of 10°, the aircraft is:

$$\frac{60 \text{ times } 3}{10} = 18 \text{ minutes from the station}$$

Multiplying the minutes flown between bearings by 60 converts the minutes flown to seconds flown. If the time flown between bearings is less than one minute no conversion is necessary. The number of seconds flown divided by the degree of change gives the time from the station in minutes.

For example, if it takes 40 seconds to fly a 10° bearing change, the aircraft is:

$$\frac{40}{10} = 4 \text{ minutes from the station}$$

This formula may be further simplified by the following rules of thumb:

50 Change: 12 Time = Minutes from Station
100 Change: 6 Time = Minutes from Station

Fly a 10° change whenever practical, since this simplifies the required calculation. If the radio compass needle moves so rapidly that you cannot obtain a satisfactory time check during a 10° bearing change, the aircraft is very close to the station. (Figure 18-13.)

Calculating Distance From Station in Miles

Compute the distance from the station on the computer as follows:

1. Determine the true airspeed of the aircraft.
2. Place the speed index (heavy arrow-shaped mark) opposite the true airspeed.
3. Read the distance from station (on miles scale) opposite minutes from the station (on the minute scale).

For example, if an aircraft is 4 minutes from the station and the true airspeed is computed at

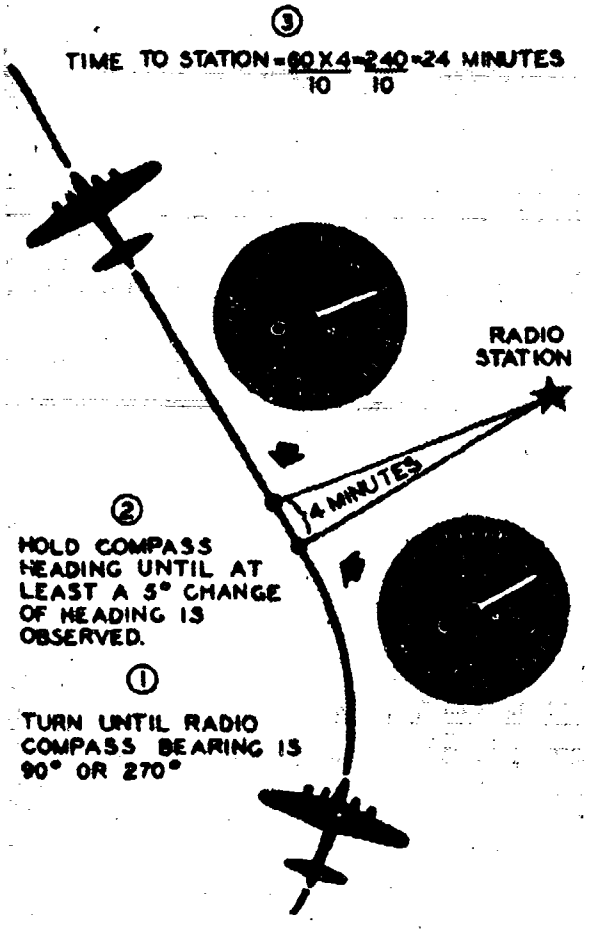


Figure 18-13. ADF time and distance calculation

230 K, set the speed index opposite 230. Read the answer (15 nautical miles) on the mile scale, opposite 4 on the minute scale.

The accuracy of this method of computing time and distances depends on the existing wind, the degree of bearing change flown, and the accuracy of timing. The greater the degree of bearing change, the larger the error. If you don't maintain a constant heading, it is impossible to get an accurate time check. The number of variables involved causes the results to be an approximation.

There are several other methods for determining time and distance from a radio station. If

it is a station to be passed abeam, you may use the conventional bow and beam bearing method you learned for visible bearings in navigation. (See Figure 18-14.) You may also use the double the angle on the bow method, similar to the same system discussed for intercepting a bearing. (See Figure 18-15.) More often, however, you'll be in a situation where you wish time/distance from a station which is your destination. If no specific course or bearing is required for approach, it is suggested you select one suitable for the double the angle on the bow interception, or one 10° off your inbound track for the 30° turn method (explained in the next paragraph), and request clearance to approach on that bearing. The 30° turn method of time/distance check is good because it requires very little alteration of heading. It is accurate if you have determined drift before beginning the procedure but may or may not be accurate in an unknown wind situation, depending upon what the real wind is.

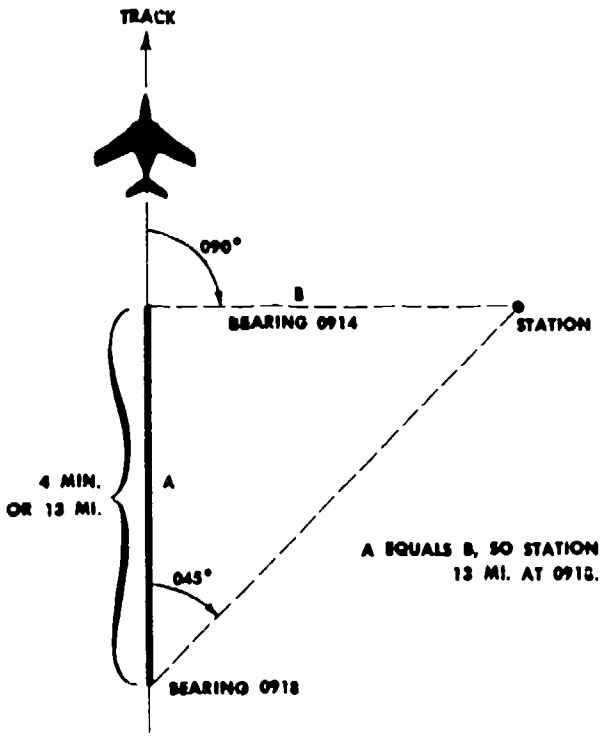


Figure 18-14. Bow-to-beam bearing time/distance check

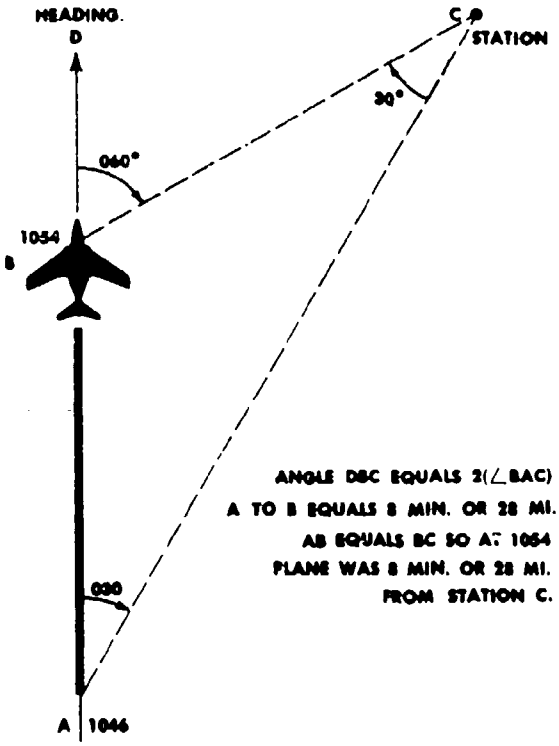


Figure 18-15. Double-the-angle-on-bow time/distance check

The 30° Turn Method (Fig. 18-16) is begun when tracking toward the station. To start the check, turn 30° right or left and note the time (to 1 sec.). Hold this new heading. If the ADF had read zero before the turn, it should now read 330° or 030° relative. If you were holding a drift correction, it should now read 330° or 030° relative plus or minus that correction. Hold this heading on the remote compass or RMI indicator until the needle of the ADF has moved 10° toward the wing-tip position from where it was after the turn (mathematically, to be exact, 9½°). Note the exact time, turn toward the station and track to the station. The time from this second turn to the station will be three times the time between turns. The distance to station also is three times the distance between turns. (Compute it at ground speed, if you know it, or at the TAS if you don't known the ground speed.)

There are two minor precautions to observe in connection with the 30° turn method. First,

determine drift before starting. If you fly the pattern no wind, and there is a wind blowing you off course, the results obtained will not be accurate. In fact, if the needle does not progress toward the wing-tip at all, you are drifting over to the other side of the station entirely. Second, if you are using MDF (aural null), knowing the drift, and the null progresses toward the nose instead of toward the beam, you have passed the station and are being fooled by the 180° ambiguity.

HOLDING BY ADF

Holding procedures are generally oriented to a range leg and a radio facility, such as a range station, fan marker, or homer. It is possible to fly the holding pattern solely by listening to the aural signals of the range and fan marker. The radio compass, however, makes this much easier and promotes accurate patterns. Refer to Figure 18-17. In this figure, the pilot is to hold on a fan marker and homer on the east leg of the range. He could just as easily hold on a certain inbound bearing as on the leg. He enters the holding pattern on the reciprocal (point A) of the inbound bearing, for example, and flies outbound for less than 2 minutes before flying a reversal (procedure) turn (point B). As he crosses the station coming from A, his ADF shows that fact and he begins timing for the reversal. As he continues to fly outbound, he can check drift by the ADF as he holds the outbound heading. After the turn, he can fly a heading which allows for such drift (now in opposite direction). Point C on the inbound leg shows as station passage on the ADF, and he can start the turn. As he rolls out of the turn, the ADF should read 090° relative. As he flies outbound again (D), his heading can allow for the drift determined by tracking on the range leg. As he continues holding, he uses the ADF to check that he is on the proper inbound bearing, to check his drift correction, and to know when he is over the radio facility to begin the turn inbound. Also, at the end of the holding, he uses the ADF to determine time of departure over the facility.

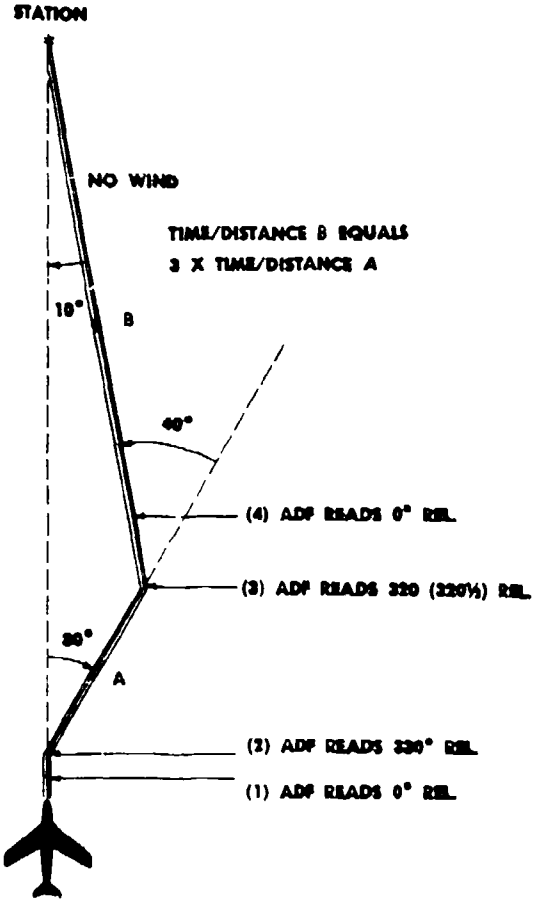


Figure 18-16. Thirty-degree turn method of time distance check

LETDOWN AND APPROACH ON ADF

Conventional aircraft may use the ADF in making their IFR letdown and approach, and a jet may use ADF in its penetration in much the same way. The procedure used is the same as that discussed before for tracking. In short, this is an application of the tracking principles to an everyday problem.

Conventional Letdown and Approach With ADF

The procedures used in radio compass approaches are very similar to radio range approaches; however, you have to plan your own approach. When you have to make a radio compass approach instead of a radio range approach, get the necessary information from the *Instrument Approach Procedure Charts* booklet and determine headings from station to field, initial ap-

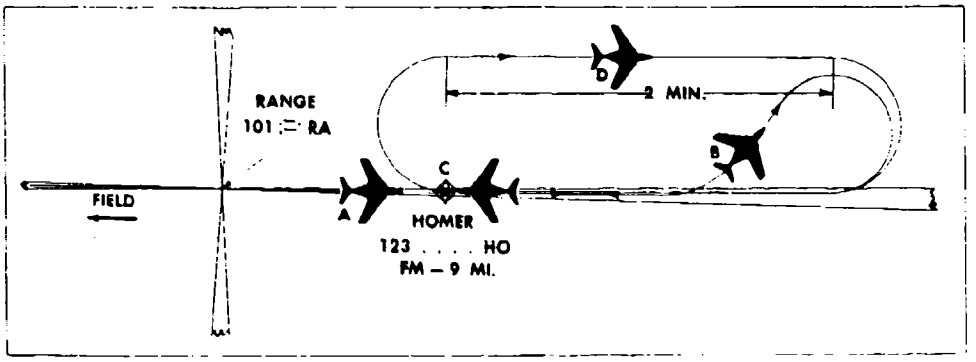


Figure 18–17. Use of the ADF to hold at a homer (RBn)

proach altitude, procedure turn altitude, final approach altitude, minimum altitude, and missed approach procedure. In selecting the altitudes, give careful consideration to the hazardous features that may exist in the area. Plan the approach carefully, as early as possible, and draw or visualize a diagram of it.

The reciprocal of the station-to-field bearing normally becomes the outbound bearing for the approach, as in Figure 18–18, which shows a CAA standard type DF approach. (Remember, however, that CAA will not approve a DF approach on a commercial broadcast station.)

If in the approach shown in Figure 18–18, you track inbound (point A) on whatever bearing you happen to be on or on a bearing assigned by air traffic control. Over the initial station (B), you turn to intercept the outbound bearing of 115° and track out on this bearing for 3 minutes. Meanwhile, you make a voice report, if required, throttle back to slow cruise, initiate a descent, and complete the landing cockpit check. The minimum safe altitude for the procedure turn should be that established for a 25-mile radius.

When three minutes out, at C, you execute a procedure turn back to the inbound bearing. This turn must be accomplished within the distance from the radio station specified on the approach plate. You track inbound (D) toward the station on the station-to-field bearing. The no-wind time inbound is about four minutes and on MDF, you can safely track for two minutes before turning the loop to the wing-tip position. On this leg, you let down to the final approach altitude, normally 1,000 feet above the terrain.

After passing the low station (at E), you continue to track on the station-to-field bearing (295°, using the heading that you have determined will correct for wind on the inbound leg of the approach. You descend to the field minimums and, after the station to field time, you should be contact or you must make an emergency pull-up.

Jet Penetration and Final Approach with ADF

In Chapter 17, several types of jet penetration were discussed as part of the radio range procedures. ADF penetrations have the advantage of being possible on any of 360 radials from various types of transmitters. In jet aircraft, this advantage is important in that lower traffic often makes it necessary to make a penetration off airways and range legs. You must plan such penetrations in advance, considering traffic, necessary terrain clearance, and bearings on which the initial approach is to be made. If possible, the penetration should be on a bearing which will eliminate the need for a large turn when you are over the station.

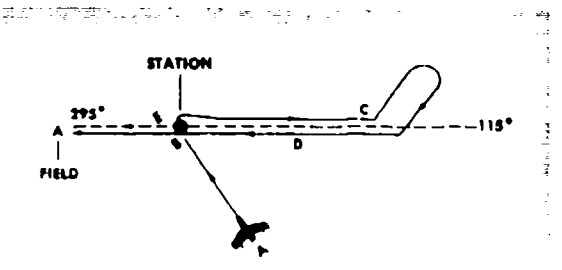


Figure 18–18. DF letdown

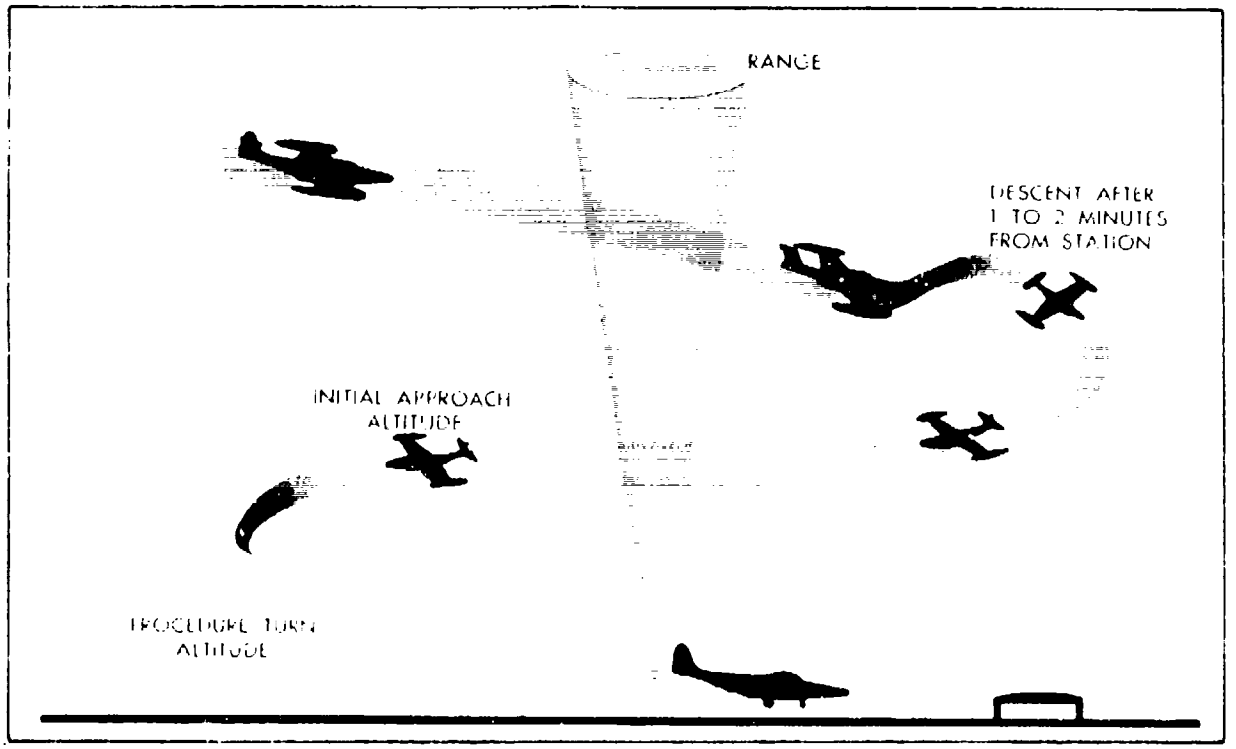
The penetration ends and the initial approach begins when you report over the station at the initial approach altitude. For stations which have a published range approach, your ADF initial approach must conform to the published altitudes and bearings. If there is no published initial approach procedure, you must determine the heading from the station to the field, initial approach altitude, procedure turn altitude, final approach, and the missed approach procedure. On an ADF initial approach, the terrain clearance must be equal to or greater than that on a range approach.

Don't try the penetration until you can be assured of an immediate approach on returning to the radio fix at minimum penetration or initial approach altitude. Before departing the cruising altitude, make sure, too, that you can complete an approach successfully.

Several types of radio-compass penetrations are recommended depending on radio aids and terrain. In the first type (Fig. 18-19), the penetration is started from a position over the range station or radio aid at the destination. To eliminate large turns at the range station when starting the final approach, this let-down is normally made outbound on a range leg or bearing which passes over the landing field. Where lower traffic exists, the letdown on the outbound track is accomplished by losing one-half the altitude before starting the penetration turn, and the initial approach altitude must be reached not closer than ten miles from the radio station.

The second type of penetration requires a homing facility on the final approach bearing so located that the final approach altitude provides necessary terrain clearance from the homing facility to the low cone. The penetration, as shown in Figure 18-20, is made from a position over the homing facility on an established bearing. Descend one-half of the altitude outbound before starting the penetration turn. Continue the descent inbound to the homing beacon until you reach

Figure 18-19. Open quadrant range penetration and low approach



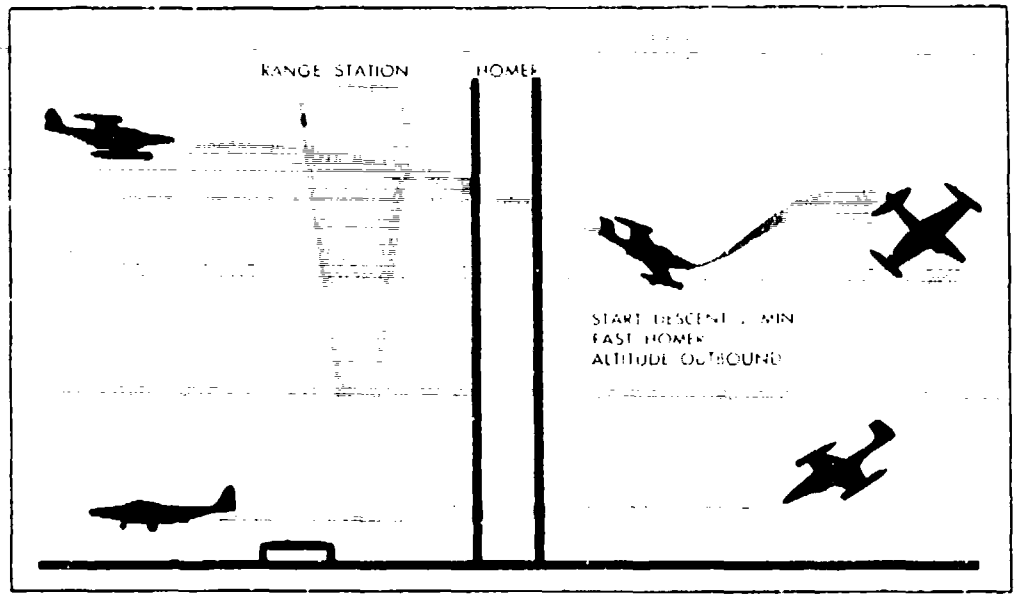


Figure 18-20. Penetration and low approach utilizing (U) facility with lower holding aircraft

the minimum penetration or assigned altitude. After crossing the homing beacon start a descent to the final approach altitude on the final approach bearing. This type penetration is especially suitable for formation flights. You may use variations of these basic penetrations as traffic, terrain, and radio aids dictate.

The third type of penetration utilizes an enroute descent to bring the aircraft over the radio fix at the destination at the minimum penetration or initial approach altitude in a position to make a straight-in or standard instrument approach. A straight-in penetration without first crossing the radio facility is permissible, provided that a satisfactory radio fix is available within 40 miles on which to start descent. The descent is usually made off airways. The procedure is not recommended unless the ceiling and visibility are high enough to permit the aircraft to continue to the destination VFR after reaching the lower altitude.

The final approach if straight-in is started after the radio station has been reached at the minimum penetration altitude. If a straight-in approach is not feasible, penetration is made to the initial approach altitude from which a standard instrument approach is executed

PLOTTING BEARINGS AND FIXES

The pilot of single-place aircraft rarely navigates his aircraft by use of a chart, or even a plotting board. Still, even if you don't use a chart to navigate, you should know how to convert a radio bearing to a geographic bearing to visualize your geographic position. The multi-engine pilot, of course, usually keeps a chart on all over-water flights. Radio bearings when plotted as true bearings are lines of position (LOP), just like sun lines or star lines or visual bearings. Of all the kinds of LOP, the radio bearing is probably the least accurate, but is still useful. Often an east-

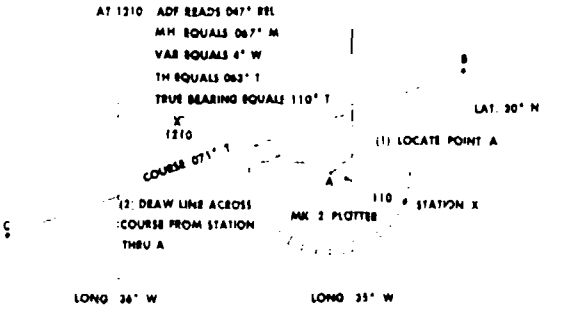


Figure 18-21. Plotting radio bearing

west flight will be approaching a destination with only morning or afternoon sun lines for positive position checks. These sun lines run north and south and provide ground speed. A radio bearing from destination or nearby may provide the track line for a two-line fix.

Converting Relative Bearings to Geographic Bearings

As you know a relative bearing is the direction from the nose or heading of the aircraft to the station. This is shown by the angle of the radio compass needle. On the standard ADF indicator, the numerical value under the needle tip is the relative bearing. It is measured clockwise from the top or zero point of the dial. To get a bearing to plot on the chart, add this to the heading. (Relative bearing plus magnetic heading equals magnetic bearing; relative bearing plus true heading equals true bearing.) If the chart is an airways chart with all values magnetic, use magnetic heading and get a magnetic bearing. (On the RMI, the numerical value indicated by the ADF needle is magnetic bearing without any addition to do.) Over the ocean, apply variation to the magnetic heading to get true heading; add the true heading to the relative bearing and you get the true bearing.

Don't forget this is a bearing from the aircraft to the station. When you plot such a bearing on a chart, you must draw it from the station to the aircraft—that is, draw in the reciprocal. You actually do this by setting the protractor for the bearing and simply plotting in reverse so the bearing runs from the station toward the aircraft position. It is not necessary to compute reciprocals for plotting purposes. Of course, if you want to know your position relative to a station, such as to tell a tower "Position 36 miles southwest of your station," the reciprocal is 180° more or less than the geographic bearing from the aircraft to the station. Look at the example in Figure 18-21 to see how to plot a bearing. This example is for a true bearing, but the magnetic bearing is similar.

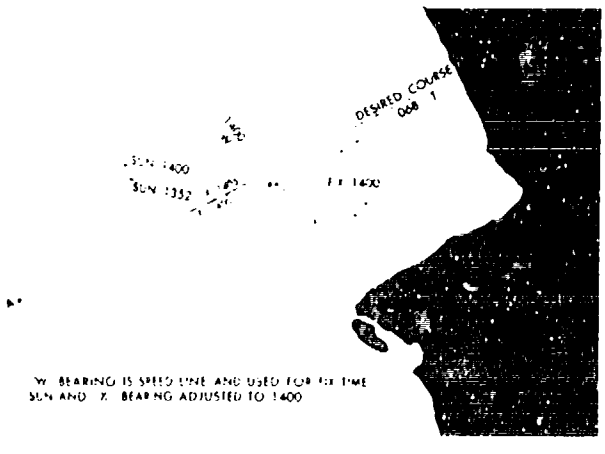


Figure 18-22. Radio and sun line fix

Plotting Bearings

In plotting a radio bearing, mark the line with the time at which it was observed. Just like star lines or other lines of position, radio bearings may be advanced or retarded at ground speed along track to the time of another bearing or LOP. A bearing on a station ahead or astern is a check on your track; one on a station more or less abeam is a check on your speed. It introduces less error in plotting fixes from lines of position to let the speed line (right angles to track) serve as time of a fix, and advance and retard those LOP's which are more or less parallel to track. Therefore, if you take several radio bearings, or a mixture of radio bearings and other lines of position (such as sun lines), select the best speed line (nearest to right angles to track) as the time of fix and advance or retard all others to that time. Figure 18-22 shows a fix consisting of a sun line and two radio bearings. Dotted lines show the original LOP's; solid lines show them as advanced or retarded to fix time.

Frequently there is a single radio station which will be passed abeam. To find position as you pass, you may use one or more of the time/distance checks previously discussed. These, however, all assume you can get good bearings at certain times. It may occur that reception is difficult and bearings may be obtained only on occasion. Also, each of them uses only two bearings for the check. For accurate work, three or four bearings are better.

Figure 18-23 shows a method for finding position from several bearings on a station passed abeam. First, take three or more bearings, observing the heading and time of each and compute

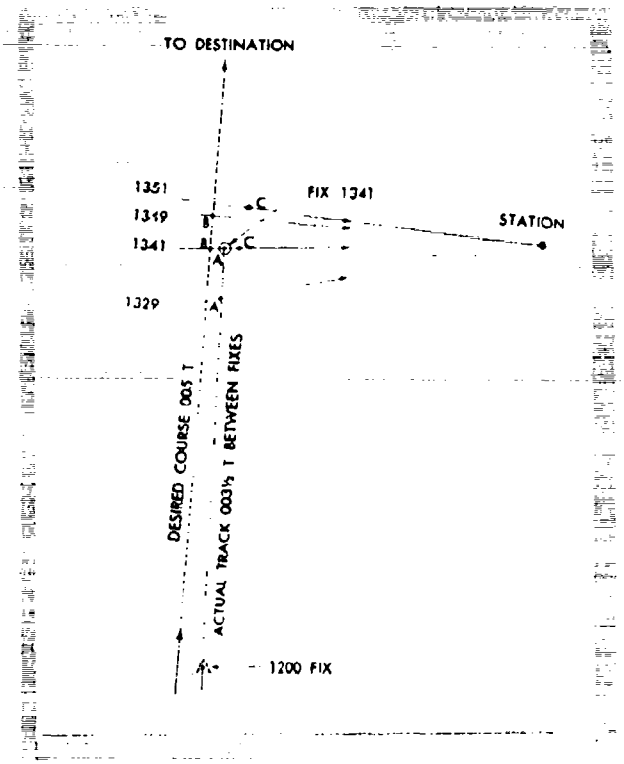


Figure 18–23. Radio fix from single station

true bearings. Plot all these bearings and indicate their time. Using the bearing nearest to abeam, compute ground speed from the last fix along your estimated track. Using this ground speed set dividers to the number of miles which should be covered from the first bearing to the beam bearing time, and pick the track which would carry the aircraft so that many miles lay between these bearings (A–A in Figure 18–23). Do the same for each bearing as compared to the beam bearing (B–B and C–C in Figure 18-23). Your estimated position is on the beam bearing at the average of these estimated tracks (marked "1341 Fix" in the figure).

MANUAL DIRECTION FINDING (MDF)

All the techniques just discussed may be done by MDF, which uses the aural null. Basically in MDF, you rotate the loop antenna to receive a minimum or zero signal (aural null), and the resultant bearing shown by the needle is either the proper bearing or its reciprocal (180° ambiguity). Unless you know your position with enough certainty (no guesses) to be sure whether the bearing is correct or is a reciprocal, you must check the ambiguity possibility to determine the definite bearing. Otherwise procedures are the same, on the whole, except that you can't constantly read your bearing and fly the aircraft as you can with ADF.

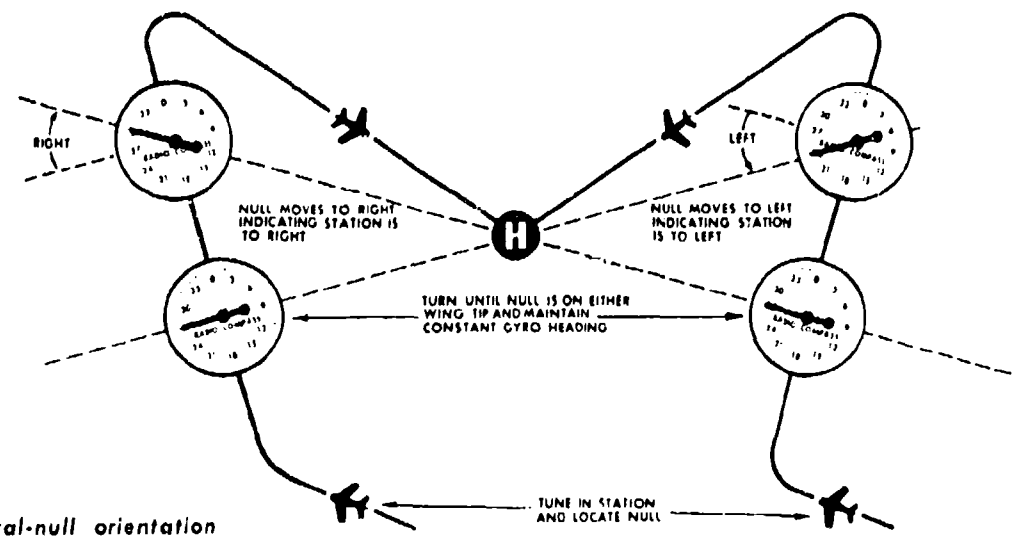


Figure 18–24. Aural-null orientation

When to Use MDF

Aural-null procedures are not often used, but a thorough knowledge of these procedures is essential since COMP and ANT positions of the radio compass are unreliable in the area of thunderstorms. This is frequently true also in an ice-crystal zone or in precipitation static. Under these conditions, the azimuth needle may fluctuate excessively or give erroneous indications when the equipment is used in COMP position; in ANT position, excessive static may prevent satisfactory aural reception. Loss or malfunction of the phasing antenna renders both the COMP and ANT features inoperative. When such situations arise, you can use the radio compass in the LOOP position and follow aural-null procedures.

The aural null is the point where there is an absence of audible sound. It (minimum reception) results when the plane of the loop antenna is perpendicular to a line from the station. Navigation procedures for homing, tracking, intercepting predetermined bearings, and approaches are the same with aural null as with ADF. However, you must position the azimuth needle manually by locating the null by sound and then check the relative bearing visually on the indicator.

The loop antenna is rotated by use of the L-R switch on the control box. Moving the spring-loaded switch in either direction results in rotation of the loop in that direction. On the ARN-6, the amount of pressure applied to the L-R switch determines the speed at which the loop rotates. Light pressure on the L-R switch results in a slow rotation of the loop; pushing the switch to the stop causes the loop to rotate at maximum speed. On the ARN-7, you speed up loop rotation by pressing the L-R switch in as you turn it.

Tuning

Tune the radio compass for aural-null work as described at the beginning of this chapter. If you can't accomplish the initial tuning and identification on the ANT position because of static or loss of the phasing antenna, tune the radio compass as follows:

1. Set the jackbox on COMP position and turn volume to maximum.

2. Turn the radio compass function switch to LOOP and the CW-VOICE switch to VOICE.

3. Tune to the desired frequency and adjust the volume.

4. Rotate the loop for maximum reception.

5. Re-tune and identify the station.

6. Turn the CW-VOICE switch to CW.

7. Re-tune for solid tone and maximum readability.

The width of the null is controlled by the use of volume. An increase in volume narrows the null, and a decrease in volume widens the null. For all aural-null work, adjust the volume so that you get a null width of approximately 5°. At greater distances from the station, the null is wider than 5° even though you use maximum volume. Regardless of the width of the null, its center provides a reasonably accurate bearing to the station. In severe static you may increase the width of the null more than the recommended 5° to eliminate the static. In conditions of severe static, it may be impossible to obtain a definite null and you will have to use the position of minimum reception.

Ambiguity Time-Check

An aural-null results when the radio-compass needle is pointing either to or from the station. You must solve this 180° ambiguity to determine the bearing from the aircraft to the station. Here is how you solve the 180° ambiguity.

1. Maintain a constant heading.

2. Rotate the loop until you find a null.

3. Adjust the volume to obtain the desired null width.

4. Note the direction and number of degrees to be turned to place the null on the nearest wing-tip position.

5. With the L-R switch, rotate the azimuth needle to the nearest wing-tip position—that is until the needle points to 090° or 270°.

6. Turn the aircraft to the gyro heading you computed in step 4. If the null is not on the wing-tip, make one correction and start the timing.

7. If the null moves to the right the station is to the right; if it moves to the left, the station is to the left. When the null has moved 5° or 10°, compute the time to the station, using the formula explained before under time-and-distance calculation.

Make the ambiguity and time check simul-

taneously to save time. Once you have solved the ambiguity, maintain the orientation by monitoring the aural signal frequently.

Tracking

In tracking to the station, begin by changing the heading of the aircraft to put the null on 0°. As the station is approached, the width of the null increases, and you have to decrease the volume so as to maintain a null width of 5°. Aside from this you track to the station as described before.

Aural-null tracking procedures are similar to those used for ADF tracking. When the null has moved 2° to 5°, make a correction toward the desired track. If the null moves to the left, the aircraft is drifting to the right of course. Make a turn to the left to get back on track; when the null moves the same number of degrees from the nose or tail position as the angle of interception, the aircraft is on track.

During the tracking, follow the null at all times except when you make a change in heading. An example of this is when the aircraft drifts off course and you make a 20° correction to re-intercept the track. In this case the procedures are as follows:

1. Turn 20° to intercept the track; then relocate the null immediately.

2. Continue to follow the null until it is 20° from the 0° or 180° position.

3. Turn back to the original track heading plus or minus a correction for drift if necessary.

Approaching Station

On aural null, the best indication of approaching the station is the frequency with which you must turn the volume down to keep the null at a constant width. At high altitudes (20,000 and above), the null does not narrow rapidly nor widen immediately when the station is passed and you should monitor the null continuously when near the station. When you use a commercial station or an Adcock range station, the voice or range signals will become audible above the carrier wave as you approach the station. This is true regardless of altitude.

A good method to use in checking for station passage when atmospheric conditions or other interferences make station recognition difficult is to turn 30° to the right of the track heading. If the null moves closer to the 0° indication, the station has been passed; if the null moves further away from the 0° indication, the station is ahead.

Station Passage

There are four definite methods of recognizing station passage—three on the nose position (used for initial station passage) and the fourth on the wing-tip position. You can recognize station passage by any one of the following methods:

1. Constant narrowing and then a definite widening of the null indicates station passage. At high altitudes, however, the null does not narrow rapidly as the station is approached nor widen immediately when the station is passed. Between 20,000 and 40,000 feet it may take as long as 3 minutes after passing the station to notice a definite widening of the null. At altitudes below 20,000 feet, when you pass directly over the station, the null may disappear and reappear quickly. In this case look for an immediate widening of the null. In static or during a change in gyro heading, the disappearance of the null is not necessarily an indication of station passage unless the null indicates the aircraft is going away from the station.

2. A definite movement of the null away from the nose position indicator station passage when the aircraft passes to either side of the station with a constant magnetic heading. It is possible to follow the movement of the null completely around to the tail position.

3. An apparent shifting of the null from one side of the nose to the other when the aircraft passes very close to, but not directly over, the sta-

tion indicates station passage. In this case, the null stays slightly to one side of the nose position and then disappears. If the null reappears quickly on the opposite side although the aircraft hasn't changed the station has been passed.

4. Set the azimuth needle to the wing-tip position when you are approximately 2 minutes from the station; then adjust the volume to the normal level, and you can notice a definite null as you pass the station. As you approach the station, a constant increase in volume indicates proximity to the station, and if an aural signal or voice is being transmitted, either may become audible above the carrier wave.

During aural-null work, it is imperative that you maintain accurate headings. A drift in heading results in a like movement of the null. When you're not moving the radio compass needle to check the width of the null, keep it centered in the null so that any CW tone you hear is an indication of drifting off course or a narrowing of the null when the station is being approached.

Intercepting Bearings

The procedures used for intercepting a track or magnetic bearing on aural null are identical to those used on ADF. When you are intercepting an outbound track immediately after station passage, don't apply the correction until the null has stopped moving rapidly. Be careful in intercepting an outbound bearing close to the station to prevent overshooting.

Penetration and Final Approach

Penetration and final-approach procedures using aural-null are exactly the same as ADF procedures. Aural null letdowns are considered emergency procedures to be used when no other method is available and an approach must be made because of low fuel, and so on. The choice of procedures, as in ADF letdowns, is left to the pilot's discretion.

Frozen Loop

There may be times when you can't rotate the loop because of loop motor failure or extremely low temperatures. Even in this situation, you can determine the direction of the station by following definite procedures. Tune in the station and identify it on the ANT position. If you can't get a signal on ANT, put the function switch on LOOP. (The loop may be in the null position relative to the station when the receiver is tuned in. If you receive no signal on LOOP, turn the aircraft until you hear a signal.) After you have identified the station, turn the aircraft until you get a null. Note the heading, and maintain it until the signal again becomes audible. Then make a turn to relocate the null. When you start the turn, an increase in volume indicates that the turn should be made in the other direction. If you locate the null by turning to the right, the station is to the right.

The station is to the left a number of degrees equal to the difference between 0° on the azimuth dial and the number of degrees indicated by the end of the radio compass needle that is pointing to the left. If the station is to the right, the aircraft is turned to the right the number of degrees indicated by the end of the radio compass needle that is pointing to the right. When you have completed the turn, the aircraft is headed toward the station.

Use of Loop Position When Flying Range Signals

When a situation exists in which only the loop antenna is available for radio reception, you must determine the procedures necessary to reach your destination safely. If there is a radio range facility at the destination you can use regular aural-null procedures or normal radio range procedures with the loop as an auxiliary antenna. You must consider the type of range station (Adcock or loop) at the destination when selecting the procedure.

If the available facility is an Adcock or simul-

taneous loop station, either aural-null or normal radio range procedures may be used with accuracy. If it is a loop range station, aural-null procedures are not as accurate, because the loop range does not transmit a continuous carrier wave. This means that a true null is difficult to recognize because of the break in the transmission of the signals. When using a loop range, you will get the best results by using conventional range procedures after determining the approximate position of the aircraft.

When using the loop antenna for aural reception, use normal radio range procedures. To do this successfully, you must rotate the loop antenna so as to provide the best range reception at all times; also, since you get the null when the plane of the loop faces the station, you must maintain orientation, once it is established, or you may interpret such a null erroneously as station passage.

Emergency Use of Visual Null

Sometimes when the ADF won't work in extreme static and electrical disturbance areas, the LOOP position will also have so much static that you won't be able to hear the aural null. In this case, as an emergency measure only, slip the phones clear of your ears and rotate the volume to maximum with the antenna set at LOOP, and the VOICE/CW switch at CW. Rotate the loop by the L–R switch to locate a minimum reading on the audio tuning needle. This may give you a 15° to 20° null (narrowing nearer the station). Though accurate radio navigation is not possible by such means, it may get you home alive.

Radio Compass Procedures on VHF/UHF

Any radio equipment which gives a bearing to a station can be used for all the procedures just described. On VHF bands, the Tacan and VOR equipments indicate a relative or magnetic bearing (depending on the type of indicator) which is even more accurate and steady than that of the ARN-6 and ARN-7. The limitations of line of sight and of the equipment are the only new problems introduced. The UHF/DF (ARA-25) indicates magnetic bearings on the RMI indicator when installed in the aircraft. It is limited by line of sight range, and also by antenna lobe patterns.

Since the procedures for use of Tacan, VOR, or UHF/DF gear in homing, tracking, intercepting courses, time/distance determination, approach and penetration procedures, and geographic bearings (lines of position) are the same, the only problem is the use of the equipment. For that subject refer to Chapter 7, and, in the case of VOR, Chapter 19, immediately following.

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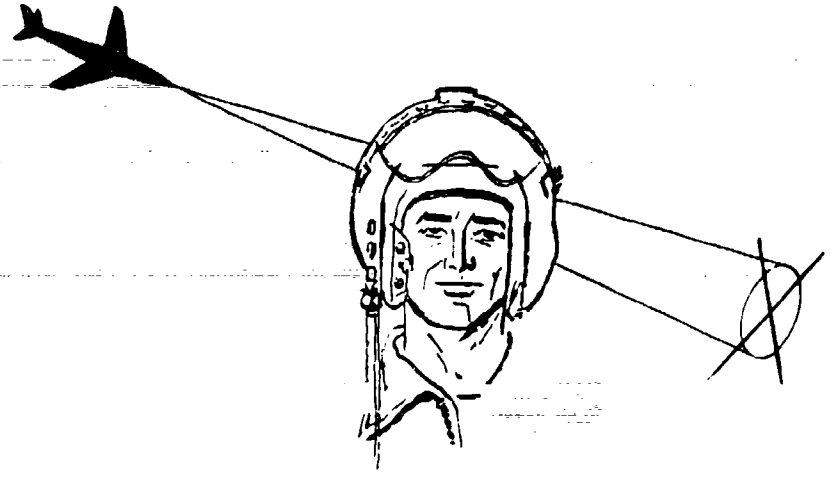


CHAPTER 19

OMNIRANGE (VOR)

THE VOR, or omnirange, is a VHF facility which offers you many advantages. It eliminates atmospheric static and multiple courses, and enables you to avail yourself of any of 360 courses *to* or *from* a range station. Because VOR is now a widely used radio navigational aid, it is important that you understand all aspects of its operation and use.

The omnirange is designed to operate within the 112-118 mc band and has a power output of approximately 200 watts. The equipment is VHF—thus, it is subject to line-of-sight restriction, and its range varies proportionally to the altitude of the receiving equipment. There is some "spill over," however, and reception at an altitude of 1000 feet is about 40 to 45 miles. This distance increases with altitude.

There is voice transmission on the omni frequency, and all information now broadcast over LF/MF ranges is also available over the omniranges. The same weather broadcasts are also available over most omniranges. A standard 3-letter coded identification is broadcast every 5 seconds and a voice identification every 15 seconds.

Although omnirange is called a range system, and although certain airways are set up to use an omnirange station, it's used in the aircraft much as is the radio compass. Like the radio compass, its azimuth indicator points in the direction of the relative bearing of a station; usually it indicates

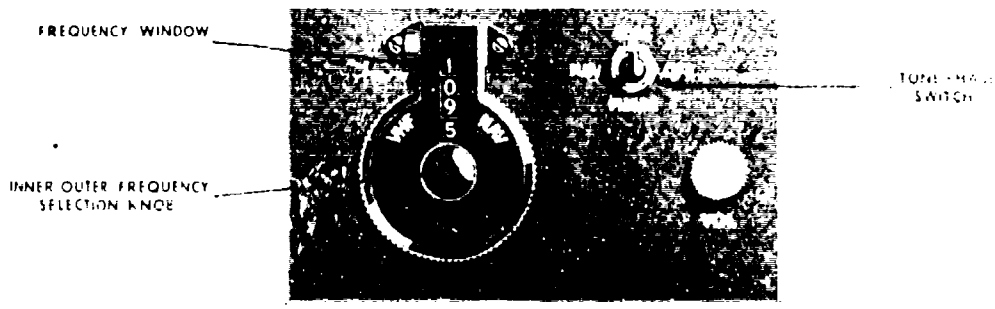
on the RMI, which mechanically adds magnetic heading to relative bearing so that the needle points to a number which is magnetic bearing. Like the radio compass it indicates an infinite number of possible directions. Like the radio compass, it allows you to select any course you desire, rather than limiting you to specific range legs. Unlike the radio compass, however, the ground station transmissions to an omni receiver differ, depending on the relative position of the receiver to the station. It can only be used with a certain type of transmitting station and receiver. Direction is not determined by a loop, but by detecting phase differences which were established by the transmitter.

PRINCIPLES OF OPERATION

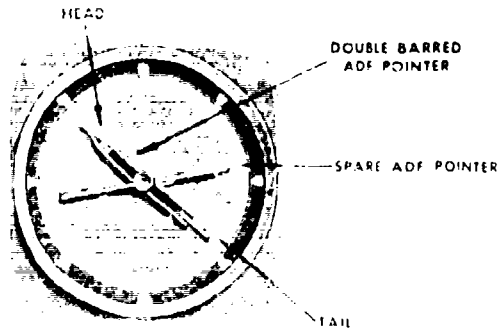
The omnirange produces a theoretically infinite number of courses, which radiate from the station like spokes from the hub of a wheel. These courses are known as *radials*. Directional information is thus generated at the station and transmitted to the aircraft. Airborne omnirange equipment intercepts these signals and converts them into a visual directional indication for use by the pilot.

The simplest way to visualize the omni principle is to imagine a device using two lights, both at the same geographical position. One flashing light is visible through 360°, but the second light is a narrow beam and is rotated at a specific rate. If the "all around" light is flashed on each time the narrow beam passes through north, a means is established for an observer to determine his bearing from the light. Assume, for example, that the narrow beam rotates at a rate of one revolution per minute. If the observer sees the all around light, and then observes the rotating light 15 seconds later, he must be on a bearing of 90° from the lights. If he sees the flash of the all around light and observes the rotating beam 30 seconds

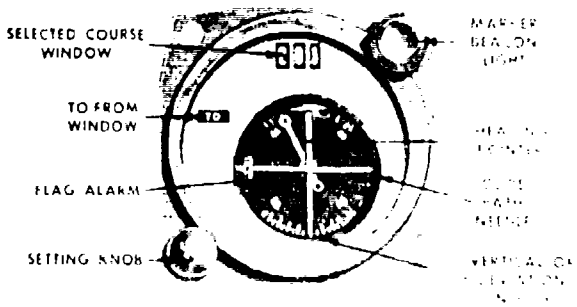
Figure 19-1. AN/ARN-14 instruments and controls



CONTROL BOX



RMI RADIO MAGNETIC INDICATOR



ID249 COURSE INDICATOR

later, he must be on a bearing of 180° from the lights.

The omnirange uses the same principle but with some refinements. Instead of rotating a beam of light mechanically, it rotates a signal electrically at 1,800 revolutions per minute while the "all around" signal is phased with the rotating signal through 360°. At magnetic north, the second signal is in phase with the base signal; in all other directions the two signals are out of phase. In the example using lights, the observer timed the interval between sighting the two lights and determined his bearing from the station. The omni receiver measures the difference in phase between the signals electronically and uses the information to indicate bearing.

TRANSMITTING EQUIPMENT

The omnirange installation is much smaller than the conventional range installation. The antenna is mounted on a tower located directly over the transmitter building, and there is a monitor located very close to the antenna. This automatic monitor system is activated when the signal is interrupted or when the phasing is changed. This monitor automatically turns off the transmitter, turns on the standby transmitter, and sounds an alarm in the control room.

For aircraft flying below 20,000 feet, there is little if any interference between stations spaced as close as 400 miles apart that use the same frequency. For aircraft flying 30,000 feet and above, there will be areas of confusion between such stations. These areas of confusion are equidistant between the stations and are indicated by an aural whistle and an oscillation of the visual indicators.

RECEIVING EQUIPMENT

Omnirange transmissions can be received and utilized in the aircraft by either of two receivers—the AN/ARN-30 and the AN/ARN-14. Both these sets were discussed in detail in Chapter 7. The AN/ARN-30 is the less complete of the two sets, but it is used in training aircraft and some older aircraft.

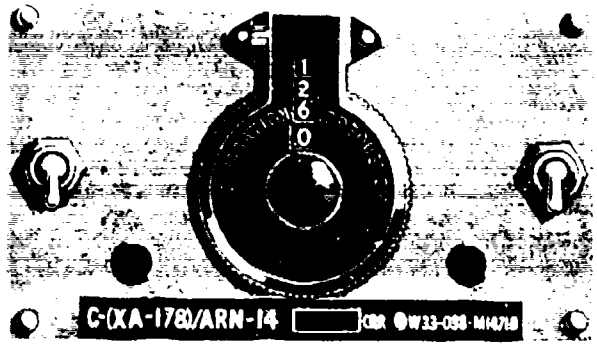


Figure 19-2. AN/ARN-14 control panel, alternate version

AN/ARN-14

With the AN/ARN-14 VOR receiving set, a control box and two instruments (the course indicator, ID-249, and the radio magnetic indicator) are available to you for flying VOR (Fig. 19-1). The control box contains a TONE-PHASE switch, two frequency selector knobs, a frequency window, and a volume control. The frequency knob allows you to select any one of 280 channels. The outer frequency knob selects the frequency from 108 to 136 megacycles, and the inner knob selects the frequency in tenths of megacycles. The TONE-PHASE switch serves as an ON-OFF switch and allows reception of phase-type ILS facilities or tone-type ILS and VAR facilities, as well as VOR. The newest control panel has an ON-OFF switch, and the frequency selected controls the type facility (Fig. 19-2).

The course-indicator consists of a bearing selector knob, a bearing window, a TO-FROM window, a bearing deviation needle (also called vertical needle, localizer needle, or vertical cross-pointer needle, a glide path needle (horizontal needle), and a compass-actuated heading pointer. The heading you select with the bearing selector knob is displayed in the bearing window. The TO-FROM indicator indicates whether the bearing selected will take the aircraft TO or FROM the station. (Remember, the TO-FROM indicator does *not* indicate whether *you* are going to or from the station. It registers whether the *bearing* you have selected in your course window is the bearing of the aircraft to the station, or the station to the aircraft. In

other words, you can have a TO indication and yet be going away from the station and vice versa.)

The deviation indicator, or localizer needle, shows the position of the aircraft in relation to the desired bearing. The glide path needle is used when flying an Instrument Landing System. The heading pointer and scale show the heading of the aircraft relative to the selected bearing. When the heading pointer is centered, the heading of the aircraft is the same as the bearing shown in the bearing window. If the pointer is deflected to the left or right, the aircraft heading is also to the left or right the number of degrees indicated on the pointer scale.

AN/ARN-30

The AN/ARN-30 airborne receiver performs the same omni-range functions as the AN/ARN-14 receiver and has the same frequency range (108-136 mc), but its controls and instruments are different.

The frequency selector of the ARN-30 is of the "coffee-grinder" type; the course selector and deviation indicator are separate instruments in the ARN-30 instead of being combined on one dial as in the course indicator of the ARN-14; and the ARN-30 has no heading pointer or bearing window. In omni-range operation, however, both are used in the same way.

Radio Magnetic Indicator

The radio magnetic indicator (RMI) can be used with either the AN/ARN-30 or AN/ARN-14 receiver. It combines on one dial the presentations of three instruments: A remote-indicating compass controlled heading indicator (usually the MA-1 compass described in Chapter 4), a direction-finder on the double-barred needle, and another direction-finder on the single needle. (You must find out which needle has the VOR—in some larger aircraft, both needles may be separate VOR's.)

You read the heading under the index point at the top of the dial. The azimuth dial rotates as heading is changed, but the index point is fixed. Certain other relative bearing points, such as 45° or 90° right and left of heading, are also shown by such fixed index points. The two needles point in the direction which is the relative bearing of the station to which you are tuned, but the numerical value under the needle tips depends on the heading. Hence both needles indicate magnetic bearing from aircraft to station at the head of the needle. The tail of each needle is the reciprocal—that is, the magnetic bearing from station to aircraft (Fig. 19-3).

The primary uses of the RMI are:

1. To indicate the heading for all flight purposes.

2. To provide magnetic bearings for visualizing position or geographic plotting. To plot VOR bearings very fast, read the magnetic bearing from the station (radial) under the tail of the proper RMI needle and draw a line from the VOR station through that radial on the chart compass rose.

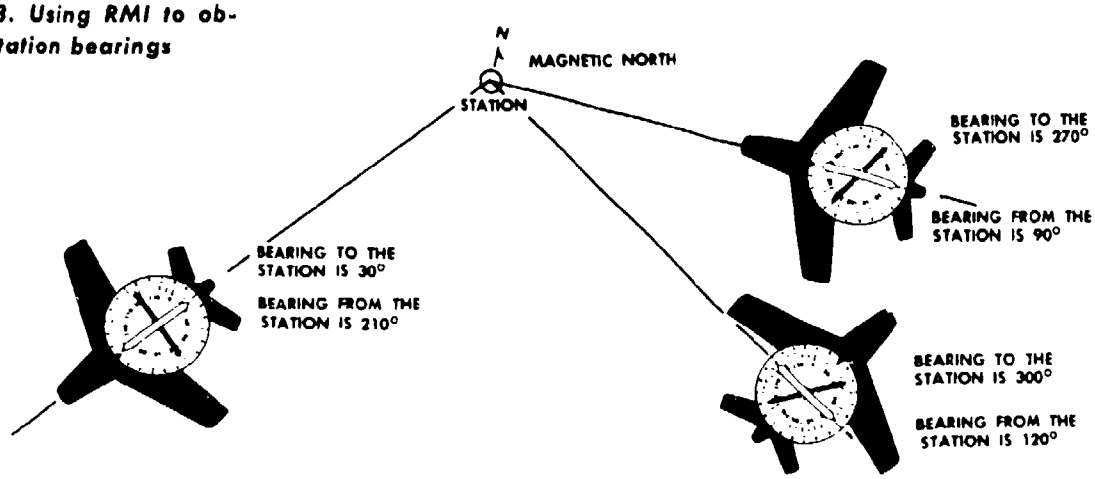


Figure 19-3. Using RMI to obtain station bearings

3. To determine the direction and amount to turn to intercept a desired course.

If the ARN-14 course indicator (or the ARN-30 course selector and deviation indicator) is inoperative, you can use the VOR needle of the RMI for tracking, intercepting, and so on, as described in Chapter 18 for the LF/ADF. (See Fig. 19-4.) In fact, you may sometimes hear the VOR needle on the RMI called VOR/ADF.

You can use the RMI to home directly to the station, or to fly a particular course by observing the magnetic bearing to the station. By turning the aircraft to this magnetic heading and making necessary crabbing correction, you can fly a definite track to the station. Crab corrections will be taken care of automatically if you utilize the deviation indicator along with the RMI.

However, you can do a much more precise job of flying a selector course by using the deviation indicator, since a small error in the position of the aircraft with respect to the selected track shows up as a large movement of the deviation indicator needle. When using the RMI to fly a track, a displacement of the aircraft from track by a few degrees shows up as a very small movement of the RMI needle over its synchronized magnetic scale.

FLIGHT PROCEDURE

After tuning in the desired VOR station, read the magnetic bearing to the station under the head of the VOR pointer on the RMI. The magnetic bearing from the station is shown under the tail of this pointer. If you desire to proceed directly to the station, make a turn toward the VOR pointer. As the aircraft turns, both the compass card and the pointer will rotate toward the heading arrow at the top of the instrument. If the RMI is inoperative, you can obtain the closest bearing TO or FROM the station by rotating the bearing selector knob until the deviation needle (localizer needle) centers. When the needle centers, if the indication in the TO-FROM window is not the one desired, rotate the bearing selector 180°.

After turning the aircraft toward the station, rotate the bearing selector knob until the desired bearing appears in the bearing window (if you have the ARN-14) or under the course selector pointer (if you have the ARN-30). The pro-

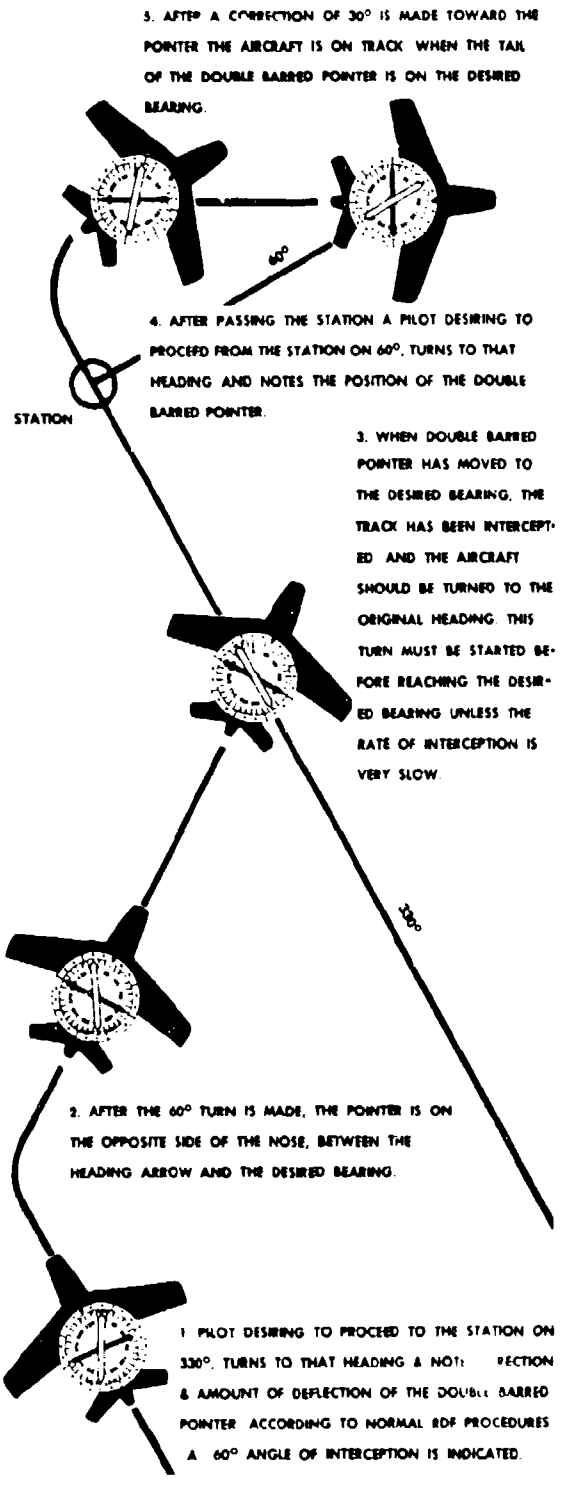


Figure 19-4. Using RMI for ADF interception and tracking procedures

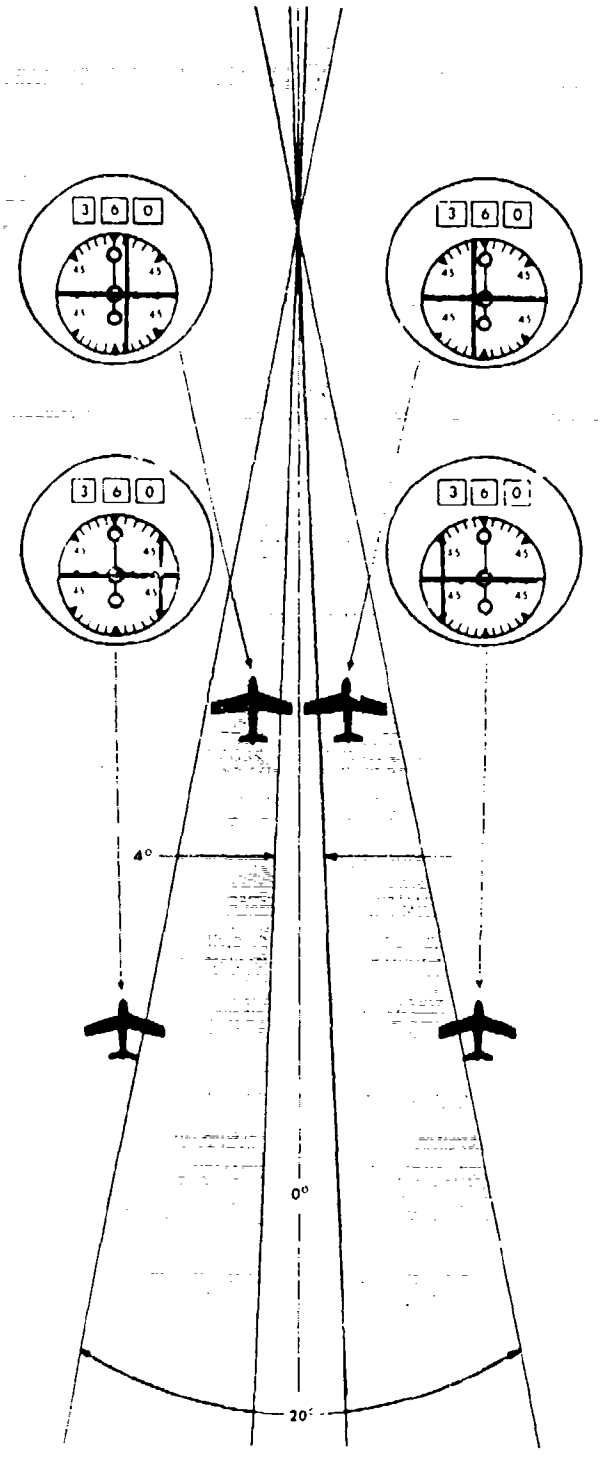


Figure 19-5. Relation of course width to deviation needle indications

cedure for tracking is then identical with that you use for inbound tracking on the ILS. If you have an ARN-14, the heading pointer shows the relation of the aircraft's heading to the desired bearing.

Tracking Inbound

The course shown in the selected course window (on the ARN-14) or under the course selector pointer (on the ARN-30) is the course selected for tracking inbound when the TO-FROM indicator shows TO. The deviation (localizer) needle will show whether you are on this course. If you are off course to the left, the vertical deviation needle will be to the right of center, indicating a right turn is needed to resume course. Turn toward the vertical needle to regain course at any time. Full deflection of the vertical needle occurs when you are 10° or more off course. (See Fig. 19-5.)

On the ARN-14, the heading pointer shows whether you are on the same heading as the desired course. If that needle is to the left also, your heading is as many degrees left of the desired inbound bearing as it shows. You can be on course with the vertical needle centered, and yet not be on the right heading. You can be on the correct heading with the heading pointer centered, but not be on course. If both are centered, you are on both heading and course. If no cross-wind exists, you will remain that way right in to the station.

Later on we shall consider the problem of interception of a desired bearing over 10° from the present bearing. At this time, assume that your aircraft is approximately on the desired course. If the vertical needle is not centered, turn it so that the bullseye of the heading pointer lies under the vertical needle. Fly this heading. As you approach the desired course, the vertical needle moves toward center and you must alter heading to keep the heading pointer bullseye and vertical needle together. This means you fly a curved track into the desired course.

As soon as both indicators are centered, fly the heading of the desired course (that is, keep the heading pointer centered) and watch for the vertical needle to drift off center as wind blows you off course (Fig. 19-6). If you drift to the left,

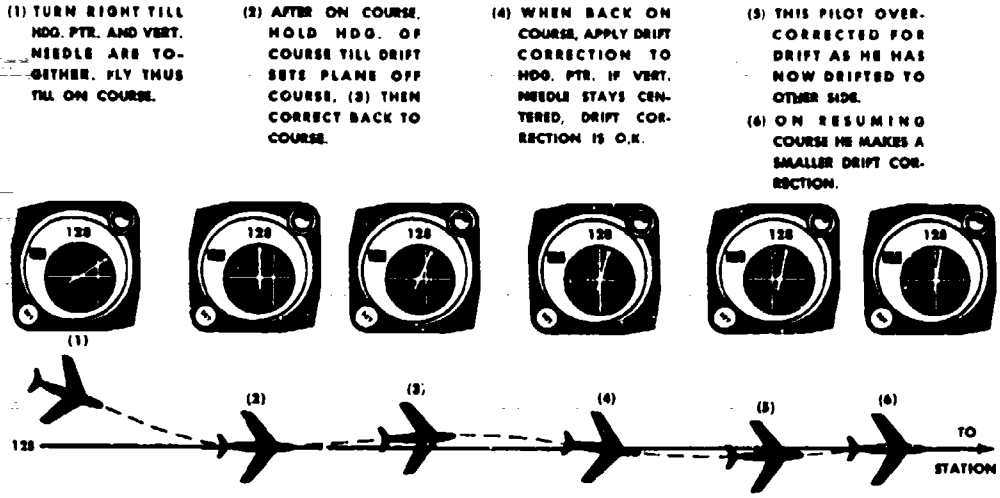


Figure 19–6. Tracking with the ARN–14

the vertical needle drifts to the right of center indicating the need for a heading correction to the right. If that should occur, turn right to put the bullseye under the vertical needle again and fly until they center again, but this time, after regaining course, make an allowance for drift in ADF tracking. The speed with which the vertical needle drifted off center and the nearness to station will suggest how much drift correction to apply. To correct for drift, adjust heading so the heading indicator is the desired number of degrees off center in the same direction to which the vertical needle previously had drifted. In the example here, left drift of the aircraft caused the vertical needle to go to the right; therefore, select a suitable drift correction and set the heading so the pointer is that many degrees to the right of center.

If the drift correction is made correctly and heading is held, the vertical needle will remain centered, indicating that the aircraft is on course. If it drifts off again, correct back to course, and modify the drift correction by placing the heading pointer a small amount toward the direction of the vertical needle drift movement.

Over the station, there is a cone of confusion similar to the cone of silence over the radio range station. This cone of confusion at high altitudes may be wide enough to require 2 minutes for an aircraft to pass through it. When the aircraft passes over the station the TO-FROM indicator changes to FROM, the RMI needle moves to the tail position, and the deviation needle fluctuates from side to side momentarily. These indications may change several times before stabilizing. When the TO-FROM indicator changes, the sensing of the receiver is automatically changed, so you should still make corrections toward the deviation needle to regain the desired bearing.

If you desire to track away from the station on the same bearing, no change in instrument setting or procedure is necessary. When you desire a different bearing away from the station, make a turn to that bearing immediately, and set the bearing in the bearing indicator.

Interpretation of the TO-FROM Indicator

The indication in the TO-FROM window refers only to the course in the course selector window (on the ARN–14) or under the pointer of the course selector (on the ARN-30). It tells you whether that course would take you toward or away from the station. It does not tell you whether you are flying toward or away from the station unless you are flying that course.

For example, suppose you approach a station on inbound course 170 and the window reads TO. You pass the station on a constant heading, and the window now reads FROM. If you execute a procedure turnback toward the station and fly

along a magnetic heading of 350°, the window will still read FROM. The reason is that the course selected is 170 and if you flew 170° you would be going *from* the station. Earlier, as you approached, 170° was then the selected bearing and it was TO the station.

Obviously, it is confusing to fly toward a station with the indicator reading FROM. The sensing of the deviation indicator (localizer needle) would be reversed from normal and the heading pointer of the course indicator would be at the bottom instead of the top. You would have to make corrections for getting off course by turning away from the vertical needle (because its sensing is reversed and it still shows deviation from the course of 170°, the reciprocal of the new heading).

To avoid this, whenever you make a major course change, particularly a reversal, rotate the course selector to the new course. Therefore, before you reverse course in a procedure turn, rotate the course selector 180°. To find the number of the reciprocal course to be set up, read the head of the VOR needle on the RMI when you are on course before beginning the reversal turn. (This assumes you are outbound and going to reverse to go inbound. If inbound, the tail of the VOR needle is the reciprocal course.)

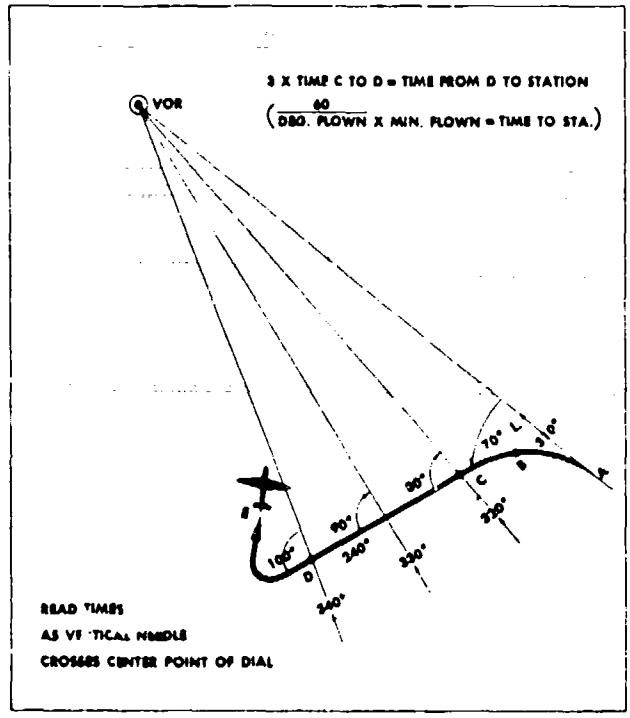


Figure 19–7. Time/distance check by vertical needle passage

SAMPLE ORIENTATION AND LETDOWN PROBLEM

The following orientation and letdown procedure does not represent any standard doctrine but is merely a representative example of the use of VOR in routine approach procedures. No clearance or control problems are considered. Fig. 19–7 shows the positions of an aircraft performing an orientation, time/distance check, homing to the station, and letdown.

1. At position A, he determines the bearing to be 310° magnetic to the station. The aircraft heading is approximately 350°.

2. At position B, the aircraft is turning to commence a time/distance check. The pilot plans to turn to a heading 70° off the original inbound bearing and fly a heading of 240° (310 − 70 = 240). After leveling off and adjusting the course selector, he will reach a point where the station is 80° right of that heading, and he will time from there until the station is 100° right. Thus he will have a 20° change of bearing and can figure his time from the station by the formula:

$$\frac{60}{\text{Degrees flown}} \times \text{Time} = \text{Time to Station}$$

In this case, he flies 20°, and his time to the station is three times the time it takes to fly the 20°. Instead of reading the 80° and 100° bearings from the RMI azimuth needle, he notes time between crossings of radials as shown by vertical needle centering. This provides greater accuracy. His magnetic heading at B is 270° because he is turning to fly a heading of 240°. The bearing he has selected on the course selector is 320° magnetic, and the deviation indicator shows that the selected course is to the left.

3. At position C, the aircraft is on a bearing of 320° and starts the time/distance check. The pilot now selects the bearing of 340° on the course selector to measure the time to fly through 20° of bearing change. The deviation needle swings to

the left when the course selector is changed to 340° magnetic. The aircraft heading is 240°, which is a perpendicular to 330°.

4. At position D, the pilot stops timing and starts his turn inbound to the station. The deviation needle is centered, indicating that the aircraft has flown through a 20° bearing change and the time/distance check is completed. He figures out his time to the station.

5. At position E, the course selector remains at 340°; however, the deviation needle indicates that the course is to the right. This is normal, since the aircraft has flown through the 340° bearing and is making a standard-rate turn to roll out on a bearing of 345° to the station. The pilot chooses 345° so he won't drive right up to the Omni bearing and possibly overshoot it.

6. At position F, the aircraft is commencing an omni approach to the field. The letdown leg bearing is 350° magnetic; therefore, the course selector was changed to 350°. The aircraft has passed the station, which is indicated by the ambiguity bar resting in the FROM position. The heading of the aircraft is 350°. (If the pilot were 10° off bearing and had to make a drift correction, he would turn 30°; if that did not show progress, he would increase it to 45° and, if that didn't help enough, he would increase it to 60°. On the other hand, if the drift were 3° to 4°, a turn of 15° would be enough.)

7. At position G, the aircraft is in the procedure turn. The TO-FROM indicator reads *from* the station and the deviation needle shows that the selected course, 350° magnetic, is to the right. In order to receive correct sensing from the deviation needle, the pilot now rotates the course selector 180° to select the magnetic bearing 170° *to* the station. The deviation needle indicates that the course is to the left. The aircraft heading is 125°.

8. At position I, the aircraft is on the bearing (radial) 170° magnetic *to* the station and is heading 170° inbound.

OTHER VOR PROCEDURES

When you desire to fly *to* or *from* the station on some bearing other than the closest bearing, set the bearing indicator on the desired bearing. After turning the aircraft to this heading, make a correction toward the deviation needle. If the deviation needle indicates a full scale deflection, use the VOR pointer of the RMI to compute the required angle of interception. You can fly and intercept this bearing by using the RMI with normal ADF procedures. To avoid confusion, you must follow the usual procedure of turning to the desired bearing, noting the direction of deviation of the pointer, and correcting toward the pointer. The aircraft will be on track when the pointer moves to the desired bearing. Accomplish tracking away from the station, holding and letdowns as previously described in Chapter 18. You can accomplish interception and tracking much easier with the course indicator. Therefore, you should normally use the RMI only to obtain the position of the aircraft, and to check the indications of the deviation needle and the TO-FROM indicator.

You may make procedure turns in any accepted manner, but the 40-second type will be the easiest to accomplish. Make the 45° turn from the bearing with the heading pointer to eliminate computation and the necessity for cross-checking

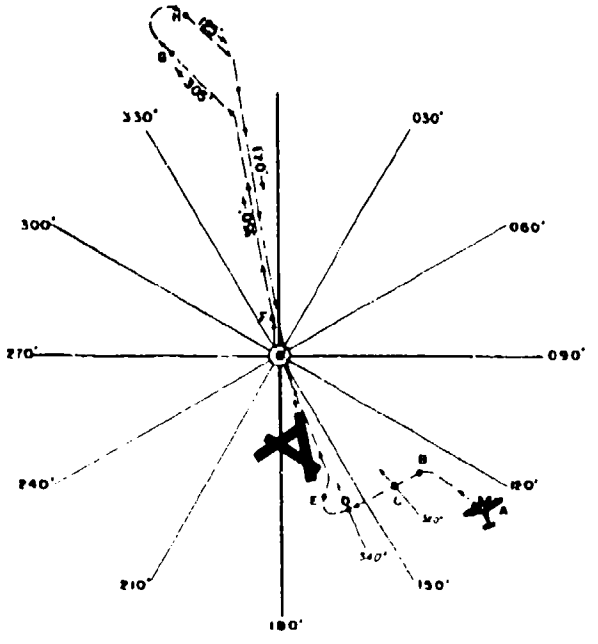


Figure 19-8. VOR orientation and letdown problem

the gyrosyn compass. During the procedure turn, rotate the heading selector 180°. You can best do this while completing the time on the 45° leg of the procedure turn.

Use the standard elliptical holding pattern when holding on a VOR. Hold on a bearing *to* the station, as instructed by ARTC or approach control, using a fan marker, or some other radio aid to enable you to maintain the required position. Changing the bearing indicator to the reciprocal bearing will not be necessary on the outbound leg of the elliptical holding pattern (Fig. 19-9).

PRECAUTIONS

The omnirange equipment is not operating properly if you observe any one or several of the following indications when tuned to a VOR station.

1. The alarm flag of the deviation needle does not disappear.
2. The TO-FROM window remains blank.
3. The double-barred pointer of the RMI circles aimlessly.

Marginal operation is indicated by fluctuation of the deviation needle alarm flag. If this is due to weak signal strength, it should improve as flight is continued toward the station.

VOR SYSTEM ACCURACY

The effectiveness of the omnirange (VOR) depends on the proper use and adjustment of both the ground and airborne equipment. You may observe certain minor irregularities in using VOR facilities, such as apparent course roughness, course deflections, and limited distance range. When you fly over unfamiliar routes, be on the alert for these apparent vagaries. Normally, however, the course selector and deviation indicator are accurate to plus or minus one-half degree.

VOR Irregularities

Course Pushing. Course pushing may be defined as an error in the deviation indicator which might be encountered at a moderate to considerable distance from a VOR station, usually about 100 miles or more. It is the result of interference between VOR courses. It is not encountered in level flight, *but only when the aircraft is in a banked attitude.* Changes in the attitude may produce the error in indication and result in your over-cor-

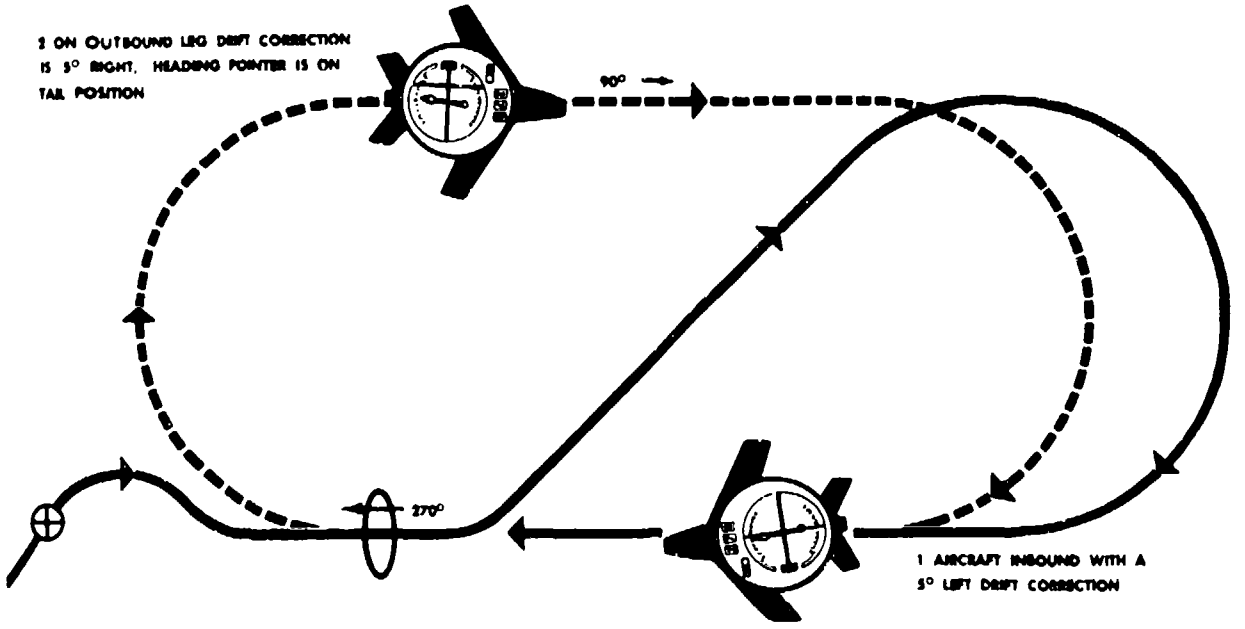


Figure 19-9. Procedure turns and holding on a VOR

recting or under-correcting your flight path while attempting to attain the desired track.

As an example of an abnormal situation where course pushing will make the deviation needle deflect either too much or not enough, suppose, a pilot flying a course of 270° to the station reaches a point 100 miles out and sees that the deviation indicator shows that he has drifted 5° off course to the right. This puts him on track 265°, so he figures that if he makes a left turn and flies until he returns to course 270° he will be back on course. Immediately after putting the aircraft in a banked attitude, he notices that the deviation needle has moved farther to the left, so he maneuvers to make a larger correction back to the course. On leveling off, instead of centering, the deviation indicator tells him to fly right. This shows that he has gone too far to the left; in other words, he has overcorrected on account of course pushing.

As another example, take the same pilot flying course 270° and finding himself on course 265° with a fly-left indication. He banks the aircraft to the left, expecting to fly back to 270°, but the deviation needle centers immediately after the aircraft is banked. Expecting to be on course 270°, he levels off, only to find that the deviation needle once again shows fly-left. Course pushing has caused this irregularity.

As a third example, take the same pilot and the same course, and put the aircraft in the same situation where the deviation needle came back to the center too soon. Under conditions of course pushing, the needle can not only swing from the left to center too soon, but it can go right on through center, and over to the right, showing reverse sensing. Still another error caused by course pushing may occur when you shift frequently from one VOR to another; you might find yourself 5°-10° off.

Course pushing can be quickly summed up as follows:

1. The needle might return to center much more slowly than the angular correction being made.

2. The needle might return to center much more rapidly than the angular correction being made—even to the extent of reverse sensing.

To avoid being tricked by course pushing, check your calculations *before changing the attitude of the aircraft*, watch for evidence of course pushing while in the changed attitude, then fly to the desired course according to your calculations or according to your deviation indicator, whichever is the better in your opinion.

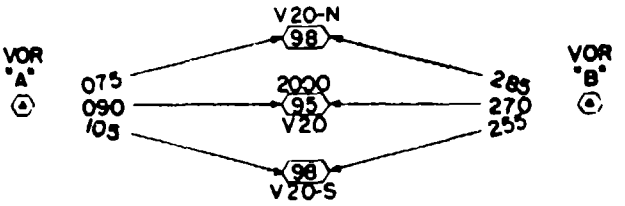


Figure 19–10. Main and alternate VOR airways

Broad Courses. If the deviation indicator does not deflect full scale unless the course selector is changed by appreciably more than 10°, the fault is due to broad courses. In proper operation, there should be a full scale deflection of the deviation indicator when the course differs by 10° from the one selected on the course selector. For example, if the course selector reads 300°, the deviation indicator should show full scale deflection when the actual heading is down to 290° or up to 310°.

VOR AIRWAYS SYSTEM

The VOR airways system is composed of *main airways* and *alternate airways* ten statute miles in width (Fig. 19–10).

Main Airways

Main airways are the normal routes followed by air traffic and are normally routed in a straight line between omnirange stations. They are designated as Victor airways and are numbered like the U. S. highways. Airways which run generally north and south had *odd* numbers; and those which run generally east and west have *even* numbers. As in the highway numbering system, segments of an airway which are common to more than one airway, carry the numbers of all the airways on it. For example, V-53 and V-7 coincide between Chicago Heights and LaFayette. In such a case, you indicate only one airway number on your flight plan.

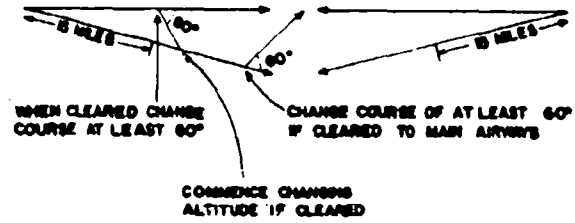


Figure 19-11. Changing altitude on course

Alternate Airways

Alternate airways are occasionally used for lateral separation when traffic conditions require it. The alternate airways are located not far from the associated main airway but are at least 15° on either side, or both sides, of the main airway. The alternate airway number includes the main airway number, plus an indication of the geographic position in which it lies with respect to the main airway. V-20-S is the alternate airway south of Victor 20. Your clearance will include Omnirange stations which form any particular alternate airway so that you will have no doubt when using an alternate airway.

Changing Altitudes

Main airways are normally used to change the altitude of aircraft en route; however, alternate airways may be used for this purpose. Altitude changes cannot be made within 15 miles of any Omnirange station.

Changing Airways

You are not permitted to change airways between Omnirange stations within 15 miles of an Omnirange station unless you started to change over the VOR station (Figure 19-11). Departure from the main airway has to be made at an angle of not less than 60° to the main airway. You have to remain on the alternate airway unless you are cleared to return to the main airway. (This may occur if you used the alternate airway to change altitude.) If you are cleared to return to the main airway (after changing altitude), depart from the alternate airway at an angle of not less than 60° from the alternate airway. Continue to the next station on the main airway.

Holding Procedure

VOR equipped aircraft can be held on any definite fix, which may include the Omnirange station, fan markers, homers, course intersections, or any combination of these.

The standard VOR holding flight path is to follow the en route course inbound to the holding fix, make a 180° standard rate turn to the right, fly a parallel straight course outbound for two minutes, make another standard rate turn to the right, and return to the station via the inbound course. (See Figure 19-12.)

VOR Clearance Phraseology

The following clearances show the phraseology used on VOR airways. All terms used have been described before and the clearances are self-explanatory:

"San Antonio ATC clears Navy 1234 to Tinker Air Force Base via direct Corpus Christi, direct San Antonio, direct to Austin, Victor 17 to Oklahoma City, direct to Tinker AFB, maintain 6,000 feet in the control area."

"Oklahoma City ATC clears Navy 1234 to descend to 4,000 feet after passing a point 15 miles to Northeast of Austin."

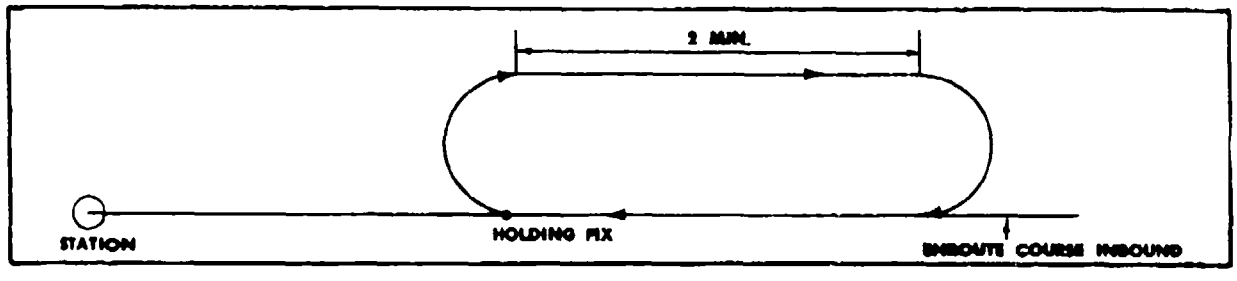


Figure 19-12. VOR holding procedure

"Navy 1234 hold on Podunk VOR radial 215 until advised by Boomtown Approach Control on 234 kilocycles."

VOR INSTRUMENT LETDOWNS

When flying a VOR equipped aircraft, you should carry the VOR Edition of Radio Facility Charts for airways work, and the appropriate booklet of instrument approach procedure charts, for instrument letdowns. In general, approved VOR letdowns are similar to that given in the Sample Orientation and Letdown Problem above.

DME (DISTANCE MEASURING EQUIPMENT)

Certain naval aircraft, particularly instrument trainers and transport aircraft, have DME equipment. Newer aircraft, however, are being equipped for Tacan instead of DME. As discussed in Chapter 7, the DME indicator may be either a pointer which indicates the range on a radial dial, or the ID-310 (Fig. 19-13) which shows the slant range in nautical miles by means of three numerals.

Slant range is the direct line-of-sight distance from aircraft to station. It differs from ground distance, but to such a small extent that it may be ignored until the altitude in miles is about one-half the indicated slant range (for example, at 12,000 feet, within 4 miles slant range). As the aircraft flies over the DME station, the indicator may go into search (that is a warning flag will drop over the ID-310 or the needle will swing around on the dial); if the indicator does not go into search, it will show altitude in miles. As you fly close to the DME station, it is enough to remember that the indicated distance is in excess of ground distance by not more than the altitude. During low approach and at a distance, the factor is negligible.

DME stations are located at certain VOR stations, over 200 such installations. They are indicated in Radio Facility Charts by the letter E after the VOR in the Class/Power column of the tables.

TACAN FLIGHT PROCEDURES

As mentioned before, the Navy is using Tacan instead of DME. So far as you are concerned, there is no important difference between navigation by VOR/DME and Tacan—you can do everything with Tacan that you could with VOR/DME, plus having the capability at most Tacan-equipped stations of using Tacan for an approach aid to minimums of 300 feet/1 mile.

As described in Chapter 7, the instrumentation for Tacan is the same as used for VOR. The pilot who has learned to fly by omnirange has only two new things to learn to use Tacan:

1. Learn to operate the Tacan control panel, ARN-21.

2. Learn the limitations and irregularities of Tacan.

The procedures for instrument interpretation, tracking, intercepting bearings, and so on, are all the same as with VOR. Time/distance checks, however, are unnecessary so long as the distance measuring feature of the Tacan is operative.

Figure 19-13. ID-310 slant-range indicator for DME and TACAN

CHAPTER 20

GROUND CONTROLLED APPROACH (GCA)

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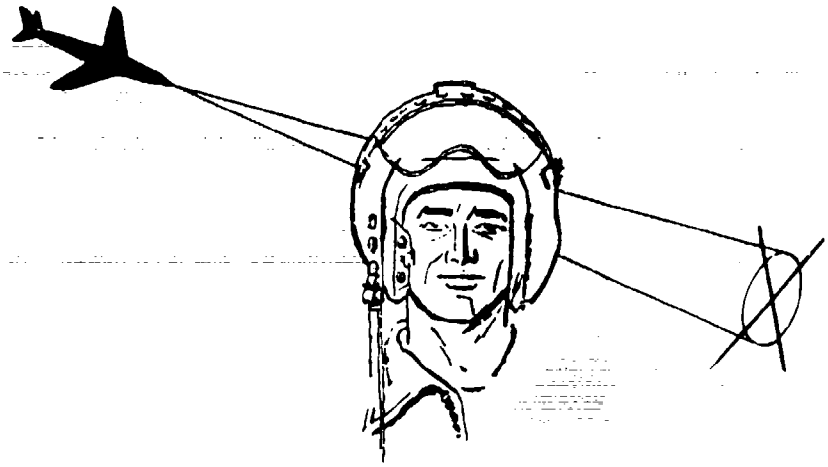


CHAPTER 20

GROUND CONTROLLED APPROACH (GCA)

THE purpose of GCA (Ground Controlled Approach) is to guide the pilot down to the runway in weather while leaving him free to concentrate on the flight instruments. The accuracy and safety of GCA has been amply demonstrated by the hundreds of thousands of GCA landings which have been made without accident.

The basic principle of GCA is that a ground radar facility locates and follows the aircraft through the low approach to a field, and members of the GCA crew talk the pilot down to the runway. No special equipment is required in the aircraft, and any radio-equipped aircraft can fly a GCA approach. In fact many successful GCA landings have been made by pilots with no training or experience in GCA procedures. It is advisable, however, to know how GCA does its job and to fly practice GCA approaches before trying to use GCA to guide an approach under actual IFR conditions.

During IFR weather, GCA is always ready to assist, but at other times, the service must be requested in advance. It is preferred that a request for GCA at destination be appended to a flight plan when a practice approach is planned. Otherwise make the request to ARTC or Approach Control at least 30 minutes ahead of ETA. Even in IFR weather, make the request in advance if possible.

The GCA crew is specially trained and has

no other duties. At Navy GCA units, there is always an officer pilot on duty with the GCA crew during IFR conditions.

GCA EQUIPMENT

There are several models of GCA equipment, the most common being the MPN-1 and the CPN-4. The MPN-1 is more or less obsolete now, but many units are still in use. The CPN-4 is the standard type.

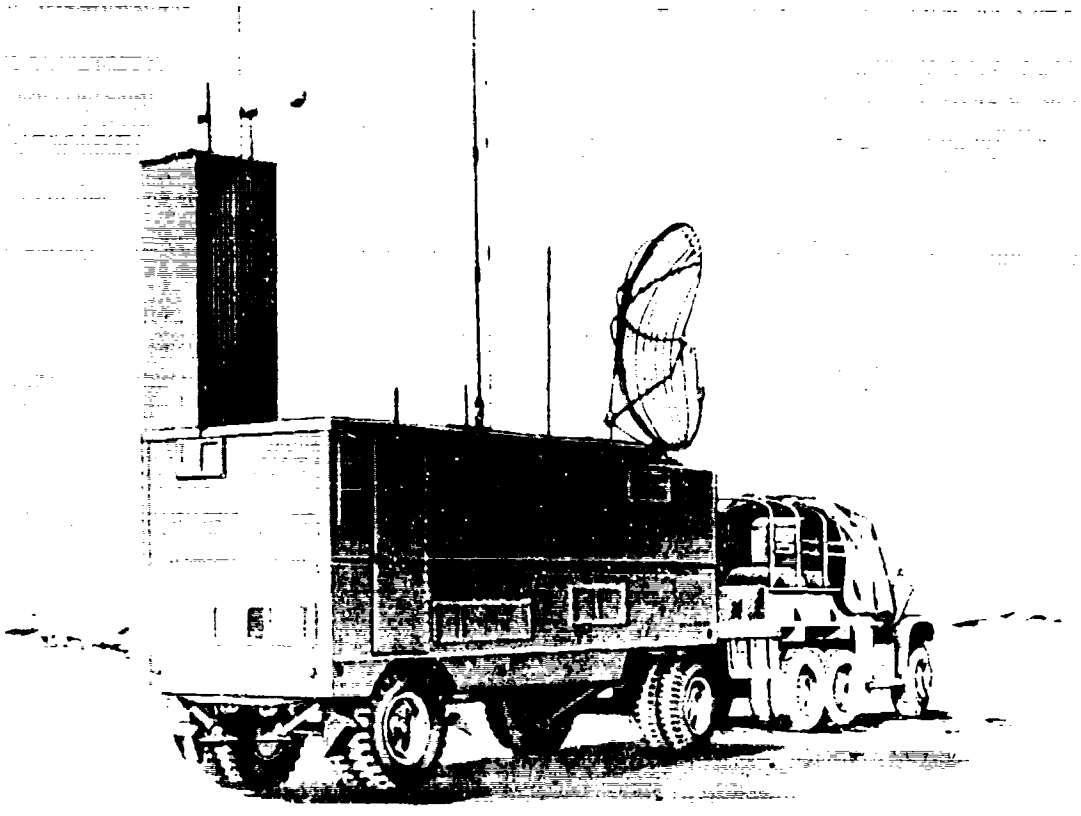
The MPN-1 (Fig. 20-1) can handle only one aircraft at a time, with intervals between approaches of about 3 or 4 minutes. Its maximum search range is about 30 miles. The CPN-4 (Fig. 20-2) can handle three aircraft at a time, with approach intervals of as little as one minute. Its search range is about 50 miles maximum (in any location at least 36 miles). Both units incorporate three systems—a search system, a precision system, and a communications system. Only the CPN-4 is discussed here, for the MPN-1 is basically similar but not as advanced.

In the CPN-4, the *search system* does the initial locating of aircraft flying within a 36 to 50-mile radius; the *precision system* tracks the aircraft down the glide path during the final landing field approach, and the *coordinating communications system* provides the means for the necessary two-way, air-to-ground communication. The entire equipment, with the exception of the direction finding equipment and associated antennas, is mounted in two mobile trailers.

Search System

As just mentioned, the function of the search system is to locate aircraft flying within the radius of the equipment. The area within this radius must be continually scanned by the rotating search antenna, so that approaching aircraft can be initially located, identified, and then directed to a position for the final landing-field approach. The

Figure 20-1. AN/MPN-1 equipment



system can provide a good presentation on the search indicators for small aircraft flying at altitudes up to 8,000 feet, within an elevation angle of 0.5° to 45°, and within a radius of 360°. Larger aircraft can usually be detected by the CPN-4 search radar at altitudes in excess of 8,000 feet. In that connection, it might be noted that jet aircraft in a dirty condition (flaps, gear and dive brakes down) make better radar targets and are more easily detected.

There are two indicators (PPI scopes), one for the traffic director, and one for the plane selector. They are identical and are used in directing the aircraft to within 10 miles of the runway. Equidistant circles on the scopes serve as range markers to show the operator how far the aircraft is from the landing field (Fig. 20-3).

During landing operations, the traffic director follows the flight of aircraft on his scope and directs them into a traffic pattern. If there is more than one aircraft, he turns each over, one at a time, to the aircraft selector who watches the flight of the aircraft on the other PPI scope and gives the pilot headings and altitudes so that he can fly his aircraft toward the glide path and maneuver it into the approach position. When the aircraft reaches a point less than 10 miles from the runway, its image appears on the scopes in the precision system as well, and the precision operators take over and use the information on their scopes to direct the pilot in landing the aircraft.

The search equipment incorporates two special features not found in the older GCA equipment. One is an automatic direction finding system. This system determines the azimuth of the aircraft calling the GCA and produces an electronic strobe or bright line from the center of the screen through the echo corresponding to the calling aircraft. This feature enables the operator to determine immediately which aircraft is calling, and facilitates his directing the calling aircraft to the proper position for a final approach.

The other new feature, not found in older GCA systems, is the moving-target indication (MTI). This system reduces the brightness of the scope echoes from sources other than approaching aircraft, including echoes from the nearby ground, distant trees, buildings, hills, etc.

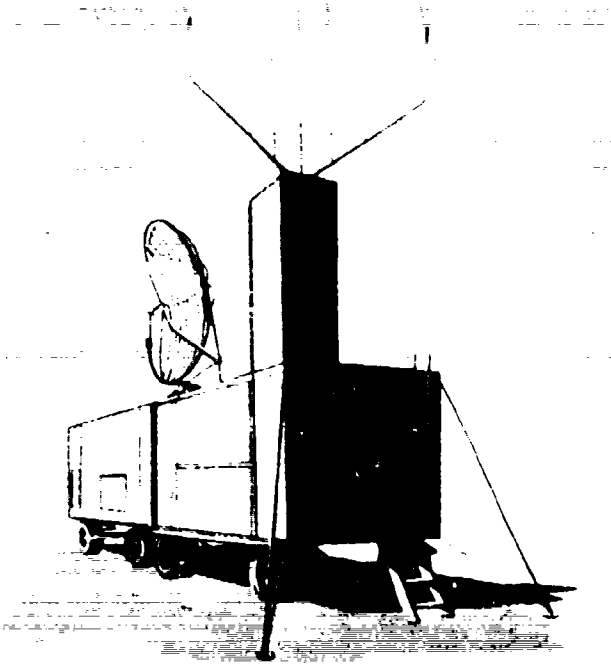


Figure 20-2. AN/CPN-4 equipment

This feature makes it easier for the operator to pick out echoes that correspond to aircraft in the area.

Precision System

As the aircraft comes within about 10 miles of the GCA trailers, it appears on the indicator screen of the precision system and from then on, the ground controller gives oral corrections for keeping the aircraft on the glide path for a final approach.

The precision system sweeps both vertically and horizontally and presents a pattern on the screen showing elevation and azimuth respectively. An outstanding feature of this precision system is that both elevation and azimuth presentations appear on the same screen, directly below the search screen. This makes it possible for one operator to control the whole system if necessary (Fig. 20-4). In older GCA equipment, elevation and azimuth were presented on two separate indicator screens and the approach controller had to rely on two operators for the correct information.

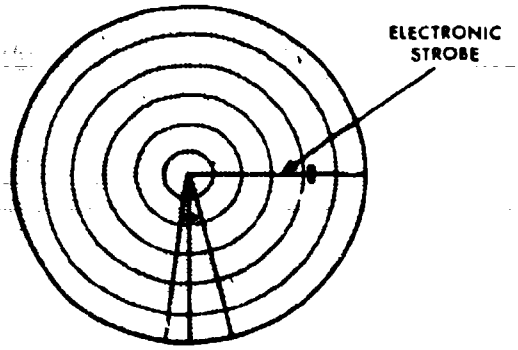


Figure 20–3. CPN–4 360° search indicator

as to elevation and azimuth of the aircraft at all times during the final approach.

The CPN–4 elevation presentation appears on the upper half of the screen and the azimuth presentation appears on the lower half of the screen. An electronic glide path cursor indicates the correct glide path. If the echo goes below or above this cursor the ground controller tells the pilot he is below glide path or above glide path, and the pilot makes the necessary corrections. Range marks also appear on the elevation presentation so the ground controller knows how far out the aircraft is at all times during the final approach.

The azimuth presentation appears on the lower half of the screen. An electronic runway course line indicates the correct course for the aircraft to follow in making the final approach. If the echo goes to the right or left of this course line, the ground controller directs the pilot to fly a heading that will bring the echo back to course line. The azimuth presentation also has range markers so the ground controller can tell how far out the aircraft is at all times. When the aircraft reaches a position about ¼ mile from the end of the runway and is on the glide path, the controller gives the pilot final landing instructions and the rest is up to the pilot.

Communications System

The communications system consists of an LF set, an HF set, a VHF UHF set, and an FM set. These sets cover all the frequencies used by various aircraft command sets and make it possible for a pilot to make a GCA approach regardless of the type of command equipment his aircraft carries.

In addition to these communications sets, the CPN–4 is equipped with a VHF/DF tower and a high frequency DF antenna system that provide the electronic strobe through the echo corresponding to the calling aircraft on the search presentation.

GCA APPROACH PROCEDURE

Completing an approach under GCA direction requires teamwork between the pilot and the GCA crew. The principal requirement on the part of the pilot is that he be able to fly basic instruments and be able to follow instructions.

Generally, a GCA approach may be initiated at any point designated in the clearance; however, Air Force fields and certain others require the procedure begin at a certain place or fix. This information is in Radfacs under "Radar Air Traffic Control Facilities."

Information concerning the availability of GCA at air bases can be found in Radfacs, and in the "Pilot's Handbook" series. These publications list the Air Force, Navy, and CAA fields that have GCA facilities, the communications frequencies used, and other pertinent information.

An actual ground controlled approach is quite simple, and there are few procedures to remember. The more important are:

ARTC approval is necessary before making a ground controlled approach under weather condi-

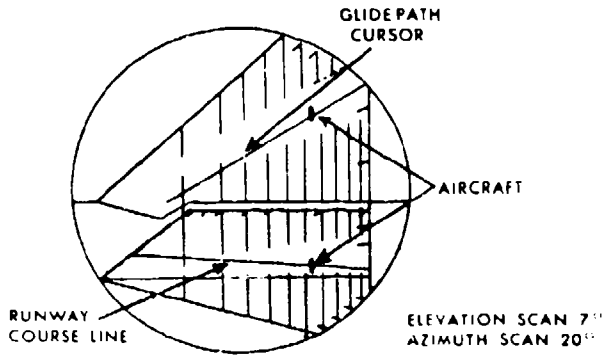


Figure 20–4. Precision azimuth-elevation indicator

tions when the destination is on or involves civil airways.

Do exactly as the approach controller instructs, and if for some reason, his instructions cannot be followed, notify him immediately and take immediate corrective action as necessary.

If you receive no transmission during any one-minute period while in the GCA pattern, follow the missed approach procedure for that particular field.

When on the final approach, if you receive no transmission during any 5-second period, follow the missed-approach procedure for the particular field and contact the control tower for further instructions.

Read back all headings and altitudes given and acknowledge all other transmissions except when instructed by the controller to remain silent during the final approach portion of the approach.

If necessary, a successful ground controlled approach can be made with only the turn-and-bank indicator, the air-speed indicator, and the altimeter.

Confine your radio transmissions to those necessary and be as brief as possible, consistent with the use of standard radio-telephone procedures.

When a pilot has been cleared by ARTC for a ground controlled approach, the GCA controller gives him instructions when he reports his position to a radio facility at or near his destination. These are the initial instructions to the pilot which enable him to get into the GCA traffic pattern. The most common patterns used are the conventional rectangular pattern and a straight-in approach from a range of 10 miles or more. Regardless of the type of pattern flown, the complete approach procedure is divided into four phases:

(1) the initial approach, (2) the final approach, (3) the pre-landing phase, and (4) the touchdown and landing roll.

Initial Approach Phase

The initial approach phase includes any holding or vectoring in the area to a range of seven miles from the touchdown point on the inbound heading of the final approach at traffic altitude. The proper airspeed during this phase is one which is normally used on the downwind leg of a visual pattern. During the initial approach phase, the GCA operator normally gives the latest weather, direction of landing, length of runway, and other landing information. This information influences the determination of the airspeed and the landing flap setting for the final approach phase. If the ceiling and visibility are low, the airspeed should be low and the flaps lowered to give the correct pitch attitude. Also, the shorter the runway, the lower must be the airspeed. In no case should the airspeed be more than 30 K above the stalling speed for the aircraft as determined from its gross weight. Flap settings depend on the speed to be held on the final approach. When a great amount of flaps is necessary to maintain the proper attitude, the additional flaps should not be added until the aircraft is on the final approach at a range of approximately 7 miles.

Final Approach Phase

The final approach phase is the portion of the pattern extending from a range of 7 miles to the instant the aircraft breaks through the overcast and visual reference to the ground is established. At a range of 7 miles, the aircraft is slowed to the final approach speed and the traffic altitude is maintained until instructions are received to start a descent along the glide path.

Pre-Landing Phase

The pre-landing phase is that portion of the pattern flown after breaking out of the overcast until just before contact is made with the runway. It is the period of transition from instrument flying to visual flying. During this phase, the changeover from the controlled flight by the GCA crew and usual flight by the pilot should be gradual. The pilot should continue to adhere to the instructions given by the controller until it is very evident that he will not lose visual contact with the ground.

GCA weather minimums are shown in Refaces. When the aircraft reaches these minimums, the controller will so advise the pilot. He will not order a wave-off for that reason, however. In an emergency, the pilot may proceed below those minimums on his own responsibility, and

GCA will continue to monitor the flight and report altitudes and other data. These minimums, which vary with location, are planned for safe clearance from terrain obstructions in the vicinity of the airport and the low approach route.

Touchdown and Landing Roll

During this phase the approach controller notifies the pilot when the aircraft is over the end of the runway. If visual contact has not been established by this time and the aircraft is in a landing attitude with a rate of descent less than 500 feet per minute, it is possible to execute a landing by maintaining this attitude until runway contact is made. Such a landing will not normally damage an aircraft structurally. If visual reference is made before touchdown, a normal landing should be executed. Don't hesitate to "go around," though, and remember that overshooting is dangerous.

The pilot may make a pull-up at any time he desires during his approach, and he will be given a wave-off any time his position on the precision radar is in doubt or when he exceeds certain limits which have been established by CNO. When a pilot is given a wave-off by GCA, it is mandatory and must be taken.

During [illegible]rument conditions, an outside observer maintains a constant lookout toward the downwind end of the runway; when he sees the aircraft or its lights, as the case may be, he instantly notifies the final controller in the GCA trailer. The controller in turn notifies the aircraft, "The outside observer reports you are contact, you are cleared to take over visually" and then continues to provide a steady flow of information to the aircraft as to the desired headings to bring him over to the centerline of the runway and his relation to the glide path. When the aircraft is over the end of the runway, the pilot is told his drift right or left—if any—and his position over touchdown.

Technique

Every effort is made to direct the aircraft to a safe landing position without violent maneuvers. However, it is you who are flying the aircraft. GCA merely tells you where it would be [illegible]tly. In other words, GCA attempts to "lead" you to a safe landing, but at no time are you relieved of the responsibility of flying and controlling your own aircraft.

Any pilot capable of flying smooth basic instruments is qualified to make an excellent GCA approach and letdown to a position from which he may make a safe and successful landing. However, familiarity with the procedure and frequent practice approaches are valuable insurance. Here are some helpful hints based on a review of several thousand approaches, both training and instrument:

Make all turns as near standard rate as possible; GCA knows the turning radius of your type of aircraft at normal speed and determines your turns by this knowledge. Also, start your turn the instant GCA informs you to turn; do not wait until you have acknowledged the transmission—in the ensuing interval the aircraft will travel from ½ to 1½ miles and your turn on final may be in line with the runway of a field in the next county.

Hold your headings as [illegible]sely as possible and take azimuth correctio[illegible] as quickly and smoothly as you can. Practice in making all turns standard rate will prove invaluable when making a no-gyro approach on GCA. On a no-gyro approach, GCA starts and stops all turns, timing them to place the aircraft on the correct headings.

A most important part of the GCA procedure is staying on the glide path. The GCA glide path is a fixed flight path set up in the trailer at 2½ to 3 degrees above the horizontal. The rate of descent necessary to remain on this flight path therefore depends entirely on ground speed and is subject to fluctuation of the wind. GCA instructs the pilot as to when he is approaching the glide path and when to start his rate of descent at 500 fpm. This rate of 500 fpm is the best rate of de-

scent to work from. As the aircraft's tendency to go below or above the glide path is noted, the pilot is instructed by the final controller to correct to glide path and what his relative position is. Make the corrections by minute and gentle movements of the yoke or stick; adjust throttles only when your airspeed gets too high or too low. Don't chase the rate of climb; let it settle down and use it for an indication only. Your rate of descent may be very good—if you are holding above or below the glide path, correct gently to the glide path and re-establish your former rate of descent. Do not attempt to stay on the glide path with abrupt changes of manifold pressure. Inertia is too great, especially in a heavy aircraft, and will tend to make you over-control and make such violent corrections as to necessitate a wave-off.

GCA EMERGENCY PROCEDURES

PPI Approach

If the precision radar system should fail, the aircraft can be safely brought around for a landing by a PPI approach, and will be assigned definite altitudes and headings. No glide-path information, however, will be available.

The downwind and crosswind legs are the same for this as for regular GCA approach. All data regarding visibility, ceiling, altimeter setting, and wind are given before the beginning of the final approach.

On the final approach, the pilot is given accurate information concerning range, in addition to corrections in headings, so as to keep the aircraft aligned with the duty runway. The pilot is given instructions as to when to reduce altitude, and to what level. These vary with the location but, in general, clear the terrain as follows:

Over 8 miles from runway: 1,500 feet.
6 miles from runway: 1,000 feet.
4 miles from runway: 500 feet.

While making such an approach, the aircraft must not proceed below range or ADF facility minimums (or 500 feet if none published), because of the lack of glide path information.

Heading Indicator Inoperative

If the pilot loses the use of his heading indicator, he is directed to turn left or right, all turns being standard rate (3° per second). His turns are timed, and, when he has reached approximately the right heading, he is directed to stop turn. The ability of the pilot to roll in and out of a standard rate turn (rapidly), together with maintaining a compass heading, on partial panel, are the only requisites for flying no-heading-indicator approaches.

GCA Monitored Take-Offs

During instrument weather, when the ceiling is below range minimum, and the pilot requests it, GCA is set up to monitor the take-off of aircraft to facilitate their return to the field if trouble develops which may necessitate an emergency landing. Depending on the case at hand, GCA will either bring an aircraft around the normal pattern, or direct it to a position whereby it may land on some part of the field. If the pilot requests GCA to monitor his take-off, he must check frequencies with GCA before take-off.

CHAPTER 21

ASSISTANCE FROM GROUND STATIONS

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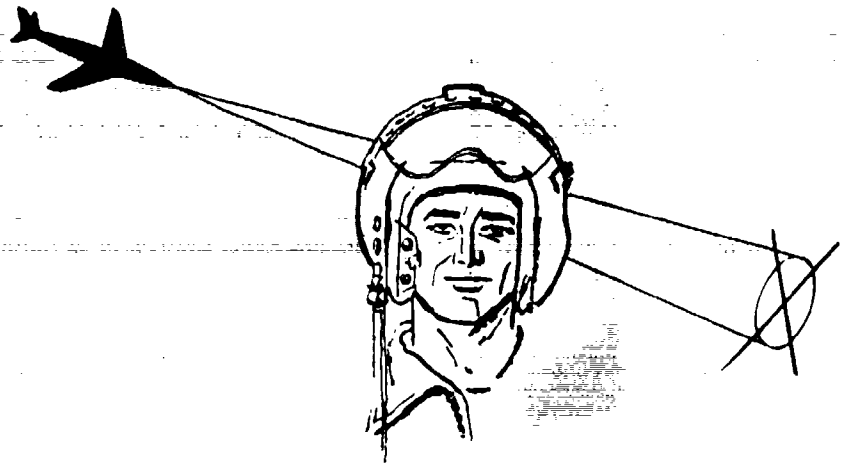

CHAPTER 21

ASSISTANCE FROM GROUND STATIONS

AS THE density of air traffic and the speed of aircraft have increased, it has become increasingly necessary that you know your position accurately and maintain course at all times. This is especially true, of course, in IFR conditions. At the same time, weight limitations keep the amount of navigation equipment in carrier aircraft to an absolute minimum. There are times, therefore, when you must rely on ground-based navigation equipment which relays its findings to you by radio.

Ground navigation aids are of two primary types: radar aids and DF steers. Radar stations observe the aircraft on the scope and determine its bearing and distance, hence its position. Direction Finder (DF) equipment is capable of determining bearing only, but if two or more DF stations take bearings, complete position data is obtained. This chapter discusses these aids and also certain other miscellaneous services available to pilots. GCA may be classed among these radar aids, but it has already been discussed in Chapter 20. In this chapter, therefore, GCA is considered only in regard to its ability to give position reports to a lost aircraft near its station.

RADAR NAVIGATION AIDS

The search radar, known also as Air Surveillance Radar (ASR), is capable of determining the bearing and distance of an aircraft within its range. Sometimes, however, small aircraft are

hard to detect near the range limits without IFF. Sometimes, too, the radar station has to ask the lost aircraft to execute a turn so that his pip on the radar scope can be distinguished from other aircraft or terrain obstruction pips.

Radar Air Traffic Control Centers

The Navy is establishing Radar Air Traffic Control Centers (RATCC) at major air stations to provide radar service at ranges beyond those of ordinary GCA equipment. The Air Force has a similar facility known as RAPCON.

Major Fleet Support Air Stations and All-Weather Air Stations are, in general, scheduled to receive modern, permanently installed radar air traffic control centers (RATCC), modern mobile GCA equipment, or both. Either of these types of facilities will increase the IFR traffic handling capacities of the activities to which they are assigned.

Fixed Radar Air Traffic Control Centers (RATCC) have the following basic equipment. (See Fig. 21-1.)

1. *Medium Range Air Traffic Control Radar* (AN/FPS-8) is capable of detecting aircraft at a range up to approximately 100 miles line of sight and at altitudes up to forty or fifty thousand feet. Where two adjacent stations are scheduled to receive RATCC, the FPS-8 will be installed at only one of the two and will serve the second through repeater scopes.

2. *Short Range Air Traffic Control Radar* (which is like the search portion of the AN/CPN-4 or AN/MPN-5 GCA) is capable of detecting aircraft at a range of approximately twenty to fifty miles line of sight and at altitudes up to fifteen thousand feet.

3. *Precision Approach Radar* (which is like the precision final approach radar of the AN/CPN-4 or AN/MPN-5) is capable of providing information required for the safe final approach of single- or multiple-engine aircraft to a runway during weather conditions as low as the GCA minimums of the particular field.

4. A *Central Control Room* is located in the operations building and accessible to the visual control tower. This room contains remote indicating scopes and control consoles for each of these radar equipments as well as for VHF/DF, UHF/DF, communications equipment, IFF equipment, and certain other maintenance and operational controls. In addition, it has large direct-view type situation displays for both traffic control radars. It also has a selective communications and intercommunications system. Except for those communications equipments which are required for emergency operation, the RATCC uses the standard air station communications equipment.

As an example of a Naval Air Station control area using the potential capabilities of a Radar Air Traffic Control Center (RATCC), see Figure 21-2.

At the present, 13 major Naval Air Stations are being equipped with RATCC, and more are being planned. The FPS-8 search radar picks up aircraft at a greater distance than GCA could formerly do. It then feeds the aircraft to the short range search radar of the GCA system and thus allows more aircraft to be operated in the control area on IFR than was formerly possible. This radar is also able to give positions to aircraft on training flights in the locality and to aircraft passing by the area on airways.

The greater range also permits the clearance of jets for straight-in penetration without so much difficulty as was formerly encountered. In previous control areas, it was usually necessary for the jet to begin its penetration while on airways under ARTC control and complete it under Approach Control clearance. This meant problems resulting from duality of control, and such clearances were sometimes hard to get. After penetrating from en route altitude on the airway, the pilot sometimes found himself at the initial approach altitude being denied clearance to complete the approach, and having to hold at an uneconomical altitude as to fuel consumption. With single agency control over the large radius required for such penetrations, RATCC can authorize such penetrations more often.

GCA and ASR Radar Aid

Even though you are not making a GCA approach, you may request position data from the search radar, providing the equipment is in operation. The ASR feature of the GCA is capable of locating the aircraft from 20 to 50 miles from the field, depending on the type of radar equipment,

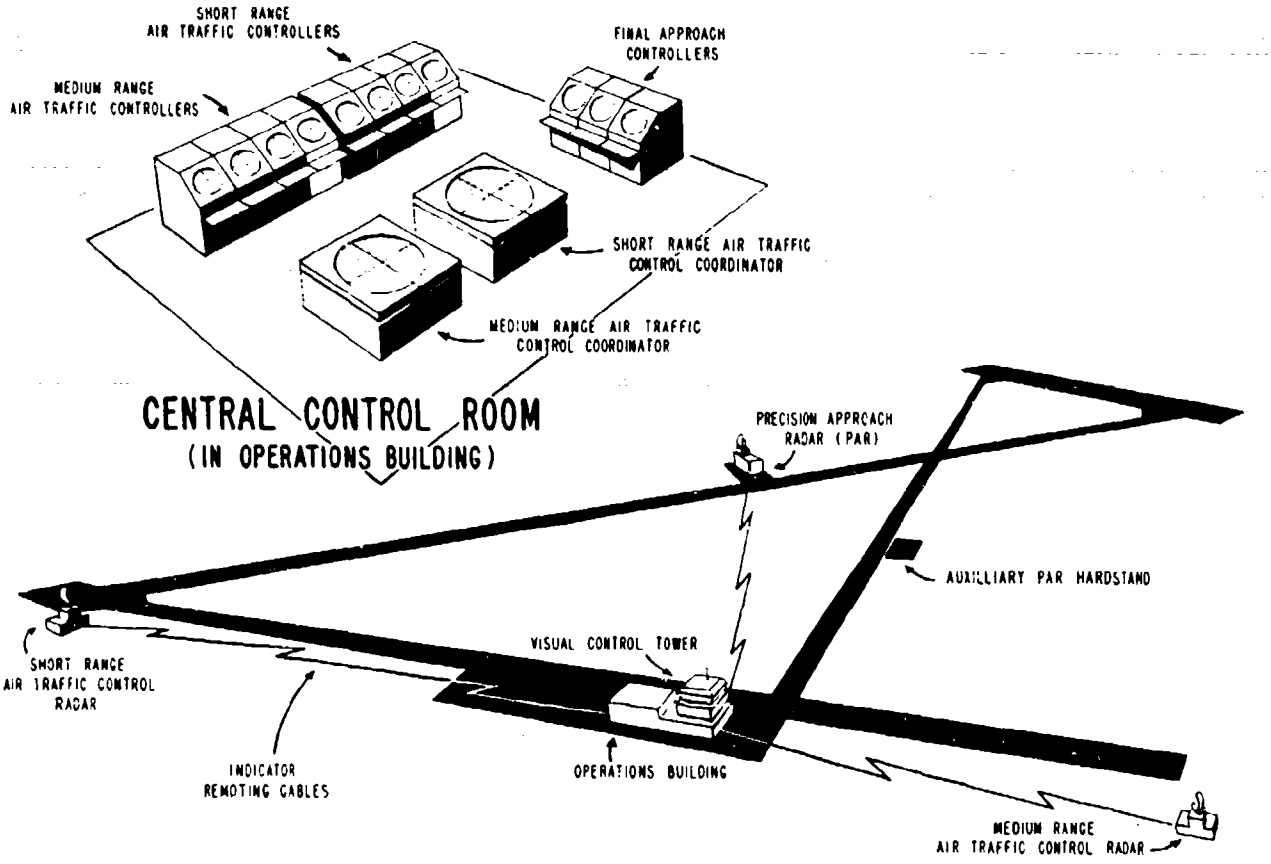

Figure 21–1. U. S. Navy Radar Air Traffic Control Center

terrain, altitude, and size of the aircraft. During IFR weather, the ASR unit monitors all traffic in the area. Furthermore, when the precision unit is inoperative or where there is none, the ASR unit can guide the aircraft to the proper glide path course, furnish distance information, and indicate proper altitudes for that distance. This is variously known as "PPI approach," "PPI assist," or "ASR approach." Procedures for requesting such approaches are discussed in Chapter 14.

After directing the aircraft to the proper course, the controller will tell you your position right or left of glide path, your distance from the runway, and the altitude which you should then have. The controller cannot determine the actual altitude or rate of descent of the aircraft. You must determine for yourself whether you are above or below the glide path by comparing your altimeter to the altitudes designated by the controller as proper for that position. You must decide when and how to correct elevation, and when to take a wave-off if you are too far off the proper descent pattern. These approaches usually have higher minimums than GCA. The minimum is often the same as the local range or ADF approach minimum except as indicated in Radfacs. The controller should advise you of the applicable minimums for the runway in use at the time he clears you for a PPI approach.

ASR approaches are available at many Navy seaplane landing areas. The ASR unit for seaplane landings operates exactly as for landplanes. At some fields, GCA is available only on certain

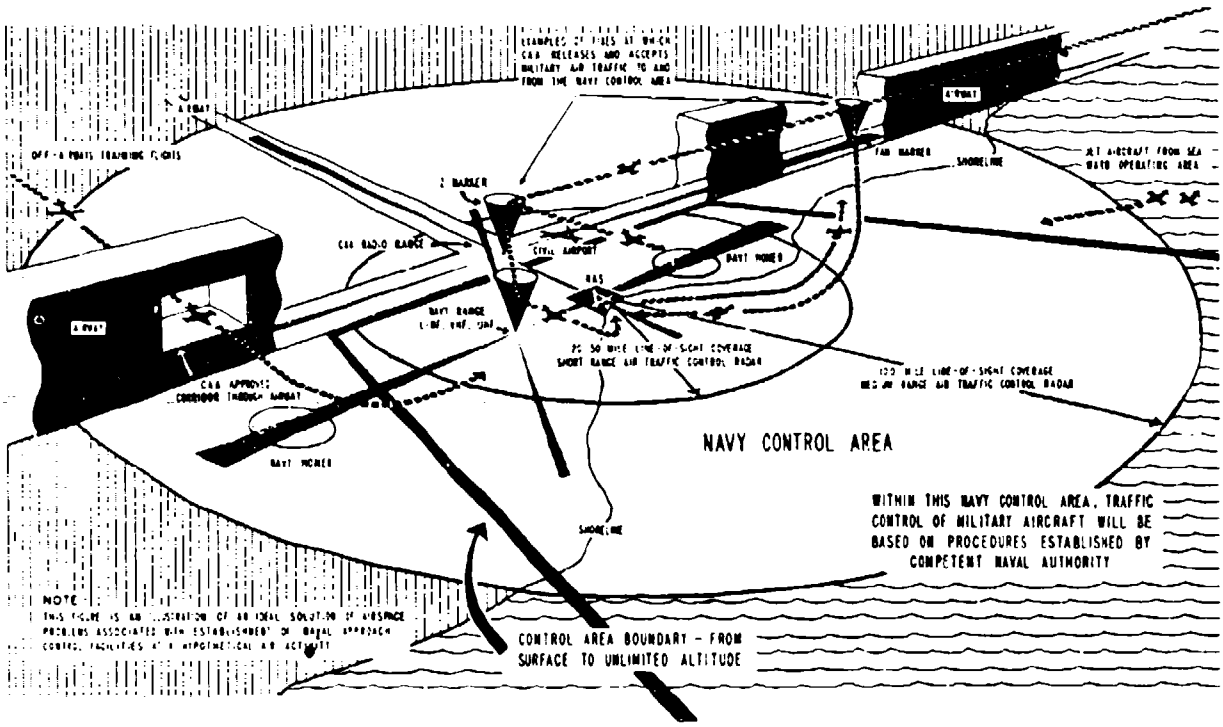

Figure 21–2. Naval air station control area with RATCC

runway, but ASR approaches are available for other runways when wind or other conditions prevent use of the GCA runway(s).

Air Defense Radar Intercept

Aircraft flying in an ADIZ (see Chapter 14) are usually being followed on radar. This radar may be used in emergency to furnish position data, or, if the aircraft has no operating radio receiver, to send up an interceptor to guide the lost aircraft.

The Air Defense Radar Network can furnish emergency assistance to aircraft lost or in distress in ADIZ's and extended adjacent areas on an around-the-clock basis.

Since radar is restricted to line-of-sight coverage, increase altitude, if necessary and possible, before initiating procedures when you are lost. If you have IFF, turn it to "emergency" to facilitate pick-up by radar. Repeat these procedures every twenty minutes until you receive instructions or accomplish the interception:

With a two-way radio, request radar assistance from the Air Defense System through any CAA range station. Call ADC Radar on 121.5 mc or 243.0 mc using distress calls of "May-day" or "Pan."

With a receiver only, tune to 121.5 mc or 243.0 mc. Fly a *right* hand triangular pattern of 120° with two minute legs and one-half needle width turns (1½ leg per second). Complete at least two patterns before resuming course. If radar contact is established, instructions will be given on 121.5 mc or 243.0 mc.

With no receiver, fly a left hand triangular pattern as just described. If radar contact is established, a rescue aircraft will be dispatched for intercept. Resuming your course will not compromise this system as your aircraft will continue to be tracked as "distressed" from the point of initial contact.

Ground Controlled Intercept (GCI)

The GCI or CIC center is equipped with search and height-finding radar similar to that

of the ADC units just described. When an aircraft enters the area under GCI control, it is either followed on the radar or is given a heading to its assigned target to fly by its own D. R. navigation. If you are operating in such an area and become lost, execute a predetermined "lost plane" procedure. This procedure consists of sending a message that you desire a steer and flying a certain turn pattern, or turning your IFF to "emergency." Even GCI training units in the States can render assistance to aircraft in their area which become lost or need guidance to a field.

The GCI crew is usually able to locate the lost aircraft and give it position or steer information. If the radar can't locate your aircraft, a change of altitude may help. Obviously, if the aircraft is below the radar horizon (below the line-of sight), it cannot be detected and must increase altitude. In addition, if atmospheric conditions or local terrain obstacles prevent detection, a change of even 500 to 1,000 feet up or down may allow detection.

DIRECTION FINDER SERVICES

Direction Finder (DF) services are usually available from ships and ground stations to the lost aircraft. These services may be classed by the frequency at which they operate. UHF/VHF steers are most reliable, being unaffected by the static which often interferes with DF work during bad weather. Though these services are readily available, don't ask for a ground or ship station to take bearings on your aircraft unless you are in a semi-emergency situation when the airborne direction finder (ARN-6 or ARN-7 on LF/MF and ARA-25 on UHF) are inoperative. Of course, this does not preclude your making requests for practice purposes.

The procedure for requesting a steer is to call the controlling radio facility and state that you "request steer" (or "request emergency steer," if such is the case). If you are unable to contact that station, the request may be relayed through any station which you can contact. You may receive instructions to transmit on another frequency if the DF facility is unable to take bearings on the original frequency. After the Homer is in communication, you will be instructed to "transmit for steer."

To transmit for steer, send a message such as this, "Andrews Tower, this is Navy 1234," followed by two long tone signals, then "Navy 1234. Over." Transmit the two long tone signals by pressing the CW key or tone button on your transmitter (if so equipped) or by a long count. The homer then replies with your no-wind course (magnetic heading) to the station, which should be repeated back in acknowledgment.

In many cases, particularly on HF, it may take five minutes for the DF station to be ready for your transmission. If you are unable to contact any station on any assigned frequency, send the following voice message: "Securité—Securité—All Stations—All Stations—All Stations (or name station)—Securité—This is Navy 1234—This is Navy 1234—This is Navy 1234—Request position (or bearing from X station or course to X station). Will transmit for bearing—(then two long tone signals, as above)—This is Navy 1234 (repeat long tones and call sign for five minutes)—Over." "Securité" is the international safety signal, pronounced SECK-*CURE*-IT-*TAY*.

(This procedure is based on the assumption that there is no immediate emergency, such as inability to maintain flight, but that there is a deferred emergency due to inability to determine position. You can find the procedures for immediate emergency in the Supplementary Flight Information Document.)

The message may also include a request for interception and escort if such need exists. When this type of message is sent blind, remember that the listening station cannot ask you to wait, and its DF equipment may not be ready. It is necessary, therefore, to continue to send the long tones and call sign for five minutes to have any assurance of being located for a steer. When you are in communication with a ground station, such repetion is unnecessary because that station will not direct you to transmit the tone signals until it is ready.

This procedure is based also on voice radio. If you are equipped with CW and are able to use it, follow the procedures in Supplementary Flight Information Document. The range of CW transmissions is greater, so use when possible.

In addition to the DF facilities at airports, the FCC maintains HF/DF stations at about fifteen locations around the country which are able to give long range service. These stations operate as a network and more than one station takes bearings at the same time. The data is transmitted to the Net Control Unit which plots a fix and reports it for transmission to the aircraft. If a fix cannot be taken, bearing data may sometimes be provided. The fix is in terms of latitude and longitude.

On the basis of the precision of the bearings and the size of triangle (if any) when they are plotted, the net control unit designates the quality of the fix:

Within 20 miles: Good.
Within 40 miles: Fair.
Within 60 miles: Poor.

The fix position is also designated as to the observation time.

The services of the FCC DF network are obtained by request for DF position to an airways radio station. A few minutes may elapse before the network has been contacted and is ready. You will usually be asked to transmit on a designated frequency. Best results are obtained between 6000 and 8000 kc in daylight or 4000 and 6000 at night; however, the network is capable of taking bearings at frequencies from 200 to 30,000 kc (30 mc). Again it is necessary to continue transmission of call sign and long (10 sec.) dashes for a five-minute period, and it is better to use CW dashes instead of voice.

In an emergency, preliminary bearings are transmitted to the ground station requesting DF service for the aircraft. Otherwise, the fix position will not be available for about 5 to 10 minutes after the bearings are taken. The FCC network does not furnish a course for the aircraft to fly, but the airways radio station may do so when transmitting the fix to the aircraft.

VHF/UHF DF Approach and Penetration

If an aircraft has no direction finder or homing equipment in reliable operating condition, but does have operating VHF or UHF communication, it can make an approach or penetration to a ship or station which has VHF/UHF DF equipment for giving aircraft steers.

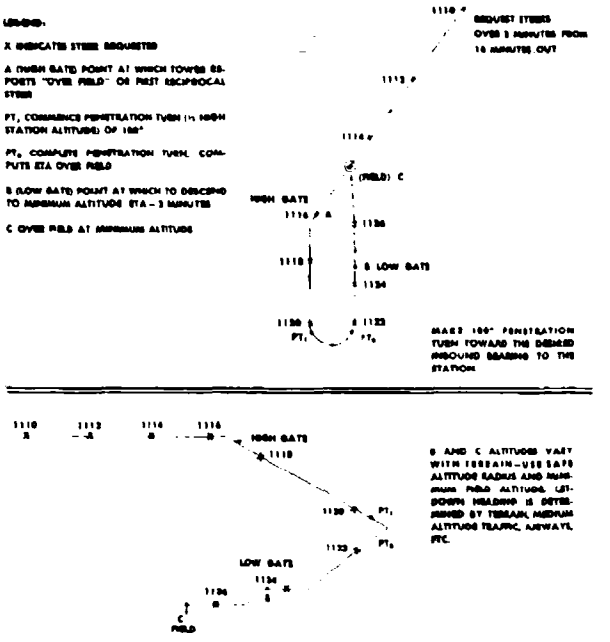

Figure 21–3. VHF/UHF DF approach and penetration

To facilitate approaches and letdowns (or penetrations) to a ship or field without radio range or GCA facilities and provide an emergency means of safe descent in cases where an aircraft's low frequency receiver may be inoperative, the following procedures have been developed for use in instrument weather or as an alternate letdown procedure for use when circumstances permit. (See Figure 21-3.)

This type of approach and letdown may be used by both conventional or jet aircraft. VHF/UHF DF fixes or headings may be used to supplement and verify visual or aural indications of the ARN/6 or other low frequency equipment. The system is relatively simple in that it generally follows the usual procedures for obtaining and following a steer to a controlling ship or station. The only disadvantage is the limited number of aircraft which can be worked simultaneously by a controlling activity.

You start by requesting a steer from the tower or CIC controller when you are ten minutes from station. Repeat the steer request at least every two minutes.

Steer as directed until you are reported "at or near the station" or until you receive the first reciprocal steer, indicating station passage, high gate. Check the time and start your turn to a clear sector for penetration letdown. Report "commencing penetration" (letdown) to the controller and establish a normal rate of descent and airspeed for penetration letdown. Continue requesting steers during descent.

At one-half the initial high gate altitude, check the time and start a turn to intercept the inbound heading to the base. Disregarding the time in the penetration turn, compute the ETA to the station. The time inbound will be approximately equal to the time outbound plus two minutes. Descend to 1,000 feet, level off, and maintain until you reach your computed ETA minus two minutes. This is the low gate. At ETA minus two minutes, descend to the published minimum altitude for the field or station controlling. If you don't see the field when you receive the first reciprocal steer, pull up to 1,500 feet or other minimum en route altitude and orientate yourself for another approach.

SAR FACILITIES

Rescue Service is provided by SAR (Search and Rescue) units of the Air Force, Navy, and Coast Guard. The RCAF also operates a similar service in Canada. These facilities can be activated through the various radio control facilities, either military or civil. (See Figure 21-4.)

This service includes the search for, rendering aid to, and rescue of personnel and equipment involved in aircraft incidents. An important function of this service is the interception and escort of aircraft which are in distress or in an emergency bordering on distress conditions. Rescue aircraft are capable of intercepting distressed aircraft by

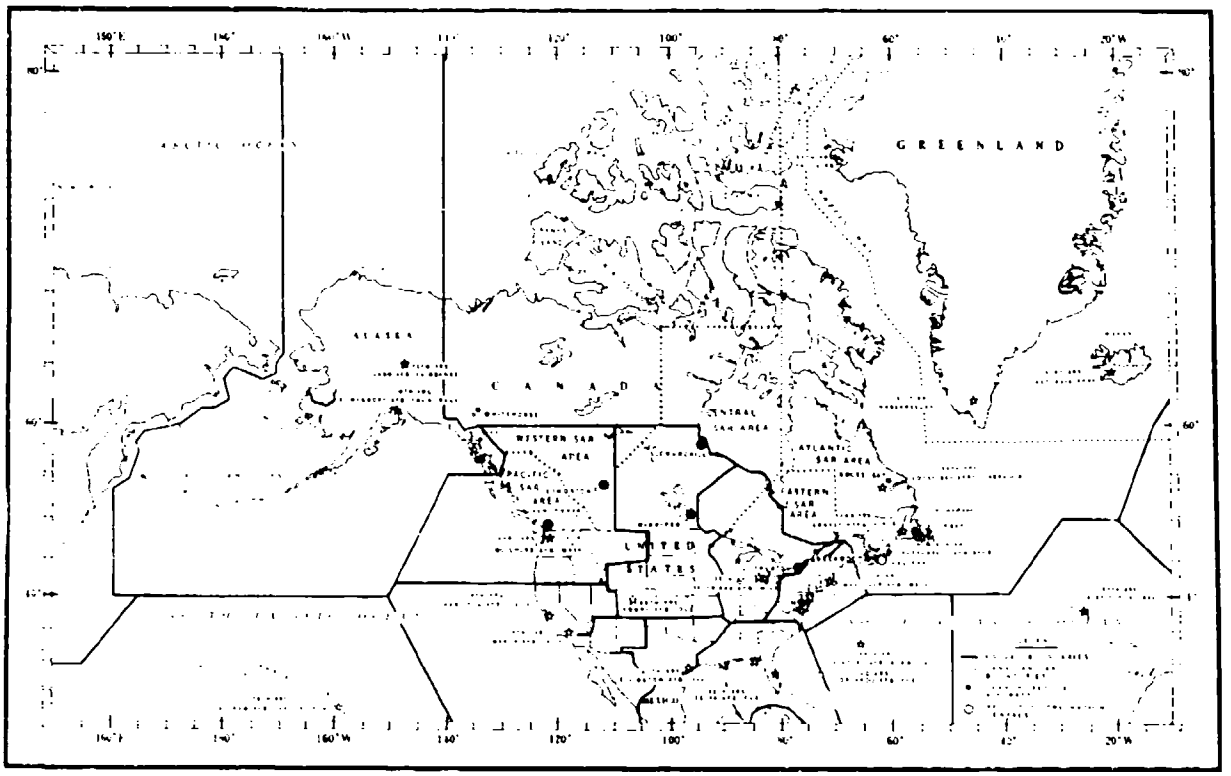

Figure 21-4. Area of operations of the Air Rescue Service

visual, radio, and electronic methods. In addition to interception, the rescue aircraft can help by providing such information as prevailing weather, instrument approach and letdown instructions, availability of emergency landing areas, best heading for ditching, etc. *Alert the rescue system any time the operational efficiency of your aircraft has been impaired. Don't wait until a dire emergency has developed.*

If you are in difficulty or distress, you should:

1. Turn your IFF to emergency.

2. Send an appropriate distress or urgency message.

Contact any radio facility, using normal route or distress frequency. If you want interception by rescue aircraft, add the phrase, REQUEST INTERCEPTION AND ESCORT. Even though you do not request interception, the SAR agency may dispatch an intercept aircraft as a precautionary measure, after evaluating all circumstances.

Maintain continuous radio contact with the ground station and standby on the emergency VHF or UHF frequency for voice contact with the rescue aircraft. Keep the ground station advised of your progress and conditions until radio contact is established with the rescue aircraft. Once in contact with the rescue aircraft, comply precisely with the rescue pilot's instructions.

Upon request, transmit a signal by depressing the VHF or UHF tone switch on the frequency specified by the rescue pilot. The initial signal should be one minute long; thereafter, 30 seconds long when requested. Transmit signals every two minutes if you can't establish contact or if voice communications are lost or undependable.

Tune the LF MF radio compass to 514 or 526 kc of any other frequency specified by the rescue aircraft or ground station. Relay radio compass bearings to the rescue aircraft and, if requested, alter heading to home on the rescue aircraft. Maintain a vigilant lookout for the rescue aircraft. Discharge pyrotechnics or turn on landing lights on request.

If you are in an ADIZ and can't establish radio contact and if the severity of distress warrants, try to alert the Air Defense Command radar system by flying one of the emergency patterns described before.

At sea, try to communicate with surface vessels in the vicinity and advise them of the distress. Use the distress frequency of 500 kc. If practicable, precede the distress call by the alarm signal of twelve 4-second dashes, with intervals of one second between each, using tone emission. If circumstances permit, separate the transmission of the full distress call from the end of the alarm signal by an interval of two minutes, but always send the distress signal SOS three times immediately after the alarm signal in order to operate automatic apparatus, which may depend on the distress signal for actuation.

SECURITY CONTROL OF AIR TRAFFIC

In case of enemy air attack within the U. S. it would be necessary to clear the air of aircraft not engaged in combat flights until the immediate emergency was over. For this reason, the Security Control of Air Traffic (SCAT) regulations have been issued. All aircraft are required to guard a CAA communications facility or a control tower frequency at all times. In case of emergency, SCAT directives will be broadcast over these frequencies. VFR flights will generally be ordered to land at the nearest field. IFR flights will proceed as directed by ARTC, but may expect diversion to an alternate in many cases.

RADAR STORM ADVISORY SERVICE

Radar Storm advisory service is provided by the Air Defense Command radar stations. These stations are listed in Radfacs. Advisories concerning severe storm areas are available in flight upon request.

If you anticipate or encounter severe weather and want radar advisory service, contact the nearest CAA Communications Station giving your position. ARTCC will clear you to standby on 121.5 mc or 243.0 mc for a call from the nearest radar station. Advice will be furnished on the location and extent of the storm areas likely to affect your flight. At your request, the safest flight path around or through such areas will be suggested.

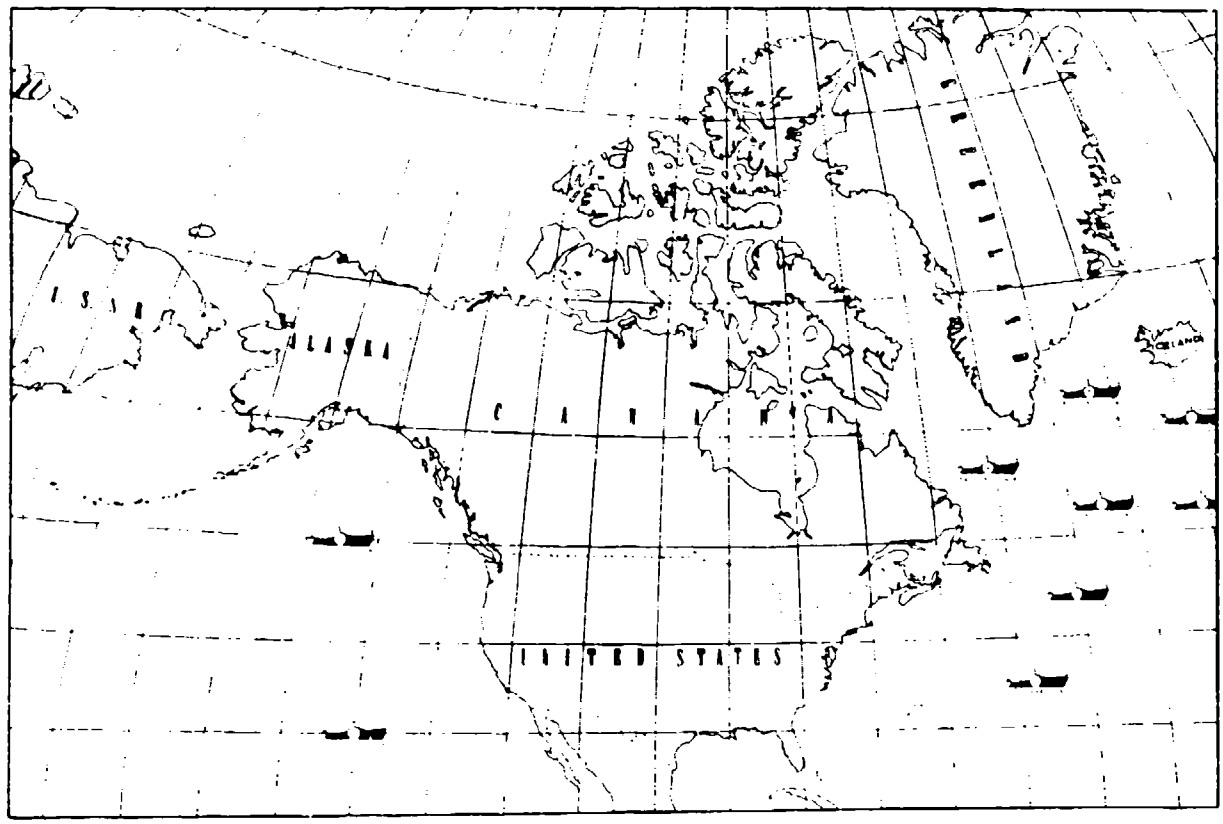

Figure 21–5. Ocean station vessels

If the radar station cannot fix your position or positively identify your aircraft, the word UNABLE will be transmitted. This will terminate contact with you. Report immediately to the nearest CAA communications station: 1. If you are unable to contact the radar station; 2. when you receive the word UNABLE; and 3. when your business with radar station is complete.

NOTE: The information given by the radar stations is *advisory only*. The responsibility for the safe and proper conduct of the flight or change in flight plan rests with you.

OCEAN STATION VESSELS

To assist aircraft engaged in transoceanic flight, a number of small vessels are located in mid ocean to provide various forms of aid. These ships sail at or near a predetermined position (Fig. 21-5) and are designated by a letter identification. The services performed involve operation of a radiobeacon (homer), radar fixes, DF bearings, weather information, search and rescue services, communications service (including relaying messages), and keeping track of air traffic en route within 100 miles. The ocean station vessel is considered a compulsory reporting point for aircraft passing within about 100 miles.

For all-weather flight purposes you are most interested in the navigation and aerology services. The weather ship will, on request, broadcast weather information in plain language or in the appropriate international code. Make your position report when you are nearest to the ship. If you wish a radar position report from the ship, request that such a fix be taken as you report your

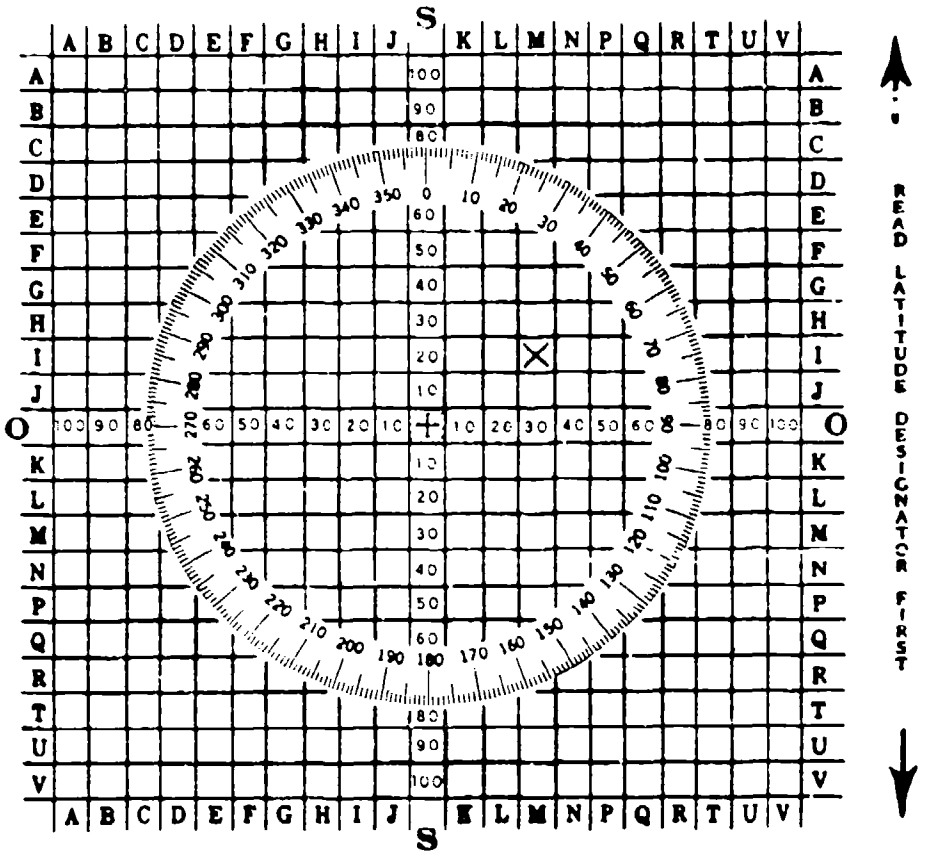

Figure 21–6. Ship's position report grid from ocean station vessel

best known position. If you don't want a radar fix, the radiobeacon will generally provide an easy check on the accuracy of navigation to that point.

Both the radar fix information and the transmissions of the radiobeacon give data based on the present actual position of the ship. If the ship's own position is uncertain or if she is off station on a distress mission, the radiobeacon discontinues operation, except on request. Reports of the ship's position are made by reference to the simple grid shown in Figure 21-6 in which a two letter identification gives the ten-mile square in which the ship presently is located, the first letter for latitude scale, the second for longitude scale. The center cross of the grid is the assigned ship position shown in Figure 21-5. This system results in an average error of 4 miles and a maximum error of 7 miles in the ship position data.

For example, suppose that ship "C," or Coca, whose assigned position is 52°45′ N, 35°30′ W, is off station so that her actual position is in the square shown off center on the grid in Figure 21-6, square IM. Her call sign is 4YC, so her radiobeacon station identification is "YC." If she found at 0821-Z that an aircraft was $18\frac{1}{4}$ miles from the ship, bearing 070° T., her radar position report would read: "At 0821 GMT your position: Range one eight point two five nautical miles bearing zero seven zero true from, repeat, from ocean station Coca on India Metro ground speed two two zero knots course over ground two six zero true."

To utilize this information on your chart, you would plot the ship's assigned position, and de-

termine from the grid that the center of square 1M bears 56° at 37 miles (each grid square is 10 miles) from the center or assigned position. Then you would plot the ship's present position and from that the aircraft position.

If this same ship at the same position were used for radio bearings, the aural signal would consist of twenty second dashes or carrier tones broken by identification signals, in this case "YC 1M," meaning "Station Vessel Coca (YC) at position 1M." To plot the ADF bearing, you must first plot the actual ship position (1M) by use of the grid as stated before.

Remember that the positions of ocean station vessels, and possibly the procedures, may change from time to time. For the latest information, consult the current Supplementary Flight Information Document.

VOR RECEIVER CHECK SIGNALS

Facilities are provided for checking the accuracy of VOR receivers to insure satisfactory operations of the airborne system. These provisions consist of three different methods: 1) a radiated test signal consisting of a signal radial; 2) certified check points on the airport surface; and 3) certified airborne check points.

The radiated test signal is used by tuning the receiver to the published frequency of the test facility. With the flight path deviation indicator (FPDI) centered, the Omnibearing selector should read 0° with the TO-FROM indication reading FROM (or the Omnibearing selector should read 180° with the TO-FROM indication reading TO). Two means of identification are used with the VOR radiated test signal. In some cases, a continuous series of dots while in others a continuous 1020 cycle tone identifies the test signal. Information as to the identification of any individual test signal can be obtained from the local control tower.

Ground and airborne check points consist of certified radials that should be received at specific points on the airport surface or over specific landmarks while airborne in the immediate vicinity of the airport. Contact the control tower, communication station, or airport manager for location details. If you find an error in excess of ±4° with the ground check or ±6° with the airborne check, don't try VOR flight without first correcting the source of error. *You can't use that as a correction factor.* You must correct the instrument before using it for flight because the error may not be constant at all times nor on all heading and bearing combinations.

The locations at which each type of VOR receiver check is available are listed in the curren Supplementary Flight Information Document. Check your VOR at regular intervals, and, if possible, every time you fly a strange aircraft.

CHAPTER 22

INSTRUMENT LANDING SYSTEM (ILS)

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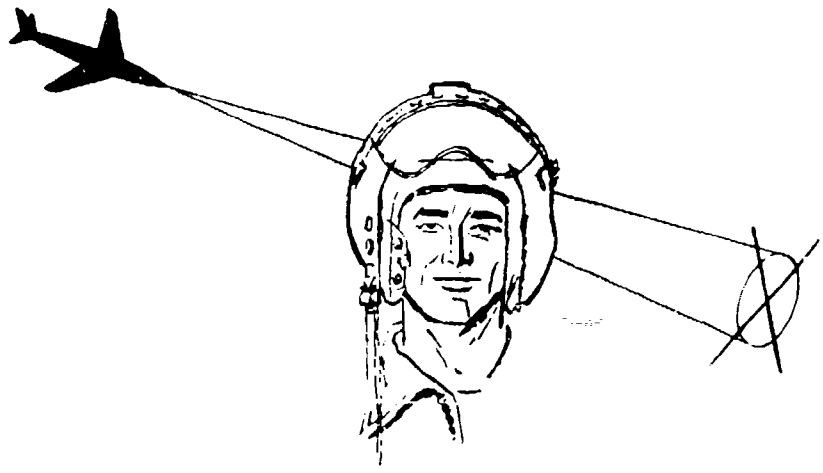


CHAPTER 22

INSTRUMENT LANDING SYSTEM (ILS)

ILS is a low approach system for instrument flight. It does not permit the aircraft to make a full landing on instruments but does provide course, descent, and range information for the final approach to guide the aircraft to [illegible] minimum altitude from which visual contact [illegible] possible.

GROUND EQUIPMENT

The ground equipment consists of two highly directional transmitters and, along the approach, three or four marker beacons. The directional transmitters are known as the localizer and glide path transmitters (Fig. 22-1).

The system may be divided functionally into three parts:

1. *The localizer*, which provides the course information.
2. *The glide path*, which provides the descent information.
3. *The marker beacons*, which provide the range information.

Compass Locator and Approach Light Lanes supplement these major components.

Localizer

The localizer transmitter, located at the far end of the runway, sends out signals which enable the pilot to steer the required course to the run-

way. The transmitter, operating on one of twelve channels within the range of 108.1 mc to 111.9 mc, sends out two patterns, one modulated at 150, and the other at 90 cycles per second. These two signal patterns overlap along a line formed by an elongation of the runway. The aircraft receiving equipment finds this line, or course, by finding the area of equal signal strength between the two patterns; just as the course of a radio range is the area of equal strength between two quadrants. The course formed by the localizer signals has an over-all width of 5°. It spreads from a width of approximately 70 feet at the touchdown point to a width of approximately one mile at a distance of 10 miles from the transmitter (Fig 22-2).

For the purpose of reference, the 150 cycle area to the right of the approaching aircraft is called the Blue area, and the 90-cycle area to the left of the approaching aircraft is called the Yellow area. The approach course of the localizer is called the front beam or front course.

The course along the centerline of the runway in the opposite direction is called the back beam or back course. The localizer transmitter has a range approximately 40 miles at an altitude of 5,000 feet, and 80 miles at 10,000 feet. It can carry voice transmissions.

Localizers are equipped with an automatic monitoring system which sounds an alarm in the tower and shuts off the transmitter if the beam is displaced for any reason.

Identification consists of three-letter signals preceded by an I (. .) transmitted on the localizer frequency. The time interval between the I and the first letter of identification is 0.6 secs.

Glide Path

The UHF glide path transmitter, located approximately 750 feet from the approach end of the runway and approximately 400 feet from the center line transmits a glide path beam 0.8° wide, at an angle of approximately 2.5° above ground level. The beam may be adjusted to angles between 2° and 4°. This variation is necessary to provide safe clearance for obstructions.

Unlike the localizer, the glide path transmitter emits its signals in the direction of the final approach and sends practically no signals toward the far end of the runway. The glide path transmitter, operating on one of 6 channels in the band from 332.0 mc to 335.0 mc sends out patterns which are modulated at 90 cycles and 150 cycles like the localizer. The location of the glide path is determined by finding the area of equal signal strength between the patterns.

In addition to the desired courses, all glide path facilities inherently produce about five additional courses at high vertical angles. These high courses are false courses so far as the actual approach is concerned, but they should cause no trouble, for they are not encountered in a proper approach. The lowest is at approximately 16°.

At present, all glide paths in commission are

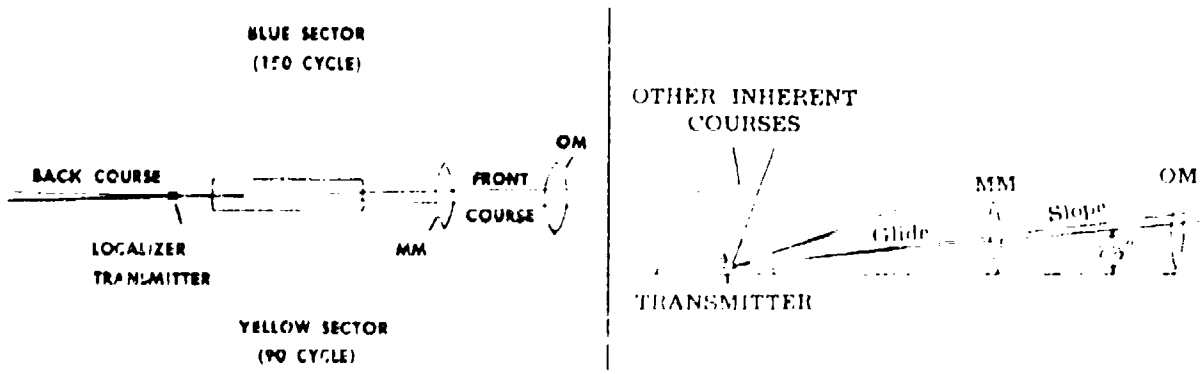


Figure 22-1. The Instrument Landing System

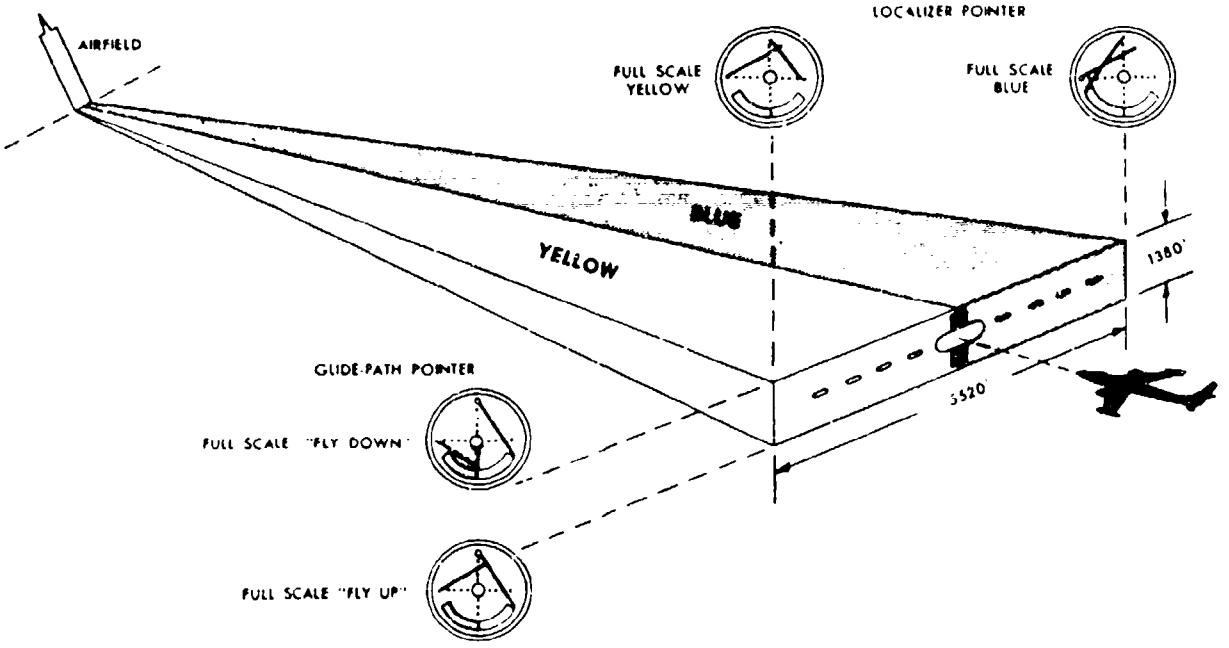


Figure 22–2. Cross-section of an ILS beam 10 miles from field, showing approximate dimensions as related to cross-pointer indications

of the straight course type. With this type of path, the Instrument Landing System is actually a low approach system, since the pilot normally must take over and effect the landing visually. However, a flared glide path has been developed which "shallows" out close to the ground like the path an aircraft makes in a fully automatic normal landing. With this type of path, fully automatic landings can be effected. It is planned eventually to convert all glide paths to the "flared" type.

Distance Markers

There are ordinarily two marker beacons, the outer and middle, but there are exceptions in some locations. Often the Z-marker of a radio range station located along the localizer beam serves as the outer or middle marker in place of the regular fan type marker. Most CAA ILS installations use only two markers.

Outer Marker. The outer marker is approximately 3½ to 7 miles from the approach end of the runway and within 250 feet of an extended center line of the runway. Its signal is keyed at two dashes per second.

Middle Marker. The middle marker lies approximately between 0.8 and 4 mi[illegible] the runway and within 250 feet of the c[illegible] transmits a series of alternate dot an[illegible]

Boundary or Inner Marker. Th[illegible] marker (which is used only at certain [illegible] installations) is placed from 225 to 37[illegible] feet [illegible] the approach end of the runway and within 260 feet of the center line. It transmits s[illegible] dots per second.

The distances given here for all three markers are subject to variation because of terrain, structures, and other local situations that affect the locat[illegible] the marker transmitters. You may fin[illegible] e older installations where the middle marker transmits a series of dots and the boundary marker a solid unkeyed signal.

Compass Locators. Compass locator transmitters are often situated at the middle and outer markers. The transmitters have a power output of 25 watts and a range of not over 50 miles.

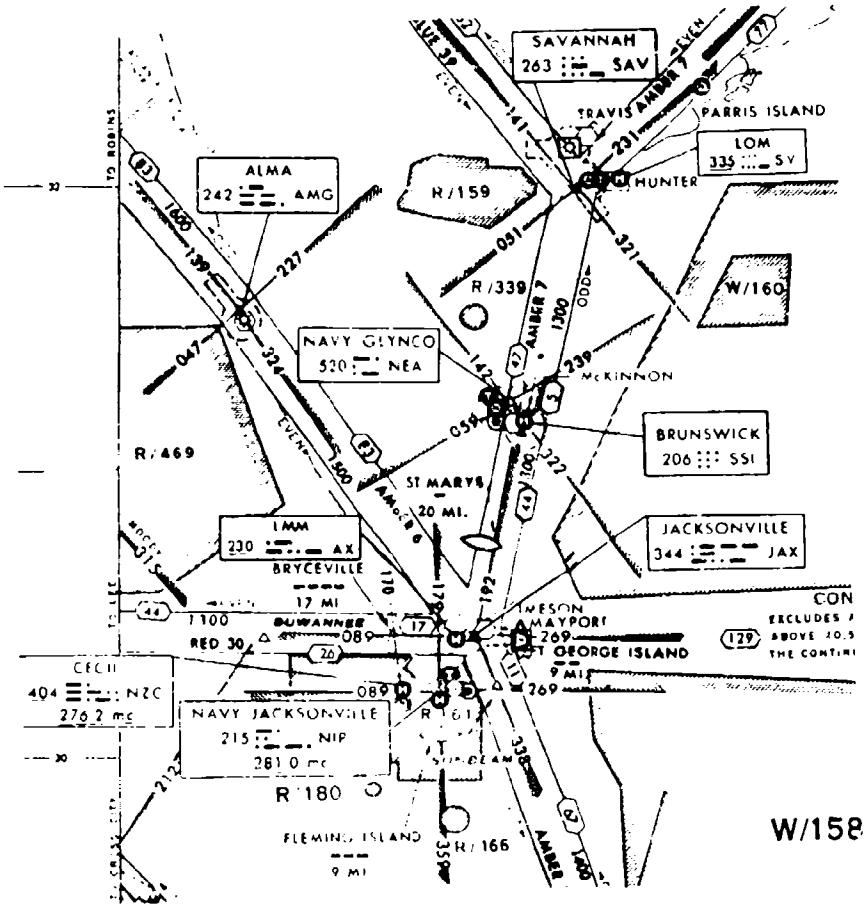


Figure 22–3. Detail from RADFACS page. Note use of LMM locator for holding near JAX and LOM for holding near SAV

Locator stations transmit two letter identification groups. The outer locator transmits the first two letters of the localizer identification group, and the middle locator transmits the last two letters of the localizer identification group.

These compass locators are essentially low power homers (RBn), operating between 200 and 400 kc. Their location, frequency, and identification are shown in the ILS tables in Radfacs and on the ILS approach charts in the "Pilot's Handbook."

Sometimes these facilities are also used in conventional range and approach work, and are therefore shown on the regular charts in Radfacs, being identified as different from other homers by the designation L (Locator). If the locator is at the outer marker, OM is added to the L, making the designation LOM. Actually the LOM homer is quite often utilized in approach procedures for purposes other than ILS and appears in many places on the charts. (See Figure 22-3.) If the locator is at the middle marker, it is designated LMM.

AIRBORNE ILS EQUIPMENT

The airborne components consist of a localizer (VHF) receiver, a glide path receiver (UHF), and an indicator. In most cases the receivers are designed so that when the localizer receiver is tuned to the correct frequency, the glide path receiver is also properly tuned. Sometimes, however, each receiver has its own control box.

ARN-14 Receiver and Indicator

When the aircraft has ARN-14 VOR installed, set the proper frequency on the frequency selector just as for a VOR station. Set the TONE-PHASE switch to TONE (except for ILS installations which operate on phase). When you tune to an ILS frequency and the glide path receiver is operative and properly tuned, the glide path needle OFF alarm flag should disappear on the Course Indicator, ID-249.

The indications on the ID-249 while you are flying on the ILS station are exactly the same as if the ILS front beam (inbound course) were a course to a VOR station, except that the TO-FROM indicator is inoperative. The ID-249 does not always have a blue-yellow color band, but if you consider the ILS front beam as if it were a selected radial of VOR, you should have no difficulty with the flight procedure.

If you set the localizer heading in the course selector window, the heading pointer will give the same indications as on VOR bearings. Inbound, correct toward the vertical needle; outbound correct away from it. The glide path needle is horizontal. It lowers when you are flying above glide path and rises when you are flying below the glide path. In short, visualize the center of the indicator as the nose, and the horizontal needle as the path to which the nose should be directed to maintain the glide path.

ARN-30 Receiver and Indicator

When the proper glide path equipment is installed and connected to the Deviation Indicator of the ARN-30 receiver, the ARN-30 receiver can be used for the ILS. The procedures are the same as when the ARN-14 is used except that the course is set on the separate Course Selector instead of the window on the ID-249.

Older ILS Receivers

Another type of ILS equipment, particularly in Air Force procurement aircraft, uses the control box shown in Figure 22-4. When you look up ILS facilities in Radiafax you will see not only the frequency of the localizer and of the glide path, but also a column headed "RTCA Priority No." In this column you will find a number and a letter. The Radio Technical Commission for Aeronautics has numbered ILS channels, and these numbers appear here. If your ILS control box uses channel numbers, these will be the RTCA numbers. However, these channels were previously identified by the letters appearing in parentheses after the RTCA number. These are the ones on the control box shown in Figure 22-4. Adjustment of the volume control on this control box affects only the audio signal in the headphones; it does not affect the needle sensitivity.

Currently, twelve localizer channels and six glide path channels are in use, as follows. (VAR ranges operate on channels in the same range as the localizer receivers.)

RTCA No.	Letter	Loc. Freq.	G. P. Freq.
1	Z	110.3	335.0
2	Y	109.9	333.8
3	X	109.5	332.6
4	U	108.3	335.0
5	V	108.1	334.4
6	W	110.1	334.4
7		109.7	332.2
8		109.3	332.0

Localizer Indication

The localizer (vertical) pointer indicates only the color area of the sector in which the aircraft is flying. If the aircraft is flying in the blue sec-

Figure 22-4. ILS localizer control box

tor, the vertical needle is deflected into the blue area of the indicator. If the aircraft is flying in the yellow sector of the transmitter, the needle is deflected into the yellow area of the indicator. When the aircraft is directly on courses, the needle is centered. (See Figure 22-5.)

When the aircraft is inbound on the front beam or outbound on the back beam, the needle indicates the direction in which the desired flight path is located. If the needle is deflected to the right, the aircraft must be turned to the right to regain course.

When the aircraft is inbound on the back beam or outbound on the front beam, sensing is reversed. If the pointer is deflected to the right, the aircraft must be turned to the left to reach the center of the beam. This reversal of needle deviation when on a reciprocal course is exactly the same as the reversal which occurs while flying the reciprocal of a VOR bearing. In the blue sector, for example, the deviation needle always points to blue, regardless of heading, and only indicates the course would be left if the plane were on the glide path bearing inbound.

The pointer gives a full scale deflection on the color board when the aircraft is 2½° on either side of the on-course. If the pointer is no farther off than one-quarter scale, the aircraft will land on the runway.

Glide Path Indications

The glide path (horizontal) pointer indicates the position of the aircraft with respect to the glide path. When the aircraft is above the glide path, the needle is deflected downward. When the aircraft is below the glide path, the needle is deflected upward. (See Figure 22-6.)

The glide path course is much sharper than the localizer course. A 1° variation will deflect the needle from full up to full down. This makes it necessary to align the aircraft very accurately on the glide slope. The way to do this is to get exactly on the glide slope at the beginning of the approach and get your rate of descent properly adjusted to stay on the glide path before you get too close to the runway. To avoid the danger of leaving the glide path, make only very minor corrections close to the field.

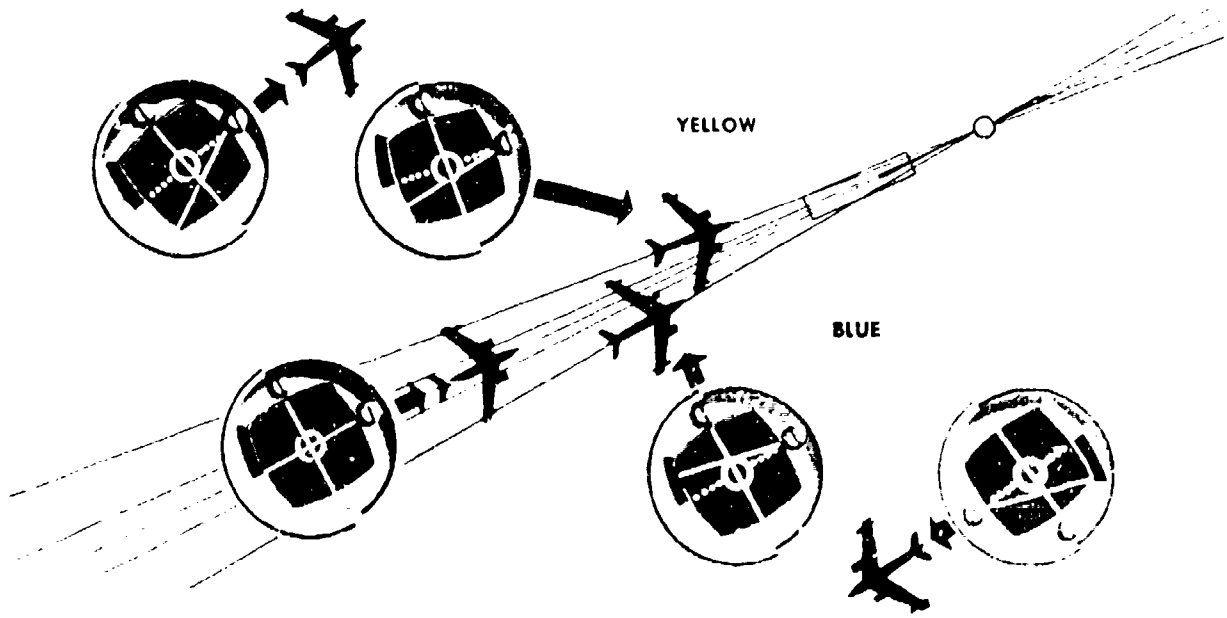


Figure 22-5. Localizer indicator needle action

ILS APPROACH PROCEDURE

You will find the information necessary for planning an ILS approach in Radfacs, and in *Instrument Approach Procedure Charts* ("Pilot's Handbook").

An ILS approach requires considerable planning before its execution. If the destination has an ILS facility, the airport diagram is shown in the "Pilot's Handbook." Here the transition from the last radio navigational aid to the ILS is shown in detail, and you will find the course to intercept from each of the fixes at which you may be held. Normally, you will intercept the localizer beam after passing the radio range station at the destination. In all cases, of course, you must obtain approval for making an ILS approach from the responsible air traffic control agency.

In the same charts you will find the physical setup and cross-section of the localizer and glide path beams, location of the markers and compass locators, and the altitudes to fly. (See Figures 22-7 and 22-8.) You can obtain such information as the station frequency and inbound heading of the localizer beam from Radfacs.

When you receive clearance for the approach, depart the fix on a heading that will intercept the localizer beam as indicated in the ILS chart and as specified in the clearance. At this time bring the cross-pointer into the normal sequence of scan. As soon as the needle starts to move away from its full-scale deflection, interpret its speed of movement to determine the correct time to start a turn to the published beam heading, corrected for any known wind. After you complete the turn, determine the position of the aircraft in relation to the on-course, and make corrections in heading if necessary to center the localizer needle. If you make the interception close to the localizer transmitter, the localizer needle moves too rapidly to allow you to make accurate corrections. In this case hold a constant heading until the needle gives a steadier indication. If you make the interception at a greater distance, the needle moves slowly, and it is a simple matter to roll out in the on-

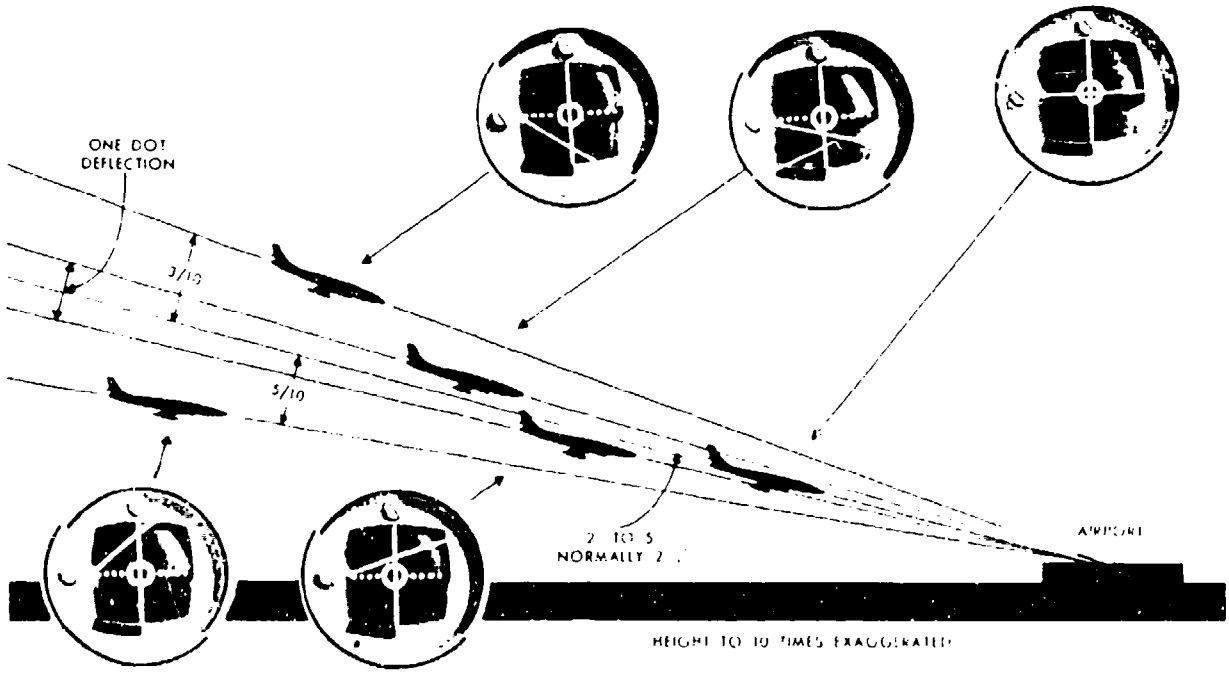


Figure 22-6. Glide-path indicator needle action

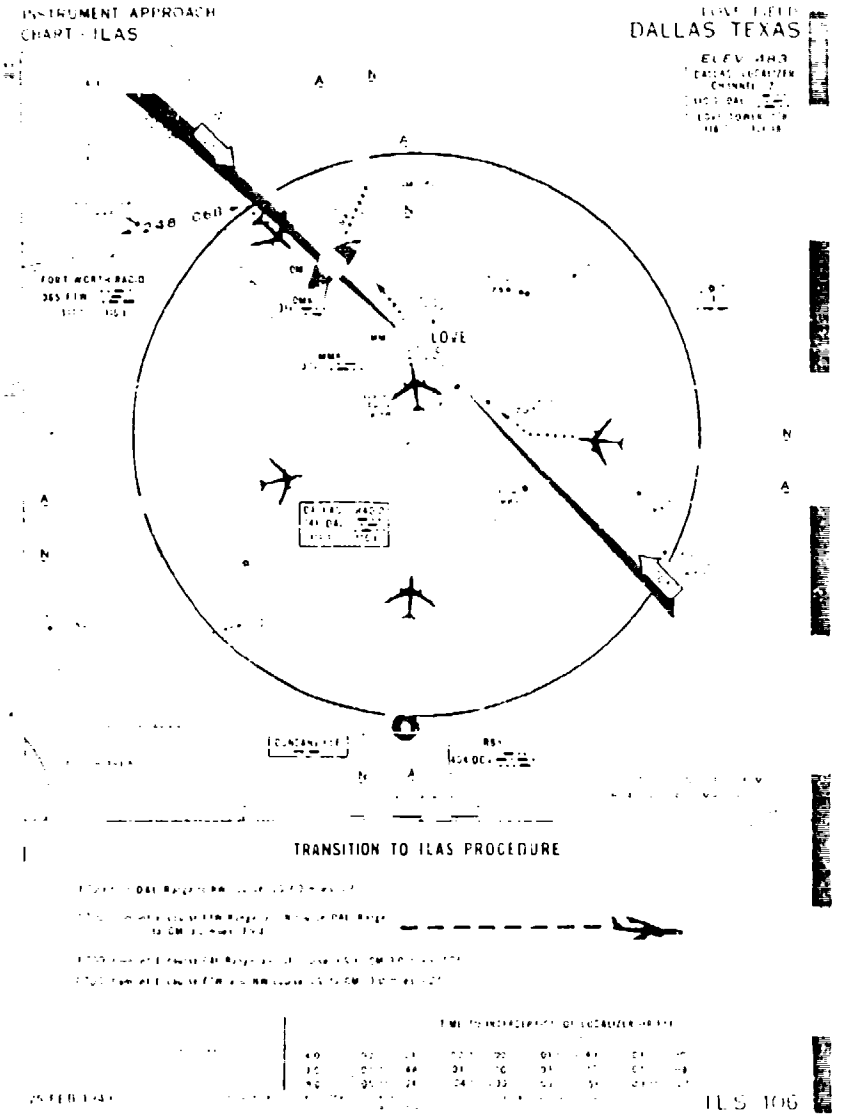


Figure 22–7. ILS approach chart

course. For all practical purposes, the magnitude of the first correction is 20° to 30°.

Once the aircraft is on course, maintain a constant heading. Movement off the beam is caused by wind (provided you maintain the accurate magnetic heading of the beam), and the rate of deflection of the localizer needle indicates the force of the wind. In most weather conditions which require an ILS approach, the surface wind velocity and direction you obtain from the air traffic control agency are accurate at the different altitudes of the approach. Apply drift correction just as you do for ADF tracking. To follow the localizer beam, once the needle is centered, change the heading only a few degrees. Cross-check the needle rapidly, and counteract the first off-course indication. You must coordinate all corrective turns and not allow the degree of bank to exceed the

number of degrees to be turned. Proper beam following will result if you determine the exact heading, within one or two degrees, that will keep the aircraft precisely aligned.

The point at which you intercept the localizer beam from the radio fix is determined by your clearance or the procedure shown in the "Pilot's Handbook." If the point of interception is 3 miles or more beyond the outer marker, turn inbound to the published localizer heading, perform the pre-landing check and reduce the airspeed to the final-approach speed. If the point of interception is less than 3 miles from the outer marker, follow the beam outbound from the outer marker for a maximum of one minute, and perform the pre-landing check. This time is variable and is governed by the amount of altitude it is necessary to lose before reaching the final-approach altitude and the amount of time required to decelerate to the approach airspeed. After this predetermined time has elapsed, make any standard-type procedure turn in the proper direction.

Cross-check the localizer needle frequently during the last 90° of the turn to the inbound heading to determine the accuracy of the procedure turn. If the aircraft approaches the heading which is 45° from the inbound heading and the localizer needle continues to indicate a full deflection, return the aircraft to level flight so as to approach the beam at a 30° angle and accomplish a normal interception. On the other hand, if you approach the 45° heading and the localizer needle starts moving toward the center, continue the turn. Then, by cross-checking the needle, you can adjust the rate of turn so as to have an on-course indication by the time the aircraft is on the inbound heading.

Start a descent to the final approach altitude when you complete the turn. When you reach this altitude, reduce the airspeed to the final approach speed, lower the landing gear, and complete the final flap adjustment. Maintain the final approach altitude during the reduction in airspeed and hold it until you intercept the glide path. Precise beam following is of primary importance. Make every effort, before reaching the outer marker, to determine the exact heading which will keep the aircraft on the projected center line of the runway.

The final approach altitude is normally 1,000 feet above the field elevation and, at this altitude, you intercept the glide path over the outer marker. At most installations, the glide path cross-pointer starts the downward movement from a full-scale fly-up indication slightly before the marker beacon light indicates the position over the outer marker or before passing the compass locator. As soon as the glide-path cross-pointer starts to move down, prepare for the power reduction to establish the descent. The amount of lead is governed by the speed of movement of the pointer.

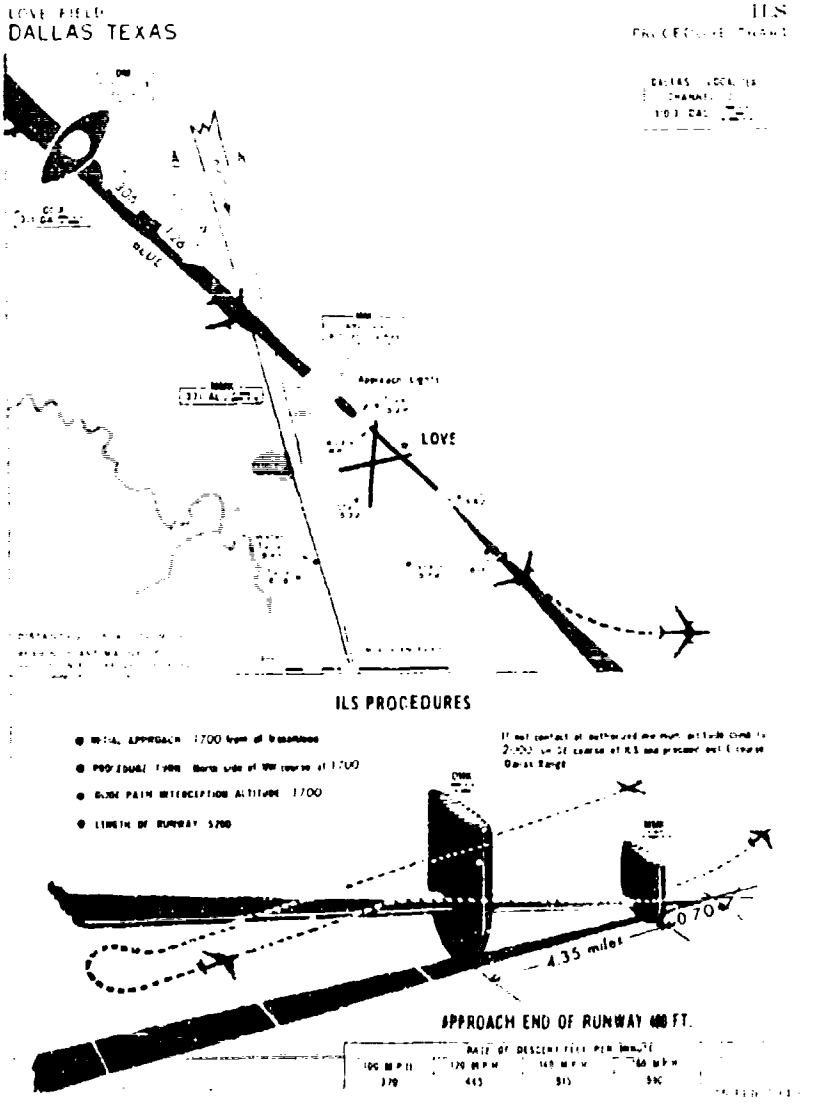
When the glide path crosspointer indicates the starting point of the descent, reduce power to the predetermined setting and establish a descent at the desired rate. During this final-approach phase, you must scan very rapidly and make small corrections in pitch and bank as soon as the cross-pointers deviate from the center. Following the glide path beam is very much the same as following the localizer. However, since the glide-path on-course is only 0.8° in depth, the rate of movement to an off-course indication is rapid. When you detect an off-course movement adjust the nose attitude to establish a new rate of descent which will intercept the glide path. Be careful to avoid overcontrolling the nose attitude.

You should make an instantaneous calculation of the amount of pitch correction to apply and as you apply the control pressure, control the amount of pitch change by cross-checking the horizon indicator. The pitch change should not exceed a movement of one half the width of the horizon bar and often a much smaller movement is desirable.

After applying the correction, cross-check the vertical-speed indicator to determine whether or not the change in the rate of descent is adequate. For example, if the aircraft is descending at an initial rate of 600 fpm and the glide path needle moves quite rapidly to a fly-up indication (a 2-dot deflection) before a change in pitch can be made, change the nose attitude so that the horizon bar moves about one-half the width of the bar. Then observe the vertical-speed indicator; it should indicate a descent of 300 to 400 fpm. Maintain this new attitude until the glide path crosspointer returns to the center. Then change the nose attitude toward the original indication on the horizon indicator; however, adjust the attitude so that the horizon bar movement is one-half the original displacement. This correction should indicate a new rate of descent of 500 fpm on the vertical-speed indicator. Maintain the nose attitude until the crosspointer again indicates the need for another correction.

From this example you can see that following

Figure 22-8. ILS procedure chart



the glide path beam is much the same as following the localizer. (Use the vertical-speed indicator as the primary pitch control instrument, and use the heading indicator as the primary bank instrument.) Normally, you keep the power constant, but bring the airspeed indicator into the scan to determine the need for a power change. During the descent, if the airspeed differs 5 knots from that desired, change power to counteract it.

Observe the minimum altitude listed on the appropriate chart. In the case of an emergency, however, if the aircraft has not broken out of the overcast and the pilot elects to continue the approach below this altitude, he should set a definite altitude at which he will go around if still on instruments.

As the aircraft progresses inbound, cross-check the altimeter over the middle marker beacon to determine the accuracy of the glide path beam. As the altitude at which the glide path intersects the middle marker may vary considerably at different installations, you should obtain the correct altitude from the "Pilot's Handbook," or ILS Charts. If the altimeter indicates a deviation of more than fifty feet from the prescribed altitude (with the altimeter set accurately, allowance made for instrument error, and with the glide path needle centered), start a missed approach if the ground is not visible. Continuing the approach under these conditions is hazardous. If the ceiling is less than 100 feet and you continue the approach, decrease the rate of descent in preparation for landing.

Most of the CAA ILS installations provide a low-frequency homing facility at both the outer and the middle markers. Information as to frequencies and location is available in the "Pilot's Handbook," ILS Charts, and Radfacs. If this aid is available, tune the radio compass to the outer marker compass locator, and after passing it on the final approach, retune the radio compass to the frequency of the middle marker compass locator. Use the locators as a check on the reliability of the localizer needle indications; they also provide a more positive position for the altitude check.

MISSED APPROACH

Check the missed approach procedure in the "Instrument Approach Procedure Charts" before starting the approach. The time when it becomes necessary to pull-up and pull-out it is not time to start trying to read the chart page. If the need for missed-approach procedure becomes indicated, be ready to act promptly.

CHAPTER 23

AIRBORNE RADAR IN WEATHER FLYING

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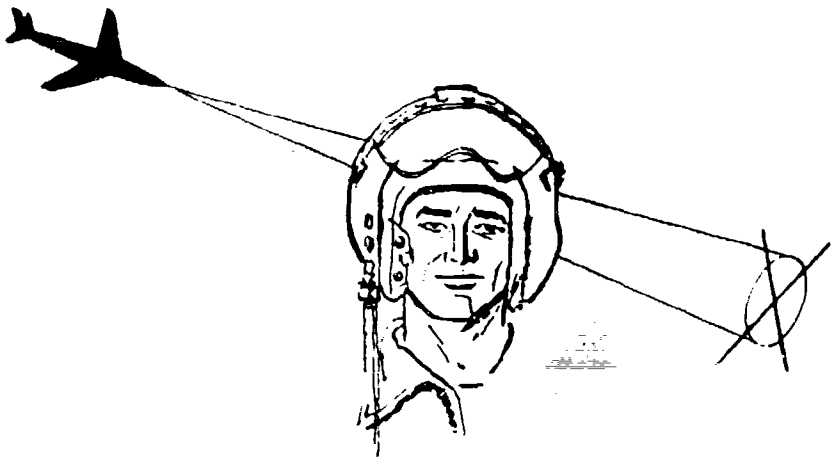


CHAPTER 23

AIRBORNE RADAR IN WEATHER FLYING

RADAR is installed in naval aircraft primarily for tactical purposes; its use for nontactical purposes is only secondary. In addition, there are many different types of radar equipment in various aircraft, and the capabilities and usefulness of these pieces of equipment for instrument flight vary. It is, therefore, difficult to lay down standards or procedures for using radar in instrument flight.

The discussion in this chapter is limited to:

1. The use of airborne radar to navigate, including making landfall, following course, avoiding terrain obstructions, using Racons, determining wind, making ground speed checks, and intercepting ships.

2. The use of airborne radar to detect and avoid precipitation (storm) areas.

3. The use of radar to avoid collision with other aircraft, especially on airways or in congested areas.

This does not mean that radar has no other uses. Nor does it mean that every radar equipment will perform all of these services.

EQUIPMENT

Not every aircraft is radar equipped. However, with the rapid increase in flying speed and the ever growing need for all-weather operations, it's becoming more and more important to be able

to seek out the enemy and destroy him without any visual contact whatsoever. For this reason, a constantly increasing percentage of naval aircraft are being equipped with radar.

As a pilot, your chief concern is with the antenna and the scope presentation of the equipment. Since the scope presentation of the equipment depends largely on the antenna, that is considered first.

Radar Antennas

The radar antenna may be fixed and simply indicate targets along a "pencil line" running out in a single direction. The antenna used with A-scope radar is of this type. It is more usual, however, for the antenna to sweep or search. Radars with antennas which search around a 360° circle from the aircraft, either level or tilted up or down, are called search radars and use the Plan Position Indicator (PPI) scope. Those with antennas which search a sector or are ahead of the plane are called sector search or forward scanning radars. The B-Scope, C-Scope, and E-Scope radars are variations of the forward scanning types, and give two of the three possible pieces of information about the target: bearing (azimuth), range, and elevation (relative to the radar plane).

Radar Scope Presentations

The radar scope presentations which you are most likely to encounter are the PPI, A, B, and C. There are other scope presentations for interception, fire control, sea search, GCA, ECM, and other uses, but they are not discussed here.

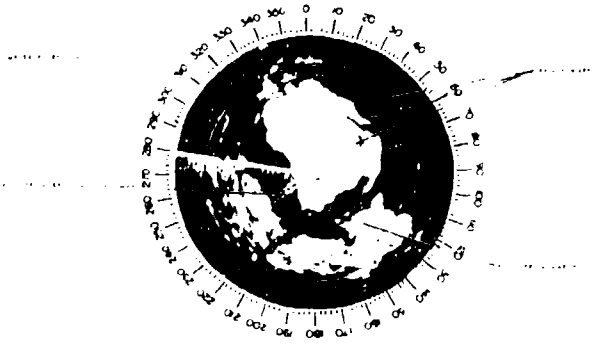


Figure 23–1. Plan position indicator (PPI)

PPI Scope

The PPI (Plan Position Indicator) scope gives a polar-coordinate presentation of the search area—that is, a map-like picture of the area covered (Fig. 23-1). The PPI shows all 360°, with the aircraft usually represented by the center of the scope, though sometimes it is offset from the center.

With sets installed in the larger aircraft, range may be estimated directly from range rings superimposed on the PPI, and bearing from radial lines. For more exact readings, movable rings and a movable radial line may be adjusted by hand so that they fall right on the target pip. Range may then be read from a counter, and bearing may be read from the bearing circle at the edge of the scope. The timing system is made to produce equally spaced concentric circles about the scope center which show the distances of objects from the transmitter. Multiples of 1, 5, 10 or 20 nautical miles are often used.

The top of the screen can represent dead ahead for the aircraft, or it can be oriented to true north. In some aircraft installations it is possible to synchronize the PPI picture with the compass so that the top of the screen represents true north.

Many PPI indicators have provision for what is called sector scan. Instead of revolving around 360°, the antenna is moved back and forth through a sector up to about 60°. The antenna scans this area at about two to three times the rate of normal revolution. Thus the search area is covered more frequently and the targets are shown more distinctly.

A-Scope. On the A-scope, only range is presented, but accurate bearings may be obtained with auxiliary aids. Ordinarily, a single line (the time base) appears across the scope (Fig. 23-2). If the gain is stepped up, the time base may appear as "grass," so called because it looks like grass. When a target is within range, it appears as a sort of peak (called a pip) sticking up from the line or out of the grass. For bearing, antenna rotation may be stopped at the point where the target pip is of maximum size. Bearing may then be read from a counter or dial locked to the antenna.

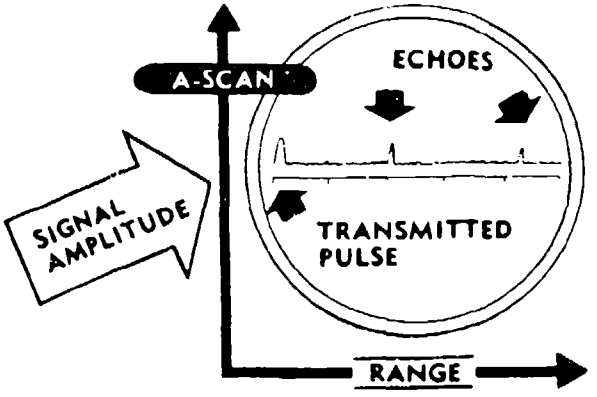


Figure 23–2. A-scope presentation, range only

B-Scope. The B-scope gives bearing and range in rectangular coordination (Fig. 23-3). The bearing scale is along the horizontal axis, the range scale along the vertical. This presentation is often used in fighter aircraft; the scope shows a sector of perhaps 130° or 150° ahead, with "dead-ahead" represented by the center line of the scope. Since the B-scope presentation puts a pie-shaped sector into a rectangular presentation, it is distorted and does not show a "map" of the sector it scans. Still, it is close enough to a map to give you a pretty good quick picture of the situation ahead. What's more, since small deviations in bearing become more conspicuous as the target gets closer, it's a good scope to use when closing in on a target or to avoid obstructions. The B scope gives very good resolution in range and bearing; that is, targets very close together can be distinguished as separate targets.

C-Scope. The C-scope gives azimuth along the horizontal scale and elevation (or depression) along the vertical scale (Fig. 23-4). You can see at a glance whether you're flying straight for a target aircraft, or whether you should move up or down or to right or left to get on it. Modifications which present a means of estimating the range are often encountered. In Aircraft Interception radar, the C-scope is used to indicate antenna deviation and scan.

E-Scope. The E-scope shows elevation versus range. It's like a B-scope tipped on its side.

Variations in Scope Presentation. On some scopes used in aircraft, you will find you can obtain all three coordinates—azimuth, elevation, and range. Since scopes are basically two-dimensional, the azimuth-elevation or range-elevation presentation must be superimposed on the range-azimuth presentation, with a switch to select one or the other; or one presentation may be placed above the other, so that, in effect, you have two scopes.

Most radars have both long and short range scales, and some have several intermediate scales. The long scale may give ranges out to 100 miles or more; the short scale may be less than a mile. For instance, one night search and intercept radar has scales of 1,500 yards and 2, 8, 20, 50, 100, and 150 miles. Usually, a scale longer than 100 miles is intended primarily for reception of radar-beacon (Racon) signals rather than echoes. However, the 100-mile (or greater) range may be very valuable in making landfall or establishing position in over-water flight.

In a number of radars, a sweep delay control makes it possible to eliminate the nearby areas from the presentation and show only the areas further out. This is done by delaying the sweep on the scope. Ordinarily, the sweep on the scope starts at the same instant that the radar pulse is transmitted. Since the closest targets are normally those directly beneath the aircraft, there is a hole in the middle of the picture. This hole rep-

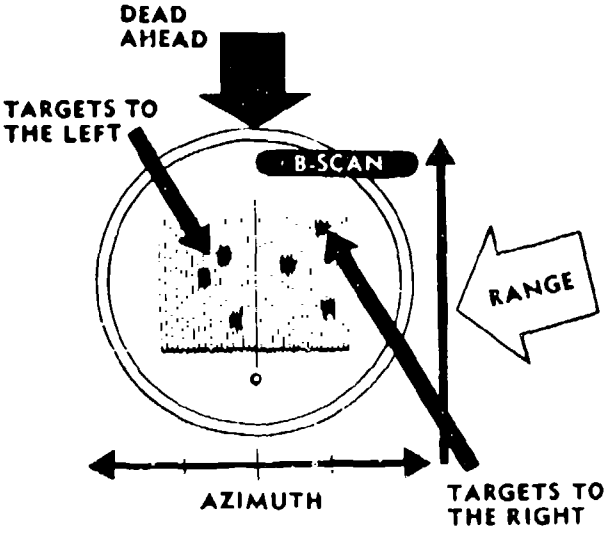


Figure 23–3. B-scope presentation, range vs. azimuth

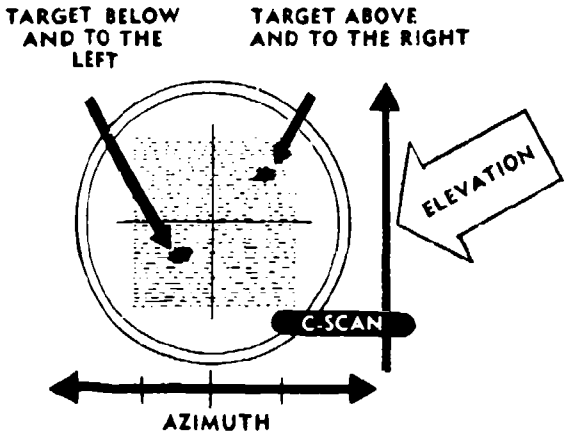


Figure 23–4. C-scope presentation, azimuth vs. elevation

resents the distance between the aircraft and the ground (Fig. 23-5). To eliminate this hole, the start of the sweep is delayed by a selected amount equivalent to the altitude. With this delay, called altitude delay, the hole is closed up and objects underneath the aircraft appear near the center of the PPI picture. Altitude delay also performs another function. As it is a measure of the distance between the aircraft and the ground or sea below, it can be used to indicate absolute altitude.

Provisions are also made for sweep delay in larger increments in order to give a more detailed picture within certain ranges. Some equipments provide altitude delay up to approximately 35,000 feet and sweep delay up to 200 miles in units of 10 miles. With a 20-mile range setting and no altitude delay, but with sweep delay set at 20 miles, the picture in this equipment would show returns from the area between 20 and 40 miles distant.

RADAR NAVIGATION

The most important use of airborne radar in all-weather flight is as a navigational aid. First of all, radar gives bearings and distance to many kinds of landmarks from which position may be determined with a chart of the area. Secondly, it gives bearings and distance to racons (radar beacons). These beacons may be those listed in Radfacs and shown on U. S. aeronautical charts, or may be those located at classified locations during wartime. Thirdly, with this data, radar fixes make it easy to determine track and ground speed. Two other procedures are less generally known—the use of radar to find surface wind over water and the use of radar to intercept a target when the wind is unknown and, in some cases, when the target is moving in an unknown direction.

The primary and easiest navigational use of radar, however, is to locate a point of landfall, a ship, or an island when flying over water. Carrier aircraft use their radar extensively for reaching their targets and for returning to the ship. Either the forward scanning sector search or the PPI types of equipment will perform this function.

Target Identification

As a navigational instrument, the PPI scope has proved highly versatile. When used by an experienced operator, the map provided by the scope shows rivers, railroads, towns, and lakes clearly enough to allow them to be used as pilotage points.

Bodies of water approximate a plane surface, and water areas appear dark on the scope. Land surfaces, on the other hand, are always uneven and present many surfaces which will reflect part of the beam. Land, therefore, gives a brighter return than water (Fig. 23-6).

Any relatively level and horizontal surface, ocean or land, gives its strongest returns at an angle of 90° to the surface. This central return is referred to, over land, as "normal ground return," or, over the ocean, as "normal sea return." Coastlines or islands having rough or prominent cliffs or bluffs along the shoreline appear at distant range as a string of elongated beads. High ground, coastal cities, and bluffs give the first returns.

There is ordinarily no return from the sea, except directly below the aircraft. However, the altitude of the aircraft and the tilt of the antenna determine the location and brightness of this sea return on the screen. There is a slight return from a choppy sea. In a rough sea, the waves sometimes reflect more echoes than a ship, and hence, you lose the ship echo in the sea return (Fig. 23-7).

When sea return interferes, it boils down to

the problem of how close an approach to the target you want to make. Obviously the lower the altitude, the less direct is the sea return at short ranges. At lower altitudes, you may tilt up the antenna sufficiently to exclude the bulk of the sea return and still retain the target. You will get a weaker target echo because you will be viewing it with the lower portion of the beam. In this situation, changes in flight attitude may lose the target for you. This loss may be temporary or permanent, depending on your ability to follow changes in attitude with appropriate changes in antenna tilt.

There is always some reflection from the land, but its brightness is regulated by the amount of gain. With low gain setting, only the bright return of the coastline shows and the land appears dark. As the gain is increased, the brightness of the land behind the coastline increases. Land and water contrast is the quickest and easiest to use in pilotage and bombing.

The far banks of bodies of water appear brighter than the near banks. This is because the ground on the near bank presents a poor surface for reflection since the beam strikes it nearly at the grazing angle. The far side is bright because the beam is striking the bank broadside. This ensures a better reflection than from the surrounding land.

Smooth-frozen lakes and rivers present no radar return unless they are directly below you. Broken ice does give a bright return. When snow falls on the smooth ice and is blown into tiny ridges, there is a slight return.

Near slopes of mountains appear increasingly brighter as the beam falls on the more vertical slopes. Far slopes are completely dark because the beam does not strike them. The ridge line is brightest. An isolated peak appears as a bright spot with a deep shadow behind it. These darker areas can be distinguished from lakes because the brightest return from a lake is always the far shore. When the aircraft is approaching a mountain or mountain range and half of the scope is black, it is an indication that the ridge is higher than the aircraft and it is time to climb or change course (Fig. 23-8).

Cities, towns, and airfields present a great variety of reflecting surfaces. They reflect back a considerable portion of the radar energy and appear as bright spots on the scope. Large cities give a much brighter and more consistent return

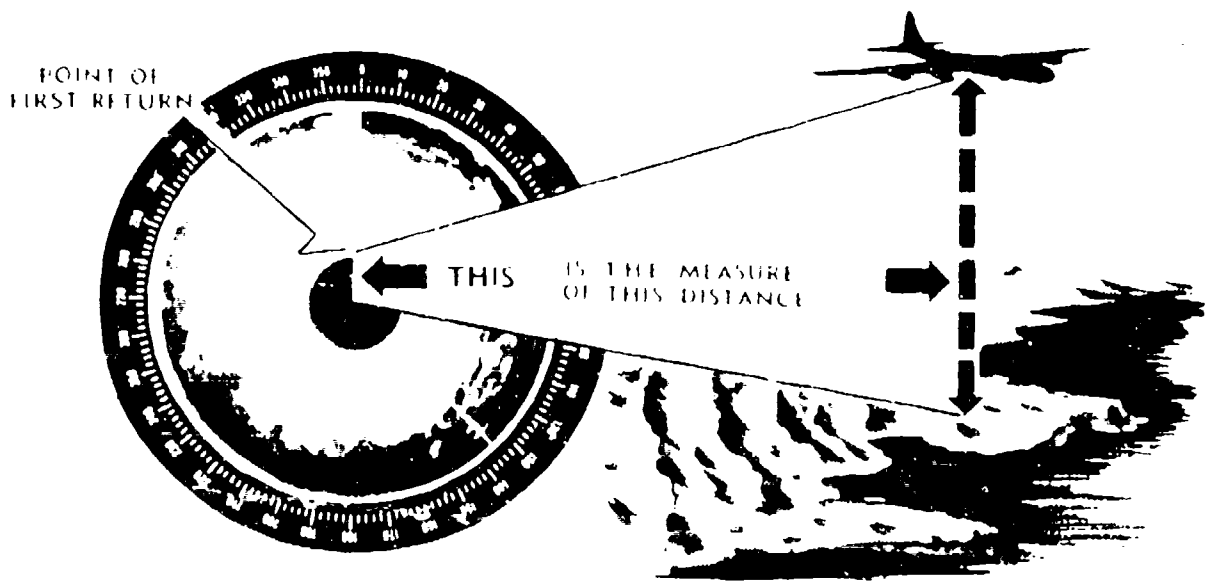


Figure 23-8. The need for altitude delay

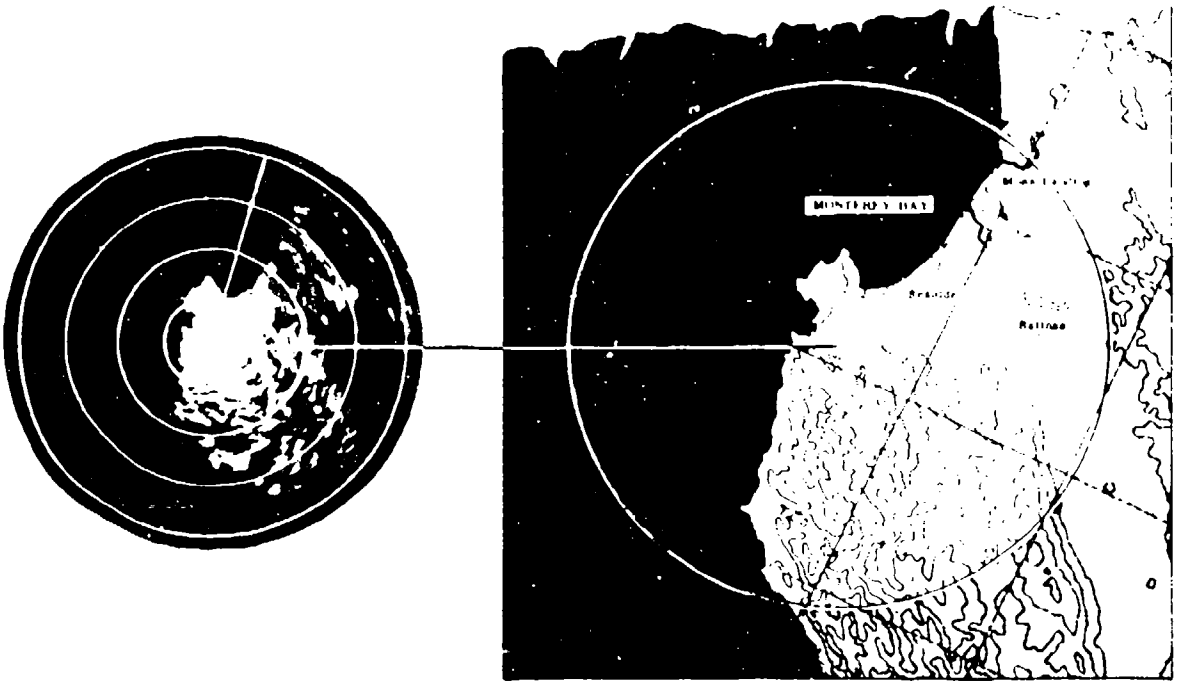


Figure 23–6. PPI scope showing land-water contrast

than smaller cities, as they usually contain larger buildings and therefore more reflecting surfaces. Within the confines of the larger cities are targets of varying degrees of brightness. These do not appear stable since their relative brilliance changes as the airplane moves over the city (Fig. 23-9).

Small towns and groups of farm buildings, other man-made structures such as bridges and overpasses, and even mountain peaks, characteristically give a glinting effect. That is, they appear bright for a half minute or less as the aircraft comes full broadside to the reflecting surfaces of the target.

A railroad or highway does not appear continuously on the scope, except in unusually level and flat country. They do, however, appear enough of the time that their returns should be understood. When they appear, they show as bright returns, generally as a narrow bright line which may be interrupted for short distances. The strongest part of the return is caused by the reflection from embankments or fills on which the roadway is built, not from rails and ties. Concrete and metal culverts, bridges, and larger fills give brighter and wider reflections along the roadway. Railroads and highways running parallel to the radar beam do not reflect back.

Precipitation can be identified apart from terrain in two ways. The first is to raise the tilt of the scan above the horizon when the altitude is equal or greater than the suspected terrain. If it disappears, the target is terrain. If it stays on the scope, the target is precipitation. The second is to use a circular polarized antenna. If the echoes are from precipitation, they will diminish or disappear altogether when the circular polarized antenna is used. They remain with the horizontal polarized feed-in. If the antenna installation permits, it's a simple matter to switch antenna polarization and pick out all precipitation echoes on the radar scope. Targets which remain unchanged upon switching polarization are ground targets. A point to remember is that in the case of very heavy precipitation it is possible that radar with less than a 10-kilowatt output will not reveal a mountain peak beyond a storm. If there is doubt, climb or turn back.

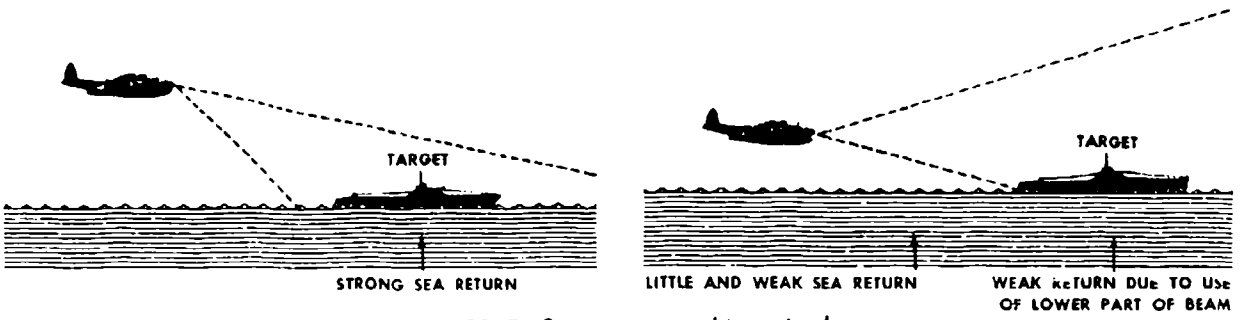


Figure 23–7. Sea returns and target echo

Azimuth Stabilization

There are two ways to view the picture seen on the PPI scope, depending on whether or not azimuth stabilization is available. With the azimuth stabilization switch on, the output of the compass is tied into the radar set. The PPI scope then becomes another remote compass indicator and you see the pattern on the scope as it appears on a chart. The top of the scope represents either true or magnetic north, depending on whether variation has been set in.

It is easier to navigate with azimuth stabilization on. A bright line on the scope, known as the lubber line, always points in the direction that the aircraft is heading. You read true or magnetic bearings on the azimuth scale, and the pattern on the scope is always oriented with the chart. With azimuth stabilization off, the top of the scope represents true heading. The bearings you take are then relative bearings.

Radar Fixes

Radar fixes simplify navigation. By using them you can measure distance and azimuth with greater accuracy and speed than by the usual methods. You can get fixes with the PPI scope in several different ways:

1. Range and bearing. This is considered the most nearly accurate method.

2. Bearing only. Getting a fix by bearing only is accurate, for it is not affected by slant range even at short range. Two or more bearings are necessary.

3. Range only. By reading the range of two

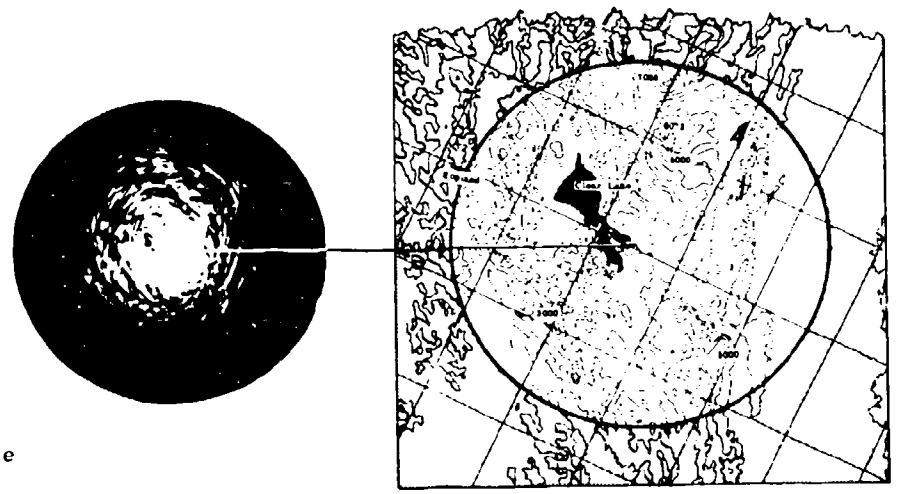


Figure 23–8. Mountain range or range line on PPI scope

or more targets on the scope, it is possible to plot intersections and obtain a fix.

When you take a radar fix on a target more than 20 to 25 miles away, you can use the slant range as the ground range for all practical purposes. When the target is less than this distance away, you must convert slant range to ground range. You can do this with the E6D computer, a computer drum chart, or a conversion table. On the newer sets the conversion to ground range is done automatically.

Groundspeed Wind and Drift

Radar simplifies the problem of accurately determining ground speed, wind, and drift to supplement dead reckoning. From a series of radar fixes or from only one fix, you can find track from the starting point. You can determine ground speed by dividing the distance from the starting point to the last fix by the time elapsed.

When you get true heading and true airspeed from the compass and airspeed indicator, you have all the data you need for computing wind and drift.

There are several ways of determining wind and drift by use of the PPI scope. Among these are:

1. Air plot. This is the use of air position and true position as obtained by radar fix.

2. Target-timing method. Drift, track, and ground speed can be determined by taking a series of bearings on a target as it moves across the scope and by recording the time.

3. Track and ground speed wind. Wind is determined by timing the distance between two fixes to establish the ground-speed and measuring the angle between the fixes to establish a track. The track and ground speed are compared on the E6D computer to the heading and true airspeed, and the wind is thus computed.

Radar Beacons (Racons)

Another radar device which is used for navigation and also for tactical bombing is the radar beacon, usually called racon. A racon is capable of responding automatically to radar interrogations by transmitting a reply which is coded for identification. It consists of a receiver which picks up radar transmissions and a transmitter which emits a reply consisting of a series of pulses

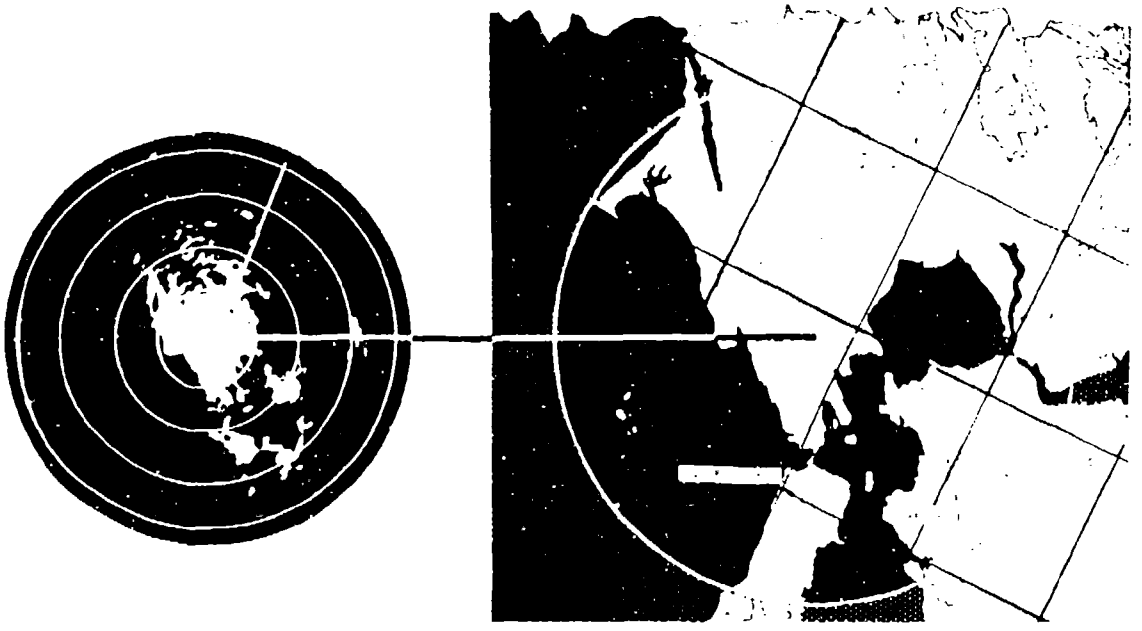


Figure 23–9. Cultural features as shown on PPI scope

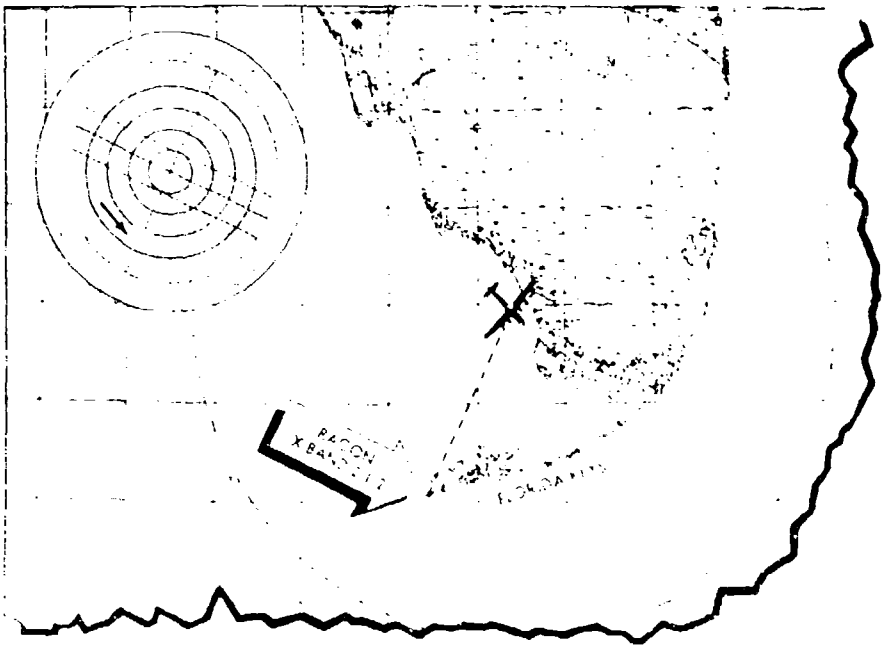


Figure 23–10. Racon reception

identifying the station by the number or arrangement (Fig. 23–10).

Most racons transmit the reply on a slightly different frequency than that of the interrogating radar, and the aircraft radar receiver must be tuned to receive the racon transmission. Because of this, racon transmissions do not interfere with regular scope returns, and vice versa.

Racons provide accurate information without regard to visibility conditions and thus are valuable as a navigational aid. In addition, they maintain radio silence except when triggered by the proper radar, and provide information only to those radar sets tuned to receive them. Racons are therefore unique among navigational aids because of the quantity, quality, and security of useful information that they provide. Racons let you get the direction of the racon from your aircraft (when you use a PPI-type scope), and the range of the racon from the aircraft (on most types of scopes).

You determine the range and direction of the racon from the radar indicator in the same way that you determine the direction and range of any other target. The chart location of the racon is given by the racon's code, which consists of different numbers and spacings of pulses and identifies the racon in much the same way as the flash coding of a lighthouse identifies the lighthouse. By determining the reciprocal bearing of the racon from the aircraft you can plot your position on a chart.

When flying within the range of a racon, you can use it either for homing or for determining the position of the aircraft. The range of the racon depends on its site and the altitude of the aircraft. When flying at 20,000 feet, you should be able to receive a racon signal at 170 nautical miles or more. To determine the distance from the racon, measure the distance from the center of the scope to the first arc of the racon signal and add the distance of the sweep delay setting.

You can take two bearings simultaneously on two racons. By plotting the reciprocals of the bearings, you can determine a fix using azimuths only. You can also determine a fix when using an A- or B-type scope by plotting ranges of two or more racons.

Useful as racons are, don't call on them unnecessarily. Although they are designed to respond to interrogations from many aircraft at once, you may interfere with other aircraft seeking racon assistance.

Surface Wind Estimation

When flying at low altitude at night over water in an area where no other radar targets appear, radar can tell you the direction and velocity of the surface wind by the difference in the sea return to windward. However, such estimations of surface wind are usually worthwhile only from altitudes of less than 1,500 feet and for wind velocities over 15 knots. Below this velocity, you may become confused between the returns from swells and the wind waves.

When the wind velocity is over 15 knots, the wind makes its own independent waves, and since the radar is sensitive to the difference between the lee and the windward slopes of waves, you can make a fair estimate of the direction and force of the wind. Base your estimate on the strength of the sea returns. You receive sea returns from the greatest distance when you scan in the direction from which the wind blows. The slope of the waves in this direction is definitely steeper, giving a better angle of reflection and higher returns. Of course, your radar readings are not as reliable as the visual estimate you make on a clear day when you can see the height of the waves and the whitecaps they make, but your radar estimates are better than none at all.

On flights at night or through continued fog over long stretches of open sea, a knowledge of the surface wind, direction and force is often the only indication of drift that you have—or can get. At the beginning of each flight, note carefully the appearance of the sea returns on the screen when you know the direction and force of the wind from weather reports. Remembering this "picture," you can spot any changes and translate these changes into a decent guess on the changed direction and force of the wind. At higher altitudes, you obtain a 180° reversal of apparent wind due to reflections from the back of the waves instead of the front. The definition of such reflections, however, is not as clear.

RADAR TARGET INTERCEPTION

Suppose a surface target of some sort appears on your radar scope at sea and you wish to intercept this target. If the target is land, and is fixed

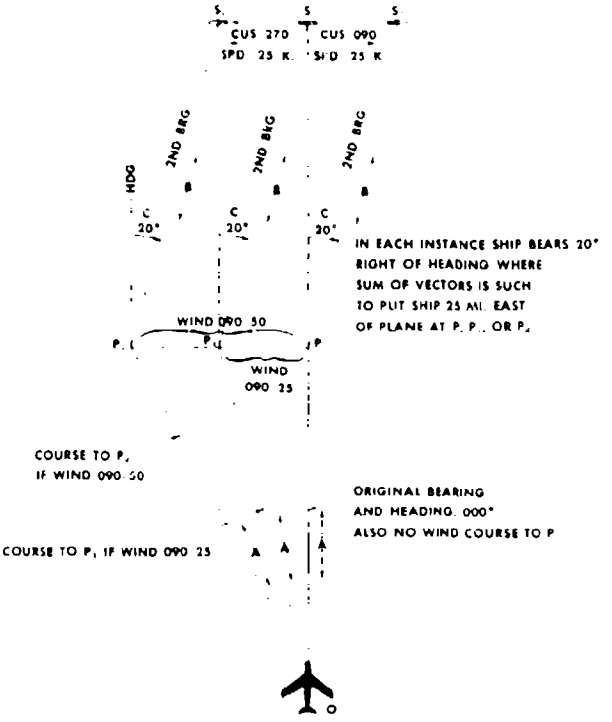


Figure 23–11. Interception of moving radar target. The sum of the vectors which caused radar drift of 20° in each of the three cases shown is the same. Thus, the pilot can intercept the ship whether at P, P1, or P2 by ascertaining change of bearing (radar drift), distance flown from A, and distance to go

in position, you can turn till it bears 0° relative and home in to it or track in to it just as on the ADF. You can use any of the methods set out in Chapter 18 for interception. If there is no wind, you will intercept it without adjusting heading. However, suppose it is a ship, and its course and speed are unknown. Homing or tracking methods will result in a curved or dog-leg course and a stern-on interception. Following is a better method to intercept any target, whether moving or not. It is especially useful over water where no position or wind drift checks are possible.

In the interception of a ship, there are several factors which would prevent you from intercepting the target if you flew the first radar bearing without alteration. (1) Wind might blow the aircraft off the bearing heading. (2) The tar-

get (ship) might move. (3) A bubber line error in the compass or radar might create a constant error. Consequently, the entire interception method given here is based on the relative position of aircraft and target, not on geographic observations.

As shown in Figure 23-11, the sum or net vector effect is what counts. In this figure, you see an aircraft at point O which takes a bearing of 000° on the target, a ship at point S. From point O it flies with this bearing as heading. One hour later it has reduced the range to half the original reading, and is at P, P_1, or P_2. If there is no wind, it is at P. If the ship vector were 25 knots on course 090 the ship is now detected at S_1 which, say, is 20° to the right of heading. If the ship were motionless, but the wind were 25 knots from 090°, the plane would be at P_1 and the ship still at S. But the bearing is again the same 20° right of the heading. If the wind were 090 50 and the ship's course and speed 270 25, the bearing would again be 20° right of heading. In short, in all cases the sum or net vector is 25 miles east of heading and the ship is in every case 20° to the right of the heading. What this means to you is simply that you don't have to know whether the target's radar drift (change of bearing) results from wind, target motion, or other cause.

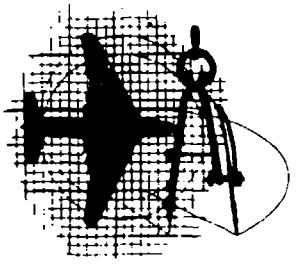
If the aircraft is at half the original range when at P, P_1, or P_2, then if it alters 20° to the right of the new bearing (40° right of heading), it will be on virtually an interception or collision course. This is approximate because on the new bearing a slightly different drift would result. For example, in the above instance, after altering 40° right to intercept in the case where the wind had been 090 25 and the ship motionless, the wind would now cause somewhat less drift on the new heading than on the original heading. Obviously, the amount of this error in miles is smaller if the distance to go is shorter. This system is also approximate because of errors in distance measurements. Furthermore, this error is on the overcompensation side that is, it tends to bring the aircraft ahead of the target at interception, which is a better attack position if that is involved. The error is therefore no handicap.

Basically, there are two ways to use this system of interception:

1. Fly the original bearing heading until quite close. At this time a considerable course alteration is necessary to get on the new bearing, but a small additional alteration will take care of any radar drift on the short leg.

2. Fly the original heading a short time and alter as soon as you can reasonably determine radar drift. The alteration to get on the new bearing is small, but the drift correction to allow for all factors is larger.

How should the new radar drift correction be determined? The answer lies in proportion. The radar drift correction is equal to the distance remaining (B) times change of bearing (C, radar drift) in proportion to the miles flown on the first heading (A). You can see this in Figure 23-12. At the left is method 1 and at the right is method 2. In each case BC/A gives the number of degrees to head off the new bearing. If the target had drifted to the right on the scope, this correction is to the right of the new bearing. This is the old rule, just as in all navigation, that if actual drift is left, crab to the right to offset the drift. The illustrations in Figure 23-12 show the situation with a fixed target, but as you have already learned, the result would be the same if the target



had moved and the aircraft had no wind or if both affected the radar drift.

After turning to collision course, recheck to track to the target. This is necessary because the wind may vary, the drift factor is slightly changed by the change of heading, or the target may change its course or speed.

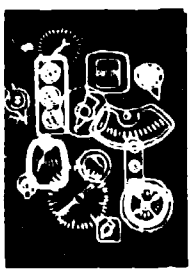
This system, sometimes known as the Turner System, should become second nature to the radar-equipped aircraft crew. The choice whether to alter early (method 2), or alter when close (method 1) depends upon your purpose. Method 2, the

standard Tanner System, is best suited to the interception of land or friendly ships because it involves less total distance. Method 1 is better for patrol or interception of hostile targets because it allows longer observation of the target motion. If the target zig zags or changes speed, this will be averaged out over this longer period. Furthermore, if the target's radar has spotted the aircraft, the target defenses will not be alerted so early if the aircraft does not appear to be on a collision course until close in. If desired, the aircraft can lower altitude to avoid detection between the radar observations. Because this method produces a maximum overcorrection, if any exists, the aircraft is likely to be in a position forward of the target's beam when it finally comes within attack range. Method 1 does not lead to pin point interception, but does bring the aircraft into attack range with a minimum of error or calculation.

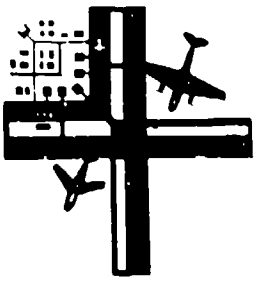
These methods permit interception of either moving or stationary surface targets. You will find them especially useful if you are a carrier pilot. Remember, though, that neither method is suitable for interception of aircraft targets.

WEATHER AND AIRBORNE RADAR

An airborne radar set has a greater line-of-sight range than a ground based radar. For that reason, it can detect precipitation at greater range.



Its ability to detect precipitation, however, is variable, depending on the frequency band used. Furthermore, radar will not tell you whether a given cloud or storm contains vertical drafts, hail, icing conditions, and so on. It only tells you that this target is precipitation, heavy or light. An extremely solid area of precipitation, however, may be hard.



With radar to advise you of the existence of a storm, you should try to find a route which will avoid the precipitation. Even with the Air Intercept (AI) Radar you can detect and often circumnavigate storms. Other sets, however, will usually be more helpful in indicating a route to avoid precipitation. Under such weather conditions, of course, you are likely to be too busy to watch the scope. The radar operator must detect the storm centers and advise you accordingly.

In interpreting echoes, always remember that the more solid and dense the object, the stronger is the echo returning from it. Clouds return echoes because they contain water particles. It is these particles which send back the outgoing radio waves. Therefore, since clouds retain less moisture around their edges, the rims of their target indications "melt" away on the screen rather than remain in sharp outline as a definite part of the echo. Since the center part of the echo may be sharp, the cue to the difference between echoes from weather phenomena and land returns lies in the fading or tapering at the edges.

Heavy clouds, rain squalls, storm centers and the like reflect the radar beam, often from a great distance, and an inexperienced operator can confuse them with land or ship targets. There are, however, certain clues that enable you to distinguish these echoes without too much trouble. The number one clue is, of course, to know where you are. If you know that there is no land anywhere near the position of the unidentified echo, you can immediately rule out that possibility. Again, the echo may cover considerably more area on the screen than ship targets could. The echo may be fuzzy and nebulous in appearance and may even appear beyond the range of ships. At close ranges, its contours will show up but the echo will not be as clean cut as a land echo not will

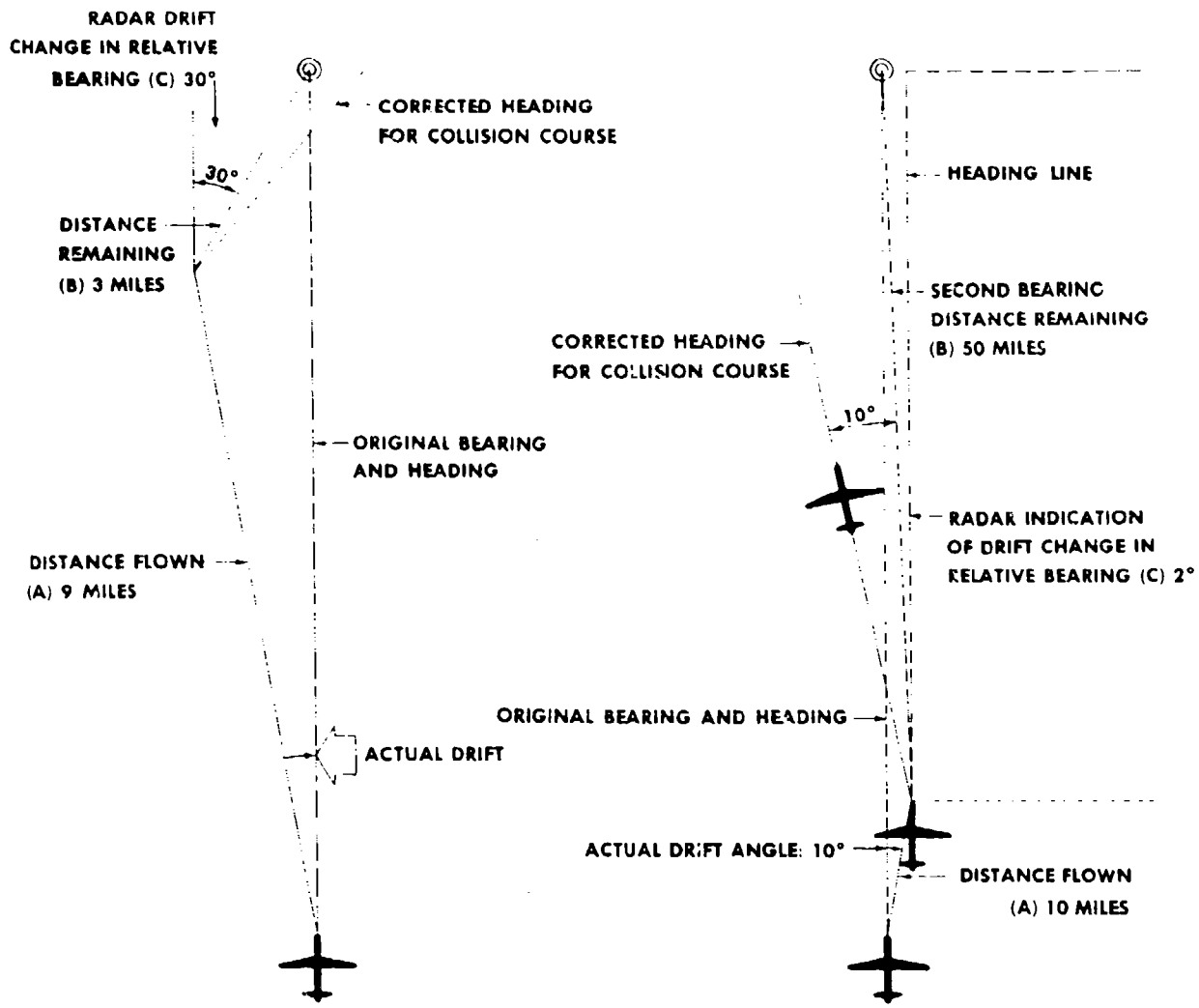


Figure 23–12. Method 1 (left) and Method 2 (right) of determining correction for drift

it is separate into distinct echoes as does a group of ships (Fig. 23-13).

Weather echoes will no doubt be confusing to you until you have experienced them a few times. At long distances, you may find it impossible to identify such an echo, but the solution is easy—get closer and investigate it. As the range closes, the echo will be more and more definite. Location, size, shape, and intensity are the four most common of these echoes.

Watch carefully the echoes from storm areas and you will usually note "dim spots" in the echo that correspond to thin spots in the weather front. They indicate the safer route through the storm area.

Most of this discussion does not hold for the A-scan radar, for it is relatively poor at picking up such echoes, seldom beyond 4 or 5 miles. At such ranges, identification is relatively easy. The PPI and B-scan can detect strong weather echoes almost to the maximum range of the radar. However, you will usually find that distance renders difficult the identification of weather echoes. The reception of cloud echoes is a function of the fre-

quency and power of the radar set. This explains why some squadrons get cloud echoes on their scopes while others do not at the same time. The difference results from the different radar sets used by each.

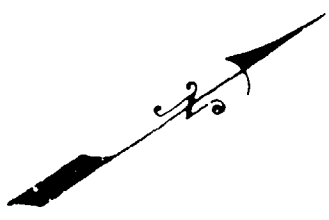
PPI Scan and Weather

Storm clouds and weather fronts in general give very good indications of their presence on the PPI screen, and, depending on the moisture content of the clouds, you may detect them up to about 60 miles and more if you have the altitude. At long ranges, however, it is possible to misinterpret cloud echoes as land, since about the only difference between them is the lack of definiteness and clear-cut edges on the part of the cloud echoes. You get range and bearing from the leading edges of the clouds just the same as with any other target.

B-Scan and Weather

The brilliance of echoes received from clouds varies with their moisture content. Violent, intense thunderheads filled with rain and hail give large, bright echoes almost to the maximum range of the equipment. At close ranges (less than 50 miles), the cloud echo is a large, irregular mass of light, dimmer than land or convoy, with "fuzzy" edges. If you see a small, bright spot within the data area, it may possibly indicate a ship which is under the cloud (at the same range and bearing). It is also possible to "see" one cloud behind another (same bearing, longer range), and a ship also at longer range (same bearing) through the cloud.

You see entire weather fronts as a series of cloud echoes, indicating the dangerous turbulent areas, which, like the "out of bounds" area of a port, are to be religiously avoided. Weather navigation consists simply in staying away from these dangerous areas, and, if necessary, flying on



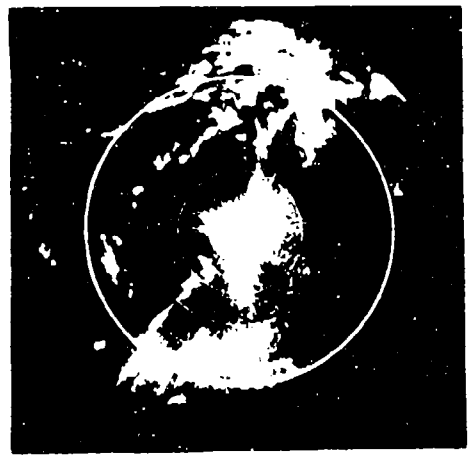


Figure 23–13. Cloud echoes. Note fuzziness and lack of definition

instruments through the "thin" places. The thickness (front to back) is also a fair indication of depth and determines the advisability of flying over instead of around (Fig. 23-14).

Avoiding Areas of Precipitation

Experience has shown that airborne radar can be most useful in avoiding areas of heavy precipitation and thus in avoiding the turbulence, electronics failures, and associated unpleasantness which go hand in hand with flying in these areas. It is especially important that jets and other high-speed types avoid structural damage which can be caused by heavy turbulence or hail. In using radar to detect areas of falling hail, there is no means of making positive identification. However, any solid white echo area next to a large storm area indicated on a radar scope is probably a column of falling hail. Mass turbulence is at the edge of the heavy rain echo and through the rain echo.

In entering a storm belt, select the spot showing the widest separation between areas of heavy precipitation. Select the altitude in accordance with the type of storm encountered and well above the highest terrain. Enter with the antiglow turned on, but with the altitude control in the off position. It is best to fly a set up such as you would use in smooth air and use rpm, altitude and airspeed, disregarding the altimeter except to as-

sure clearance of terrain. In approaching a storm, keep in mind that the radar echo increases as the distance is reduced since smaller particles of moisture are picked up by radar.

RADAR IN AIRWAYS FLIGHT

Since most civil airways lie over land and are well equipped with navigation aids, radar is seldom desired for navigation. It is available, however, for ground speed checks, particularly, when required. As an aid to avoiding terrain, however, radar is of limited usefulness. In mountainous terrain, you can detect mountain peaks projecting above flight altitude by raising the antenna tilt to horizontal. When flying down into a mountain pass or deep valley, however, proper recognition of terrain obstructions becomes more difficult. Avoid areas of sharp, bright echoes and the areas behind such echoes which are shadowed. Try to fly in areas of flat, unshadowed echoes, when possible. Except in emergency, however, it is not safe to rely solely on radar to fly through mountainous terrain at any altitude below the peaks near the route or below the CAA airways minimums, whichever is applicable.

CHAPTER 24

NIGHT VISION

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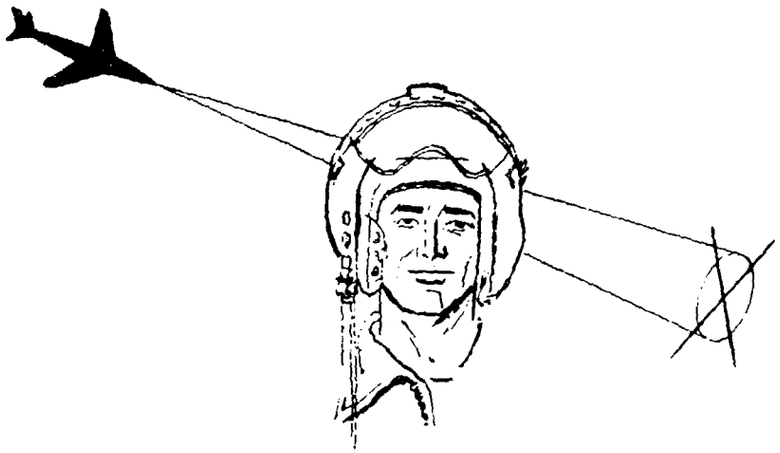


CHAPTER 24

NIGHT VISION

NO MATTER how good you are at instrument interpretation, you can't entirely replace vision with instruments. Electronic, gyroscopic and magnetic devices can give you complete flight information. Yet there are times—the last few feet to a touchdown in a night flight, for instance—when night vision makes all the difference in the world. As you undoubtedly know, night vision is an art and, like other arts, must be understood and practiced before proficiency can be achieved.

THE EYE

The light sensitive nerve endings at the back of your eyes are of two kinds—cones and rods. The cones, millions of them, are concentrated in the center or bull's-eye area. The rods, more millions of them, are concentrated in a ring or circle around the cones. You use the cones to see color and detail and to pick up far-away objects. The rods see color only as shades of gray and see neither detail or distant objects. You *do* use them, however, to see out of the corners of the eyes and catch objects in motion. They won't tell you the colors in a set of signal flags, but they will keep you from running into your wingman. (See Figure 24-1.)

Broadly speaking, you see with the cones in daylight and with the rods at night. There is no sudden boundary. In daylight you depend on the cones to do most of your seeing. In full moonlight the cones and rods divide the work. In star-

light the rods alone do all the seeing. As the cones lose their efficiency in dim light, the rods take over. They can detect light at 1/5000 of the intensity at which the cones go blind.

From the illustration you can see that the art of seeing at night requires more than aiming the eye in the direction of expected activity. You have no doubt often had the experience of an object crossing your line of sight but not noting it until later because your mind was busy with other things. In seeing at night, your attention is required more than otherwise because contrasts which might alert your mind in the daytime just aren't there at night. Further, because of its construction, the part of the eye able to determine such contrasts be brought to bear.

DARK ADAPTATION

What you see when you look at something in the dark depends on the state of the dark adaptation of your eyes. As you've noticed on entering a theater from the lights or sunshine outside, your vision improves steadily until after 30 minutes your eyes are fully accustomed to the darkness. After 6 or 7 minutes the eyes are 100 times more sensitive than they were upon entering a darkened room. At full dark adaptation, the rods are 100,000 times as sensitive as they are in sunlight. You can become adapted to sunlight in 10 seconds - to adjust for the dark takes 30 minutes.

The inability of your cones to undergo rapid adjustment in the presence of extreme brightness ratios is a problem in day flights; in night flying, the problem is even more critical because of the nature of your rods. When your rods are fully dark-adapted, a strong light striking your eyes can ruin your vision for several minutes; if the light strikes your eyes for a while, it will be at least half an hour before your eyes are back to peak efficiency. (See Figure 24-2.)

In view of this characteristic of your rods, some means of dark-adapting your eyes before a night flight is advisable. You can sit in a darkened room for half an hour before flight time, but this would prevent you from being briefed with any visual aids. Fortunately, red light allows the eyes to become dark-adapted to a considerable degree; so by being briefed in a room with red

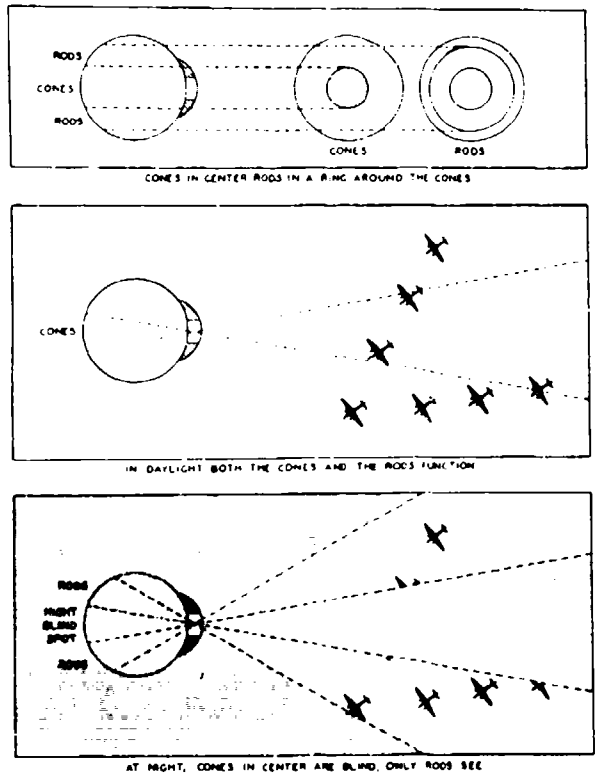


Figure 24-1. Function of the rods and cones

lights or by wearing red adaptation goggles in normal white light, your rods will be fairly well warmed up. Once the rods are warmed up and the eyes have attained a large degree of their night vision efficiency, they will retain this efficiency until white light strikes the eyes.

When your eyes are adapted to the darkness, continue to avoid all but red light. Red light is totally harmless. So wear your red adaptation goggles when you expect to be out in the dark. A word of warning, though - red markings of any kind are nearly invisible through red goggles or under red light. That means that when you look at charts bearing red markings, you won't see the items in red. Be certain you have white light available for use with these, or superimpose another color over the red.

On the instrument panel, too, red light is the best because it can be seen by the cones in your

retina but not by the rods. It is important for you to preserve the dark-adaption of your rods, but it is also important for you to be able to use your cones to distinguish the detail on the instrument panel. Red instrument lights allow you to do both because your rods and cones respond differently to different wave lengths of light and, as Figure 24-3 shows, the cones are more sensitive at the red end of the spectrum.

In any event, whether your instruments are red lighted or white lighted, staring at them will tire your eyes and may reduce your visual efficiency by as much as 50%. So look at your instruments as briefly as possible and keep your lights turned low. Of course, circumstances will dictate the intensity of your cockpit lighting. If there is an enemy about, you'll quite naturally have no lights outside and very few inside. However, if you are over a brilliantly lighted city or in an area of severe lightning discharges, you will want full light intensity. In that connection, if you are caught in a searchlight, shut one eye so that you can retain your dark adaptation in that eye and put on your red adaptation goggles as soon as possible if you are not already wearing them.

As further protection, make sure there is no switch, button or control which you can't operate totally blindfolded without delay. This will help save your night vision by enabling you to perform tasks of flying without light.

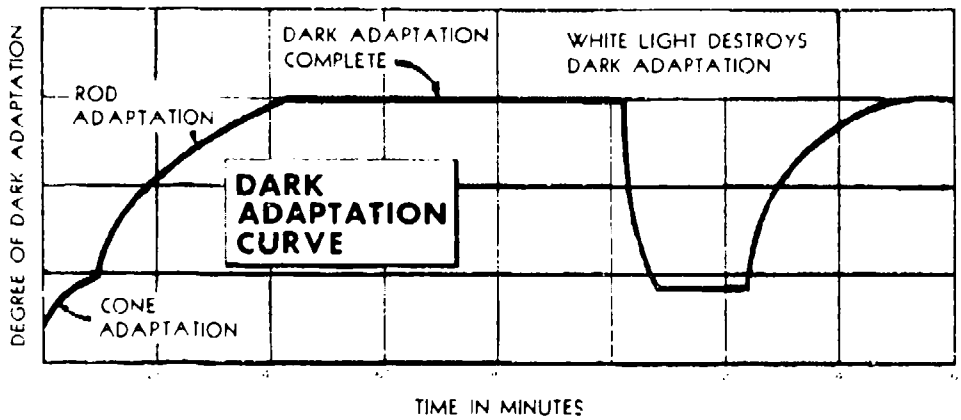
NIGHT SCANNING

After you have adapted your eyes and learned to keep them adapted, your night seeing problems have just begun. When something catches your attention out of the corner of your eye, ordinarily you turn your eyes toward the object to get a better look. This is the right way to look in daylight when the point of sharpest vision is at the center of the eye. At night, it's all wrong when you look directly at an object you are trying to see through your night blind spot in the center of your eyes. Night vision is impossible at the center of the eye. To take advantage of the rods at night, always look slightly away from the object you want to see. The angle of off-center vision varies with the individual. It is usually best at 6 to 12 degrees.

When you catch an object out of the corner of your eyes, try to hold your eyes just a bit off center and you will have the object at the point of maximum sensitivity. If your eyes move irresistibly toward the object, let them swing through so that you can pick it up again at the other side of your eyes.

If you see an aircraft or ship and then lose it, don't try to bore through the darkness to find it again. Instead of staring gimlet-eyed at the spot where you lost the aircraft, move your eyes around the spot in a circle, focusing always slightly away from that point. If the aircraft or ship is there,

Figure 24-2. Dark adaptation curve



you will pick it up again by looking to one side of it or over or under it. It takes practice but it works.

Learn to move your eyes frequently in dim light. The rods tire quickly and are at their best only for short periods. As you search, don't sweep the sky or sea at random; scan by searching a small area carefully, then jumping your eyes to the next area. You can't see anything while your eyes are in motion, but they are sensitive just after moving. Move them in short jumps of from 12 to 20 degrees so that you see all parts of the search area in succession with your best off-center vision. Do it more slowly than you would in daylight. Blink your eyes if an image becomes blurred. Periodic rests are conducive to better scanning.

Since this kind of seeing is not natural, you will have to practice it until it becomes automatic. Remember that every bit of training and practice you give to night seeing will repay you in better seeing.

There are a few general rules that can be laid down for night work. On patrol, make full use of the moon's path. Looking away from the moon (down moon), you can see the wake of a submarine up to two miles away. Toward the moon (up moon), you can pick up a submarine on the surface at four miles and a snorkel at 1 mile.

It's hard to estimate distances at night. Nevertheless, if you search methodically, taking the movement of the aircraft into account, you can develop a scanning routine for night visual searches by patrol aircraft. The idea is to avoid the extremes of blank staring or sweeping the sky. Divide the lookout sectors so that, with each man responsible for scanning a limited field, all visible areas are covered.

The average aircraft is not large enough to be seen much beyond 600 feet in clear starlight. It is visible within that limit only if you are above or below it so that you have a chance to see it in plan view. From ahead or astern it presents too small an area. In passing from a position below to a position above the enemy (and vice versa) remember the risk of losing sight of him as you cross his altitude.

Tactical conditions permitting, always take a position which allows the enemy the least contrast between your aircraft and your background and provides the greatest contrast between him and his background. In general this means, stay below the enemy if you are over dark ground, above him if you are above bright clouds.

In clear starlight, if you can see a large aircraft in plan view above you at 600 feet, he can't see you below him over dark ground at more than half that distance, say 300 feet. On the other hand, if you are flying above the enemy with a cloud floor on a moonlight night, you can see him at a distance of 6,000 feet and he can't see you over him at much more than 1,200 feet.

It is also better to be above him if you are above water in moonlight. Range of upward vision, however, is greatly increased when the background is mostly thin high cirrus clouds and there is only a quarter moon. Above all, every time you fly at night, study the conditions of light and contrast so that you know the answers under all conditions in a given flying area. The best view of the ground is usually vertically down.

IMPAIRMENTS TO NIGHT VISION

Tests show clearly that a person's night vision can be improved. There are three things which lead to this improvement:

1. Learning better dark adaptation technique.
2. Learning through practice how to see in the dark.
3. Removal of factors impairing night vision.

In a sense, almost all of the impairment to night vision results from loss of oxygen in the blood or vitamin deficiency, usually the former. This oxygen problem, however, is not as obvious as it might seem. Not only altitude, but also alcohol, tobacco, hunger, and fatigue may help rob

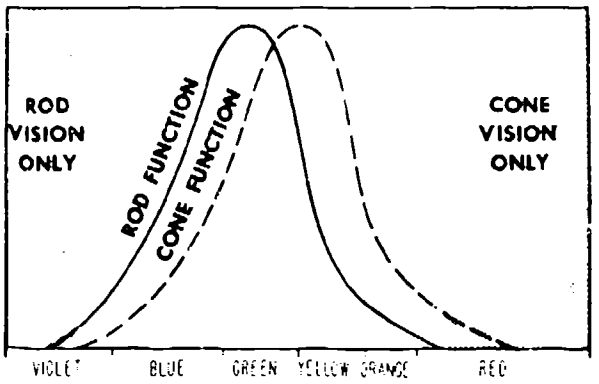


Figure 24–3. Color sensitivity of the eye

the blood of needed oxygen. The lack of vitamin A also reduces night vision. You can't store vitamin A in your body, so you must take in fresh supplies every day. However, if you are in good health, a normal, well balanced diet will take care of this.

Oxygen

When it comes to factors that impair vision, there is one that is of more importance than all the rest put together: lack of oxygen. Here, again, rods and cones differ. Your cones start to lose efficiency at 10,000 feet but bad effects are noticed in your rods at altitudes as low as 5,000 feet. For this reason, oxygen lack is even more of a problem at night than it is during the day. When your side vision disappears and you feel as if you are looking at the world through a pair of shotgun barrels, you are suffering from oxygen lack severe enough to knock out the rod vision at the side of your retina, but not the central cone vision. Obviously, you wouldn't cut down on your oxygen by closing the valve, but you can achieve the same effect in other ways through alcohol, tobacco, hunger, or fatigue.

Alcohol

Even a little bit of alcohol has the same effect as if you cut down on oxygen. Experiments have shown that alcohol raises your *physiological altitude*, so that, for example, when you are actually at 10,000 feet, your body may act as if it were at 16,000 feet.

Obviously, this is very rough on your dark adaptation. The situation is no better during the day because another thing that alcohol does is decrease your depth perception. Day or night, if you have consumed any alcohol within the last 18 hours, you are more likely to make mistakes about the thing you see and, in addition, your reaction time will be longer.

Tobacco

Most pilots are aware of the lingering effects of the bottle and treat it with respect. Unfortunately, most pilots do not realize that tobacco acts in a way similar to alcohol so far as vision is concerned. Tobacco also raises your physiological altitude, partly by cutting down on your supply of oxygen and partly by increasing the rate at which your body uses oxygen. This is due to the carbon monoxide. Incomplete burning of tobacco puts a few percent of carbon monoxide in the smoke, and whether you inhale or not, the carbon monoxide is absorbed by the blood stream in place of oxygen. If you do inhale, you simply make things easier for the carbon monoxide. When the blood stream is loaded with carbon monoxide, oxygen has a hard time getting in. The fact that blood actually prefers carbon monoxide to oxygen and absorbs it 210 times more readily makes things worse.

If you have been smoking steadily, you have enough carbon monoxide in your blood so that at 10,000 feet altitude your body acts as though it were at an altitude of 14,000 or 16,000 feet. Your vision will be correspondingly affected. Once carbon monoxide enters the blood, it leaves very slowly. About half of it is still present at the end of six hours, and there may still be some carbon monoxide left at the end of 24 hours.

Hunger and Fatigue

Hunger and fatigue belong in the same class as alcohol and tobacco so far as vision is concerned. With hunger and fatigue, the primary source of trouble is a low level of blood sugar. The energy that your body needs to keep it running is supplied by the chemical reaction of blood sugar with oxygen and, when either one is in short supply, the activity of the body slows down. As usual, the brain is very sensitive to changes in its energy supply, and as soon as your blood sugar runs low, you suffer some decrease in night vision.

AIDS TO NIGHT VISION

Clean Windshields

It is even more important at night than in daylight to keep your windshield and windows clean and unscratched. Tests prove that a thin film of oil or dirt on a windshield will reduce visibility by more than 50%. Haze, fog, dirt, scratches--anything which absorbs or scatters light--reduces contrasts and makes seeing harder. Scanning is made more difficult due to these distractions. You can't do much about haze or fog, but you can keep the glass and plexiglas spotlessly clean. The same thing applies to goggles—if you use goggles, they should be of clear glass and spotless.

Make sure that there is no glare or reflection from the instrument panel in your windshield. Keep your reflector sight on as low as you can get it and still see the reticule clearly. When you want to see best, get your face up close to the windshield. The best visual set-up is to look through glass at 90°. As this angle decreases you suffer a loss in visual range.

Binoculars

In everything, including single-seat aircraft, binoculars are extremely useful at night. Because

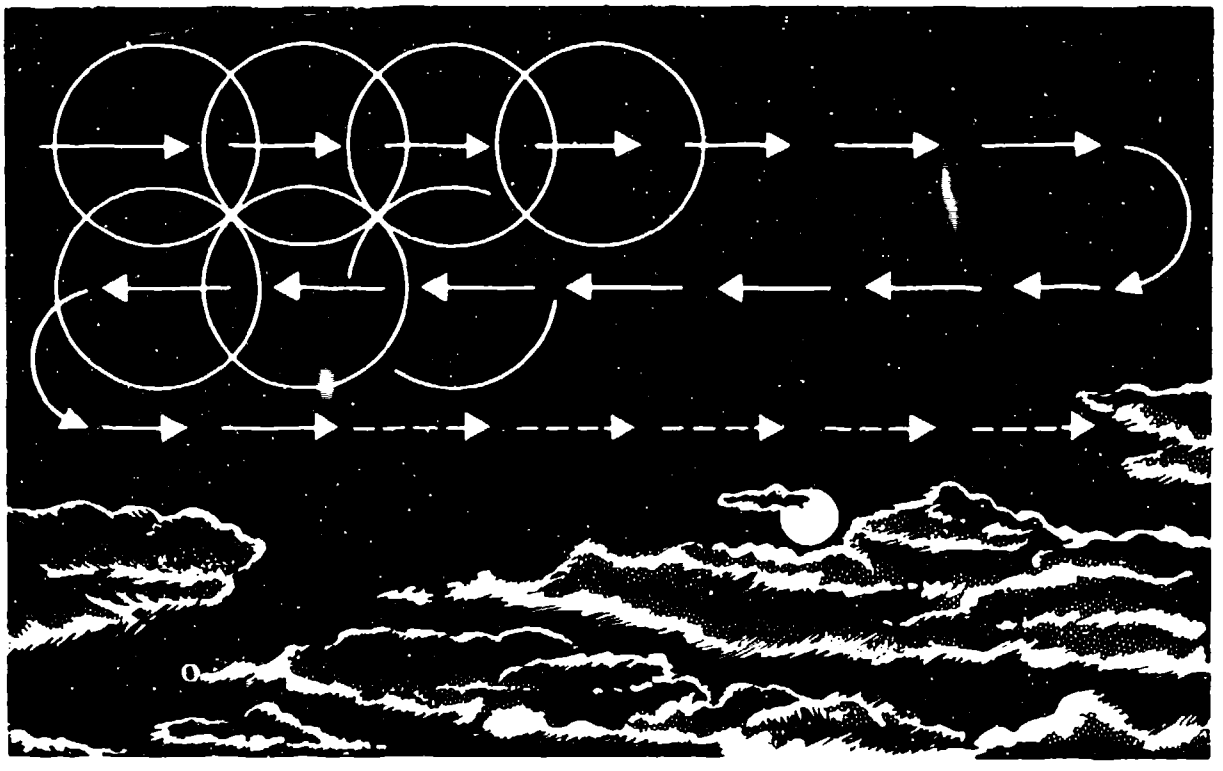


Figure 24–4. Scanning technique

of the lack of light and the vibration of the aircraft, they are no good for scanning. But if they are properly adjusted and you practice with them, you will find that they will help in identifying objects already spotted with the naked eye. They are not easy to use--but they are well worth the trouble both for airborne and ground targets.

The standard 7 x 50 Navy binoculars are excellent for night work. Be sure to adjust them while you are on the ground. It is difficult to do it in the air at night. First adjust the eyepieces so that they are the same distance apart as your eyes. If necessary, have the medical officer measure the distance between the centers of your eyes with a rule and then set the eyepieces accordingly. Next, focus the glasses with your eyes relaxed, that is, accommodated for distant vision. Screw out the eyepieces as far as they will go. Turn the glasses on a starlit sky, then focus for each eye in turn, screwing in the eyepiece until the stars are clear. Repeat this process several times and average the readings. Remember the average reading so that you can always set the glasses accurately.

Oxygen

Since night vision is impaired over 5,000 feet by the reduced amounts of oxygen available, Navy doctrine requires the use of oxygen on night flights over 5,000 feet. The distances at which you can see at altitudes above 5,000 feet at night can be increased two or three times by use of oxygen.

Good Physical Condition

Good seeing and good physical condition go hand in hand. Fatigue, cold, improper food resulting in a vitamin deficiency, excessive alcohol, smoking to excess, various stimulating and cold curing drugs all have a serious effect on night vision. The action indicated is obvious, but your flight surgeon is an expert in this field. Should you entertain doubts of any kind, avail yourself of his experience if you are conducting night operations.

CHAPTER 25

CARRIER-BASED ALL-WEATHER FLYING

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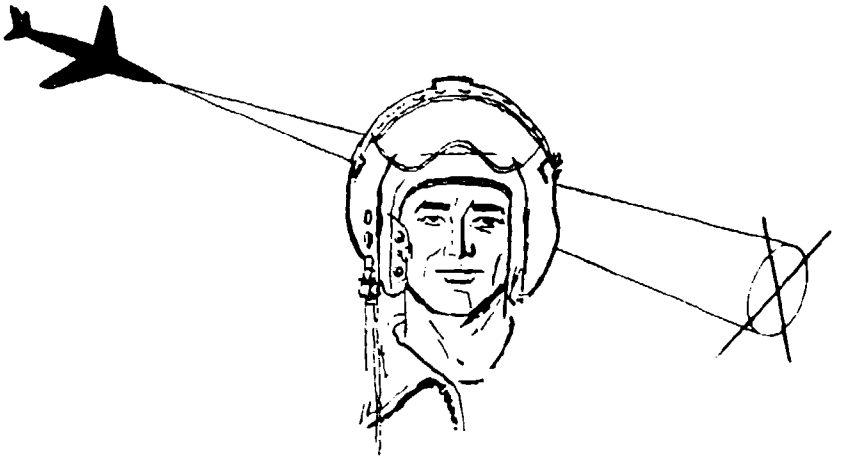


CHAPTER 25

CHAPTER 25

CARRIER-BASED ALL-WEATHER FLYING

THE last few years have brought great progress in the development of carrier-based all-weather flying. With increasing aircraft capabilities and with new electronic equipment and new techniques such as Tacan, the mirror landing system, and carrier control approach (CCA), carrier procedures are changing rapidly.

New procedures for take-off, rendezvous, let-down, and low approach are beginning to be standardized, but they are still in a state of flux. Many of these procedures are of necessity classified. In addition, aircraft carriers vary considerably in the equipment and arrangements they have available for control of all-weather flying. Consequently, firm and detailed procedures can not be prescribed in this chapter. Instead, this chapter presents basic information and representative procedures so that you can be prepared for the new procedures as they are developed and standardized.

ELECTRONIC NAVIGATIONAL EQUIPMENT

Every all-weather carrier procedure depends in large part on electronic navigational equipment, either on the carrier or in the aircraft. The radar equipment used by CIC and CCA, of course, is of key importance in control. YE-YG, though on the way out, is still being used to some extent for homing. Another type of homer, a UHF homer, has been recommended for installation on carriers so that aircraft can home on them with

the ARA-25 UHF/DF. The greatest possibilities, however, are being offered by Tacan, which can serve in every phase of carrier all-weather operations.

YE/YG

YE/YG is currently in use aboard carriers, but as Tacan becomes more generally available—and this expected in the near future—YE/YG will be removed from both carriers and their aircraft.

YE/YG gives you your bearing in terms of sectors which are related to true north. YE/YG beacons transmit a VHF carrier wave from a rotating antenna which radiates a directional beam approximately 45° wide. The transmitted carrier wave is revolved through 360° at a rate of one revolution every 30 seconds. As it is revolved, Morse code characters are impressed on the carrier wave at definite intervals. A different character is used each 30° of rotation and this character is transmitted twice in its 30° sector. Thus the characters are transmitted at 15° intervals, but only for the duration of the character. The complete transmission is set up in relation to north, south, east and west so that each code letter is always seen in the same direction on each revolution of the antenna. (See Figure 25-1.)

Because of the directional-beam type radiation, a receiver remotely located from the antenna, receives only those signals which are radiated in the general direction of the receiver. This means that the receiver in any given location will receive only a limited number of letters. The volume setting influences the number of letters heard.

When you use the receiver and tune in on any particular beacon, you will hear no sound until the directional beam is radiated in the general direction of your aircraft. Adjust the receiver output control so that you receive four code letters during each revolution. Identify the middle two, then look up that letter (or letters) on the decode card and locate the direction of the transmitter. After some practice, you will be able to determine the direction of the transmitter within about 5°, and you will be able to home on it.

It is possible to determine the direction of the transmitter even without a decode card. Since the letters are transmitted clockwise, a difference in code sequence indicates on which side of the aircraft the station is located. Therefore, when you don't have a decode card, hold the heading and note the sequence in which you hear the letters. When the next code sequence comes around, check to see if a new letter has come into the picture. If no new letter comes in, the station is astern or ahead. If a new letter does come in, and it is at the beginning of the sequence, the station is to the left. If it is at the end of the sequence, the station is to the right.

If there is no change for some time, say three minutes, turn the aircraft 90° and check for a change. After you determine on which side of your heading the station is located, make a 90° turn toward the station, hold your heading and check the code sequence. If the station is still on the same side as before, turn 45° toward the station and check the code sequence again. If the station is on the opposite side, turn in the opposite direction. Continue checking the code sequence, cutting your turns to the station in half until you find a heading which produces an unchanging code sequence.

Always carry a copy of the sector code used by any station which you plan to use. YG beacons at certain shore stations are listed in Radfacs, together with a diagram of the sector transmissions. Note that the sector designations from these shore stations are not the same as those from a ship station.

ARA-25

Many of the procedures which have been recommended for intermediate use until Tacan is fully operational make use of ARA-25 UHF/DF. This equipment, which was discussed in Chapter 7, enables you to home on any UHF station in the air or on the surface which you can receive on your ARC-27 communications receiver. The ARA-25 has excellent capabilities as an air-to-ship navigation aid and will probably be used extensively when UHF homers are installed in carriers and support ships. The ARA-25 has advantages over the widely used ARN-6 Radio Compass in that it is not affected as much by precipitation static nor by thunderstorms, which render the ARN-6 almost useless.

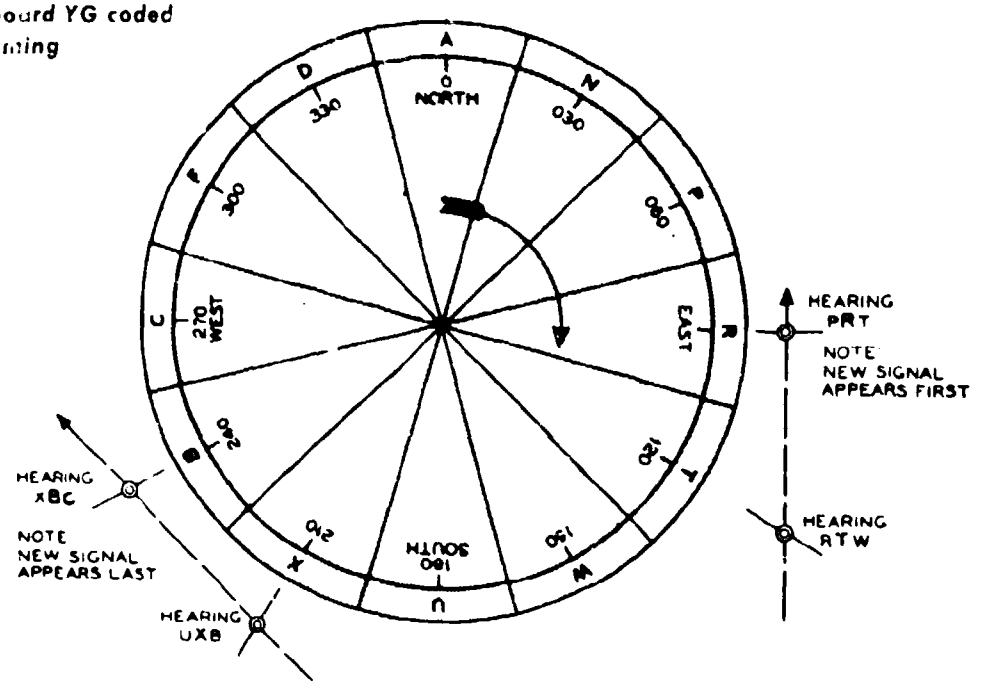


Figure 25-1. Shipboard YG coded sector homing

Tacan

Tacan has already been discussed in some detail in Chapter 7. There is no difference between shore-based and carrier-based Tacan except for the fact that, on a carrier, it is a moving transmitter and ships do not have standby transmitters in event of material failure. Therefore, when you fly in on a radial of carrier-based Tacan, the heading necessary to stay on that radial may be a few degrees off the value set on the course selector even in a no-wind condition. To reduce the number of heading changes in tracking, you may use the Tanner System (method 2) described in Chapter 23. However, the homing and tracking methods discussed before for VOR and ADF work will work well enough for approaching a ship by Tacan. The only difference will be that the final drift may be more than usual.

So far as rendezvous, approach and letdown procedures with Tacan are concerned, they are still classified and cannot be covered here.

Search Radar

Every carrier, of course, is equipped with search radar. This gear can pick up aircraft as far as the line of sight, but the best procedure to insure pickup is to have the IFF on. Search radar is used primarily for other purposes, but it is available to provide position or a steer on request. If you anticipate any chance of fuel shortage, don't hesitate to call on radar for aid even at some distance and in fair weather.

PRE-FLIGHT PREPARATION

The keynote in night and low visibility operations is reliability. Therefore, such operations require thoroughgoing pre-flight preparations. Minor failures which would not prejudice the mission or endanger the aircraft in good weather can result both in failure of the mission and disaster to the aircraft when the weather is bad. Consequently, it is important that the aircraft and its equipment, especially the electronic equipment and the instruments, be checked thoroughly before take-off.

The pilot needs to be completely checked out, too. Since all-weather operations are more complicated and more demanding than routine operations, the pre-flight all weather briefing must be more detailed and more comprehensive than a routine briefing. At least one hour before the launch-

ing, pilots should be supplied with the current weather, upper winds, the nearest field (bearing and distance), the best alternate (bearing and distance), all the necessary information for communications and navigation, including channels, frequencies, and identifications, and any other pertinent information.

Provision must also be made for the pilot to check the aircraft and equipment before take-off. It has been recommended that twenty minutes before the engines are started, the order "Pilots man your planes" be sounded, and when it is executed, each pilot be provided with external power to check the electronic equipment on his aircraft. During this pre-start period, minor discrepancies can be corrected if provision is made for trouble-shooting crews. As a part of this pre-start electronic check, each pilot should check into Primary Fly by radio. He should check in again with Primary Fly when his engines are started.

To avoid excessive use of fuel as a result of starting engines too early, a careful starting plan must be worked out for each launch to insure an orderly and rapid flow of jet aircraft to the catapult. No jet aircraft should be started sooner than three minutes before it is to be launched.

TAKE-OFF

When the aircraft is lined up on the catapult, the gyro element of its compass should be set to coincide with the ship's launching course, and it should not be reset until the aircraft is steady on the first climb-out heading. Then the stabilized indication should be checked against a magnetic reference until faithful slaving is confirmed. (The launching course should be broadcast from Primary Fly at frequent intervals.)

When light and visibility permit immediate section join-up, aircraft can be launched in sections. If aircraft are launched separately, a 30-second interval should be observed. At night or in low visibility, aircraft should be launched singly and at not less than 30 second intervals.

RENDEZVOUS

The following rendezvous procedures have been recommended as a basic for standardization

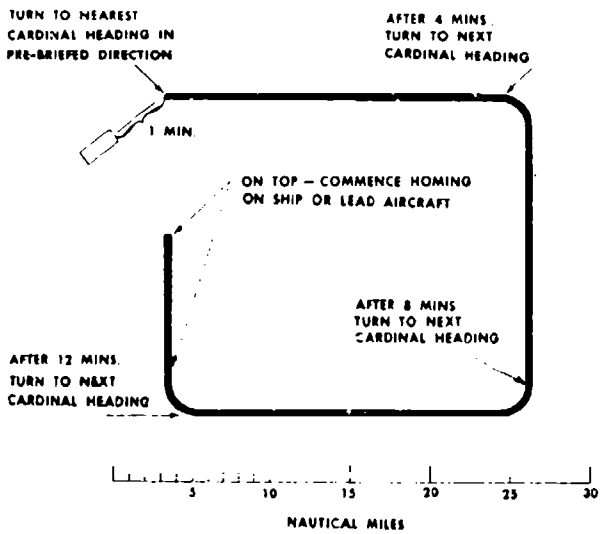


Figure 25–2. Overhead rendezvous

until Tacan becomes fully operational. These procedures, which are based on extensive operational testing, use the ARA–25 UHF/DF in the aircraft and a UHF homer on the carrier in addition to the usual navigational and communications equipment.

Overhead Rendezvous

A combat air patrol can rendezvous over the force from which is was launched most quickly and safely by a climb-out which takes the form of a timed square flown on cardinal headings, such as the one shown in Figure 25–2.

The pattern shown in Figure 25–2 is one which was worked out for eight F2H–3's, using the climb schedule realized at 98% power, full load. It is designed to facilitate rendezvous at 36,000 feet. Notice that each turn takes place at 4-minute increments after launching time. This pattern was made by drawing to scale a square with 3-minute legs, working out the time taken for each turn, then averaging out the odd seconds to give the 4-minute increment.

By using the climbing schedule and time to altitude for the power settings to be used, a similar pattern can be worked out for any type of aircraft. The most suitable power setting is 98% rpm, for this enables aircraft with lower performance to maintain their position in the climb.

The largest number of aircraft that can climb satisfactorily in one pattern on one radio frequency is eight. If more than eight aircraft or two different types of aircraft are used, two climb-out patterns should be prepared. They should each use a different communications frequency and should go in opposite directions, as shown in Figure 25-3.

The rendezvous should always be planned to take place above the cloud tops. When cloud tops are known, the rendezvous can be accomplished at any desired altitude by adjusting the timed legs of the square pattern. For times when cloud tops are not known, a pattern should be worked out to enable aircraft to rendezvous at or near their operational ceilings. Even though the cloud tops are low and rendezvous is required at altitude, the best practice is to fly the overhead rendezvous using the pre-arranged pattern described here.

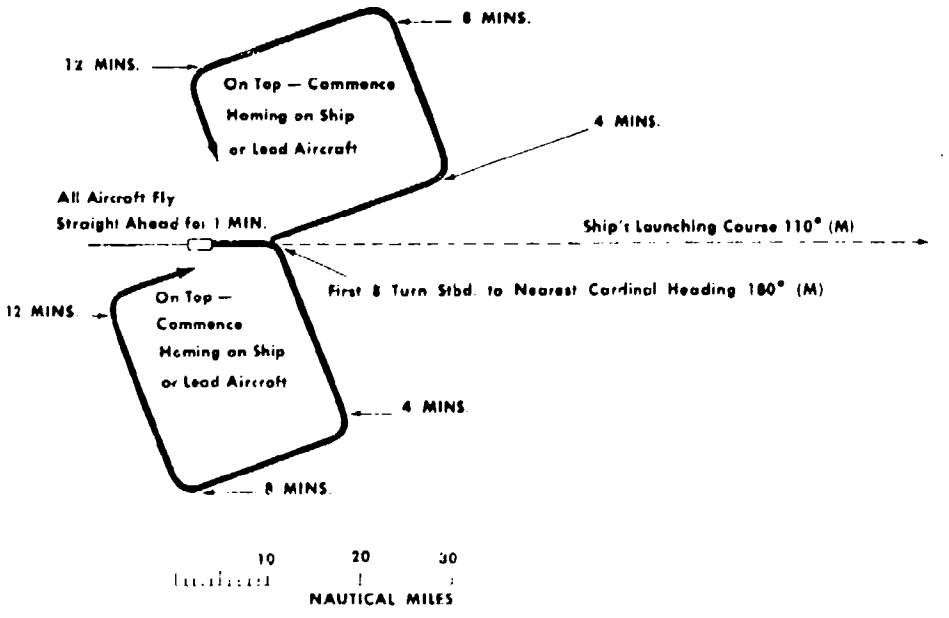
After the launch, the pilot starts his stopwatch and flies straight ahead, level or in slight climb, for one minute, raising wheels and flaps as soon as possible. After one minute, he turns (still accelerating) in the briefed direction to the nearest cardinal heading. The timing of each leg is based on the time the stop-watch is started at the launch. All turns are then made at fixed times from the launch. When aircraft break out on top, on the last leg of the square, they start homing into the ship, using the ARA-25. When the leader obtains a station passage, he starts an orbit, on station, using 30° of bank and transmitting on a prearranged frequency to enable the following aircraft to join up.

Picket Rendezvous

To rendezvous a combat air patrol over a picket which is too near to allow a straight climb-out, a "dog leg" climb-out pattern is used to insure that aircraft reach the required altitude before reaching the picket. The pattern shown in Figure 25-4 permits the shortest time to altitude and also provides for safe aircraft separation during the climb through overcast.

This figure shows a picket climb-out (drawn to scale) for F2H-3 aircraft using the climb schedule realized at 98% power, full load. A sim-

Figure 25-3. Overhead rendezvous, two patterns



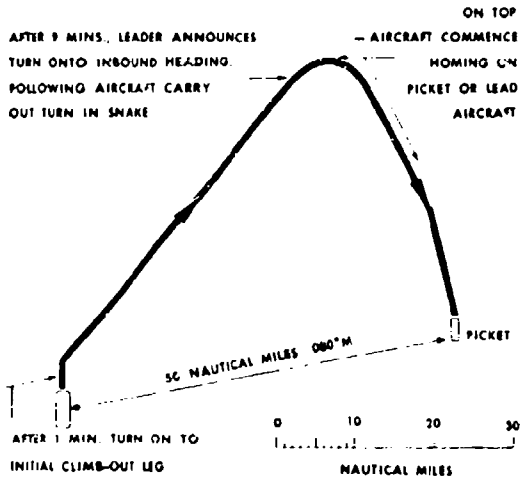


Figure 25—4. Picket rendezvous

ilar pattern can be prepared for other type of aircraft. When the position of the picket is known, a similar pattern can be drawn using the aircraft climb schedule which will insure aircraft reaching the required altitude before reaching the picket. The most suitable power setting for the climb is 98%. This enables aircraft with slightly lower performance to keep station in the climb.

The bearing of the inbound heading relative to the first climb-out course can be obtained from the drawing and can be used by the pilot of the leading aircraft (with ARA-25) to determine when to turn inbound to the picket. The aircraft which follow execute this turn in "snake." This is a follow-the-leader procedure in which each of the aircraft that follows the leader makes the turn at the same time interval after the leader turn as its time interval behind the leader at launching. When the aircraft arrive on top, they proceed to home into the picket or onto the lead aircraft.

The launching of the first aircraft is broadcast from Primary Fly, and all pilots start their watches *at this time*. It is essential that succeeding aircraft know their respective launch time after the leading aircraft. After the launch, if a pilot does not know his position in the climb or his time interval behind the leader, he can request it from the Primary Fly, using his side number for the communication call-up.

To provide this information, the controller in the Primary Fly should be an officer who knows the climb technique. It is his responsibility to record the interval and order of the aircraft in the launch and to provide this information when called.

When all aircraft are airborne, the leading aircraft is informed of this, as well as of the time interval between the first and last aircraft launched. No turns are made from the original climb-out course until all aircraft are climbing on this course.

When the leader of the climb learns that all aircraft are climbing on the initial climb-out course, he can announce the turn onto the new course for the inbound run to the Picket. He determines the new heading from ARA-25 bearing information. The climb leader announces his intention to turn and this is acknowledged by the other aircraft in the flight.

At the moment the leader starts his turn, he transmits "This is Red Leader, turning onto ----- degrees, *Now*—Out." The aircraft which follow make the turn at their appropriate launching time interval behind the leader. They turn onto the heading announced by the leading aircraft, not onto the homing bearing to the picket indicated by the ARA-25. When the aircraft arrive on top, they then home directly to the picket. The leading aircraft makes a moderately tight orbit (30° bank) after he receives the picket station passage. He transmits on pre-arranged frequency to facilitate join-up.

Rendezvous of Jet Strike Group on Course

This procedure is designed to rendezvous a group of aircraft of different types and configurations above the overcast or at some specific altitude (usually the practical ceiling of the bomber) on course to the target without penalizing the range of the bomber.

This procedure requires careful planning. A common climb schedule has to be worked out, based on the bomber's optimum climb-out at 100% rpm. This should be done by test flying in advance of actual weather operations. The power

settings thus obtained form the power schedule to be used for all climb-outs with that particular bomber. The variation in acceleration from the runway or catapult should also be established between the types and configurations. These acceleration differences can be minimized (but not eliminated) if the slower accelerating aircraft retain full power until climbing speed is reached.

Briefing, too, must be thorough. There should be a thorough description of the climb as applicable to the operation drawn and explained on the blackboard with appropriate headings and all other necessary information. Radio and electronic procedures must also be carefully covered. During the execution of the procedure, an officer who knows the climb techniques should man the land launch frequency in Primary Fly. It is his responsibility to give radio checks, record the interval and order of aircraft in the launch and announce the ship's launching course at frequent intervals.

The climb consists of a straight on-course climb-out as shown in Figure 25-5. The aircraft take off as described before. When all aircraft are airborne, the leading aircraft is informed of this fact and also of the time interval between the first and last aircraft launching. No turns are made from the original climb-out course until all aircraft are climbing on this course. After being launched, pilots fly straight ahead on the launching course for one minute, accelerating to climbing speed. At the end of one minute, each aircraft turns, using a 30° bank, still accelerating to the initial climb-out heading. With current jet aircraft types, this turn starts at approximately 1,000 feet on the initial climb-out course. Depending on the rendezvous altitude and upper winds, the rendezvous takes place at any distance up to 185 nautical miles from the launching point.

Somewhere along the climb-out, the leading aircraft may obtain a fix and consider it necessary to alter course. When he decides what the alteration of course should be, he transmits this alteration. Each of the aircraft in the climb acknowledges this in order. On receiving this acknowledgment from all aircraft, the leader then transmits, "This is Black Leader turning onto ____ degrees *Now* -out." The word "now" is the time at which the pilots in succeeding aircraft restart their stop-watches. Each pilot then turns to the new heading at the stop-watch time equal to his launch time interval behind the leader.

The leading aircraft continues climbing until he reaches the briefed altitude or on top, whichever is higher. He announces this altitude, the remaining pilots acknowledge it, and they announce when they have attained it. As each pilot reaches altitude, he levels off and flies straight ahead on course at the best climbing speed for that altitude until the last pilot to reach altitude calls in. All pilots then reduce airspeed to economical cruise.

Thirty seconds after the last aircraft reaches altitude, the leading pilot starts a timed orbit or racetrack circuit to bring him back to the point in space from which he started the circuit. The leader makes his orbit time equal to the time interval between him and the last aircraft so that the last aircraft launched arrives at the orbit point simultaneously with the leader. The leading aircraft should carry out only one circuit and then proceed on course. During the circuit, the leader should [illegible] to enable the following aircraft to use [illegible] join up.

The first aircraft launched has its lights bright and flashing and the succeeding aircraft have their [illegible] bright and steady. As aircraft join up, their lights are put to dim and steady except that the last aircraft joining goes to

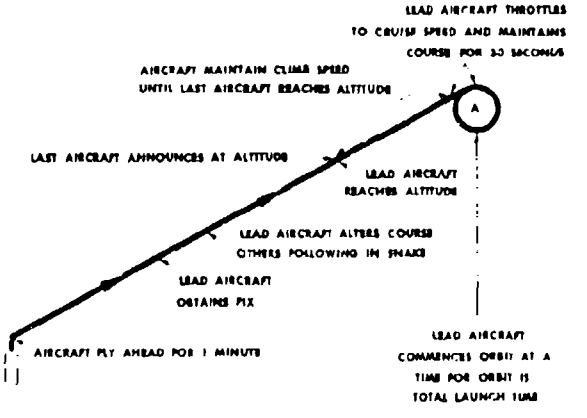


Figure 25-5. Rendezvous of jet strike group on course

bright and flashing until the next one joins and so on until all are joined up.

Pilots who do not rendezvous during the first circuit should have only lateral displacement (they should be approximately the same distance from the launching point) and can home in to the main group by setting a converging course and maintaining a constant relative bearing indication on the ARA-25.

LETDOWN AND RECOVERY PROCEDURES

The following letdown and recovery procedures have been recommended for standardization until Tacan becomes fully operational. These procedures, which are based on extensive operational testing, use the ARA-25 UHF/DF in the aircraft and a UHF Homer on the carrier in addition to the usual navigational and communications equipment.

Division Letdown

The division letdown is designed to provide a safe procedure for letting down and breaking up divisions of aircraft in night VFR or in moderately low visibility day conditions down to 800 feet ceiling and 2 miles visibility. (See Figure 25-6.)

In this procedure divisions start letting down at a distance from the ship depending on altitude and wind. This position can be in any convenient direction relative to the carrier. The divisions can be positioned at the correct distance by Approach Control using radar, or by proceeding to overhead using ARA-25 and carrying out a timed runout to the letdown position. This runout time is computed by Approach Control or by the division leader. If there is more than one division, the divisions should fly in comfortable line astern.

When the appropriate position is reached, the division (or the first division of a group) turns onto the inbound heading. When an aircraft is on the inbound course at the letdown speed, speedbrakes are opened, letdown power selected, and the descent is started and announced. At suitable altitudes (for example, every 10,000 feet), the division leader can call for range from Approach Control. For any given range his appropriate altitude in thousands of feet should be equal to his range in miles minus 5. For example, at a range of 20 miles, his altitude should be 15,000 feet.

Rate of descent corrections should be made by adjusting power if possible. Airspeed should not be changed, for this will alter the interval between divisions and introduce the danger of overrunning when more than one division is letting down.

The inbound letdown is maintained to 1,000 feet (night) or until contact. (The recommended day minimum is 800 feet and two miles.) The

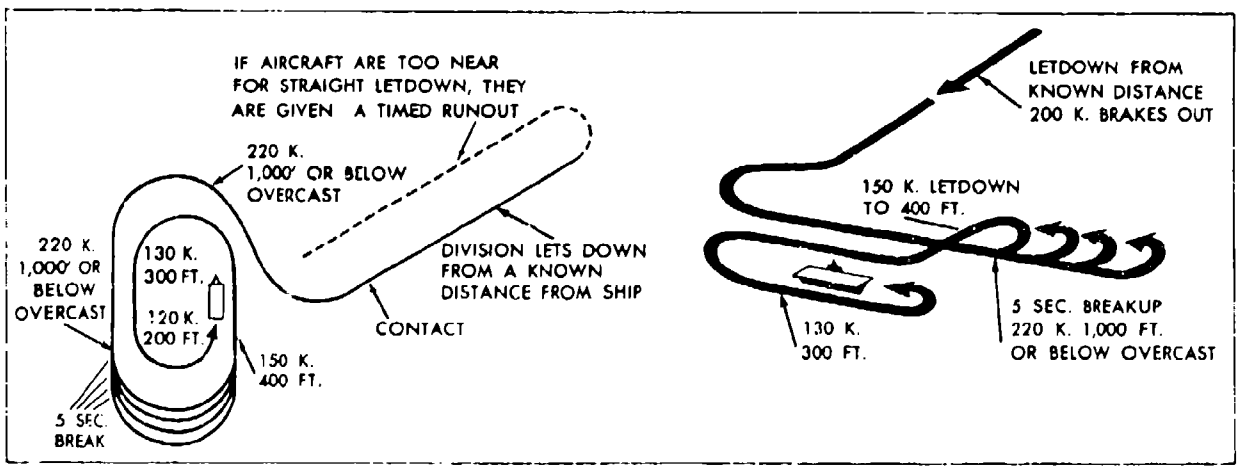


Figure 25-6. Night or low-visibility jet letdown and breakup.

division maintains this altitude until visual contact with the carrier is established. When the carrier can be seen and is known to be on the recovery course, the division turns so as to enter the pattern and be on the downwind leg in echelon starboard at 1,000 feet (night) and contact (day).

When the carrier is passed abeam, the leader breaks port onto the recovery course. Individual aircraft break at five-second intervals. During this breaking turn the aircraft slowly reduce altitude to 400 feet and reduce speed to fly up the starboard side of the carrier at 150 knots. After passing up the starboard side of the carrier, they execute a normal day or night carrier pass. The remaining divisions carry out a four-minute orbit at altitude at the letdown point and start letting down on the inbound heading one division at a time as directed by Approach Control.

Penetration Letdown

This procedure is designed to recover up to 16 jet aircraft with weather minimums down to 300 feet and 1½ miles without close control and to provide safe separation between individual aircraft during the descent through the overcast. It provides straight-in approach and landing from a gate vessel in weather down to 300 feet and 1½ miles or a feed-in to a CCA final if the weather is lower. (See Figure 25-7.)

(A gate is a ship equipped with a UHF homer stationed at about five miles, bearing 160° to 220° relative from the carrier, to which aircraft home and pass over during a letdown. Its function for final approach is similar to that of an outer marker.)

When aircraft formations return to the Force, they home at their operating altitude to a gate vessel. The recovery course is broadcast, and the formation leader maneuvers to pass slightly to starboard over gate on the recovery course. The approach to gate is made in echelon at the letdown speed. If the formation consists of more than one division, divisions should be in line astern at comfortable intervals.

On receipt of a station passage at gate, the leader of the leading division transmits, "This is Red Leader, Breaking port onto ——— degrees. *Now!*" The remaining divisions start an orbit to starboard.

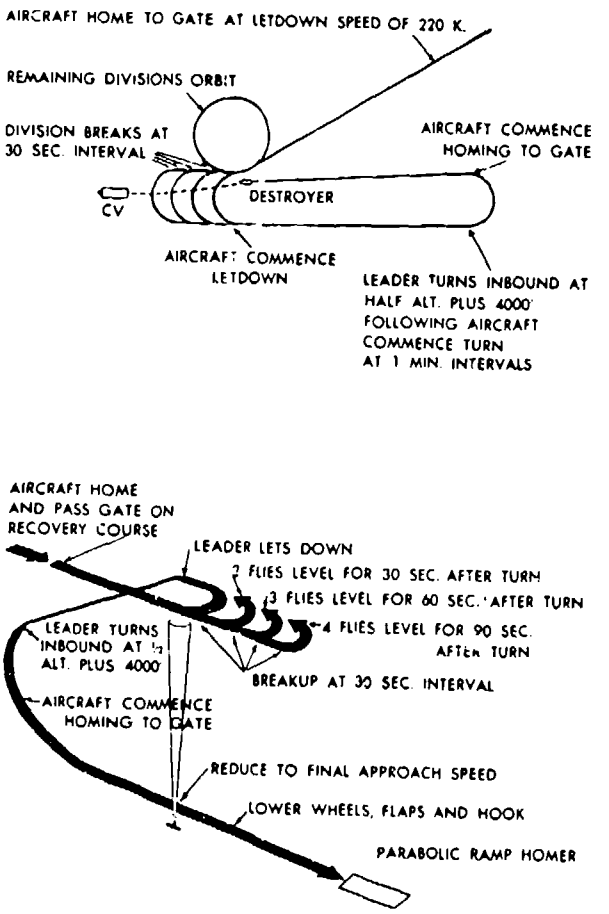


Figure 25-7. Jet penetration letdown

After breaking, the division leader turns onto the reciprocal heading, and the other aircraft of the division break at 30-second intervals, onto the reciprocal heading. (This produces a one-minute interval at the ramp.)

Once on the reciprocal heading the leader selects letdown power and configuration, and announces, "This is Red Leader letting down. *Now!*" One minute later, Red 2 starts the descent and announces it; then 3 and 4 follow at one-minute intervals, each aircraft announcing that it is letting down.

At half the initial altitude plus 4,000 feet, the leader turns onto the reciprocal heading and starts homing inbound to gate. The leader should announce this 180° turn long enough ahead of time to let the other aircraft acknowledge. He then fol-

lows with the transmission "This is Red Leader, turning onto —— degrees. *Now!*", which he makes at the actual turning altitude.

The other aircraft start this turn, *not on altitude*, but *by timed interval* behind the leader—that is, one minute after each other. Each pilot should announce his turning so that, if a pilot misses the leader's transmission, he can take his timing from the next aircraft ahead. Exact specified airspeed must be maintained during this turn.

After this turn, each aircraft starts to home into gate. It does not have to maintain a specified track into gate, but it should be on the recovery course after passing gate. Aircraft should reach an altitude of 400 feet before arriving at gate. If it develops that a given type of aircraft consistently passes gate at a higher altitude, or if it consistently has a long drag to gate at 400 feet, the height of the 180° turn should be adjusted.

Letdown speed is maintained until gate is reached. At gate, the pilot switches to the ramp homer frequency, and homes directly to the ramp. After passing gate, he lowers wheels, flaps, and hook and reduces speed to the final approach speed. The sequence for reducing speed, and lowering the wheels and flaps, depends on aircraft type, but it is essential that the sequence be made uniform in each particular type.

Aircraft home into the ramp until high intensity lighting and the carrier become visible. The pilot should then open his hood and be ready for landing aboard. The final approach can be controlled by the LSO either on the ramp homer or the tower frequency. If the latter frequency is

being used for this purpose, pilots switch to this frequency when the ramp is sighted. (If the final approach is being monitored or controlled by the CCA final controller, he should use the ramp homer transmitter so that the pilot can use his ARA–25.)

The divisions remaining on top adjust their orbits to start their letdown two minutes after the last pilot of the preceding flight has commenced his letdown. Approach Control may hold divisions at altitude if necessary.

APPROACH CONTROL SYSTEMS

Two special control systems have been developed to provide radar assistance for carrier aircraft recovery operations during instrument or marginal weather. These two systems are Carrier Controlled Approach (CCA) and the Hooker Control. These two systems are similar in concept, but they differ in equipment and procedures.

The Carrier Controlled Approach system requires radar equipment having a high level of accuracy and resolution and specially trained aircraft controllers and radar operators. The Hooker system requires less precise radar equipment and fewer personnel than the CCA system, but it does not meet all-weather control requirements as completely as CCA. The Hooker system is suitable where the traffic requirements are light and where CCA equipment is not available.

CCA PROCEDURE

CCA is still in the development stage, and new equipment and traffic patterns are being worked out. However, CCA is already proving itself to

be an effective operational system. In CCA, control of aircraft is being divided into four operational functions—pickup, traffic, final, and wave-off.

The following are the steps in a straight-in approach with CCA. It permits aircraft to land in the shortest possible intervals and is adaptable to various types of aircraft. (See Figure 25-8.)

Pickup

An inbound flight contacts the Pickup Controller as soon as practicable. The Pickup Controller mans a radarscope to pick up and identify returning flights. He vectors the flight to a position astern of the carrier at an altitude where the flight can maintain contact flying. The distance and range astern are variable and are determined by the altitude of the flight. The PPI scope used by the Pickup Controller is calibrated to take care of altitudes from 5000 to 30,000 feet.

When the flight reaches the desired position, the Pickup Controller orders it to orbit. At a convenient time, he relays the following information to the flight:

1. Sea-level altimeter setting.
2. Force and direction of surface winds.
3. Weather en route to carrier.
4. Ship's magnetic heading.
5. Range and bearing of flight from carrier.

The Pickup Controller gets the landing order by side number from the flight leader. As soon as conditions permit, he vectors the first division in the landing order to the breakup point. When the division approaches the breakup point, the Pickup Controller gives it a vector that is the reciprocal heading of the approach and orders it to assume a left or right echelon as applicable. When the division leader reports the echelon formed, the controller orders the leader to break off and assigns him a vector. Every 20 seconds he

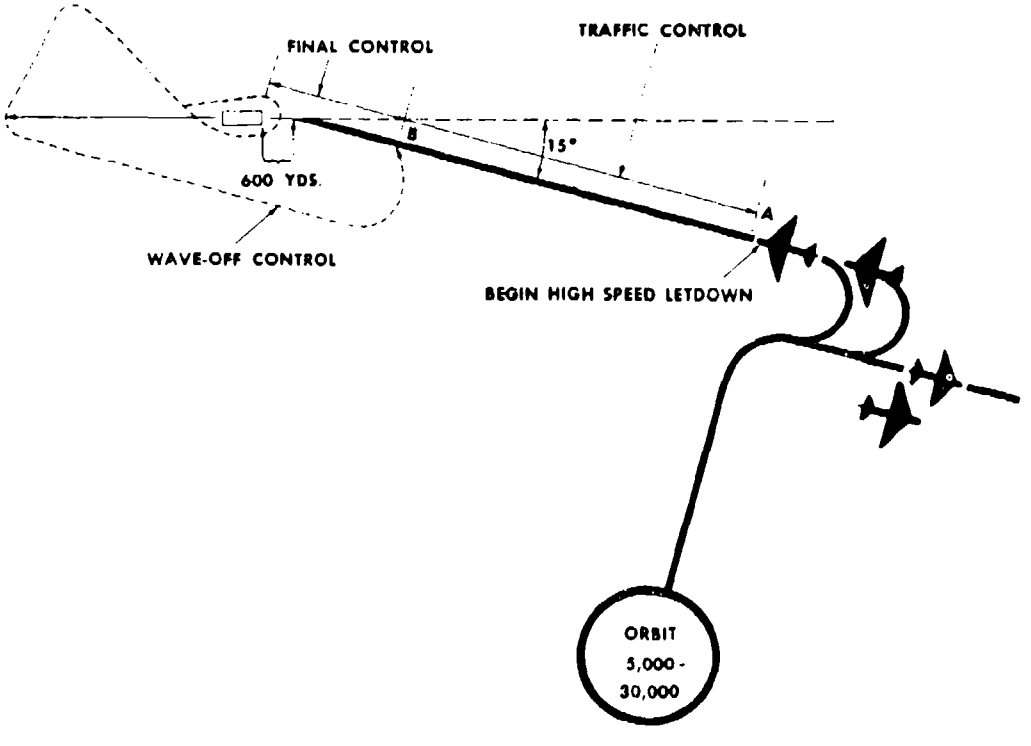


Figure 25-8. Straight-in approach, CCA

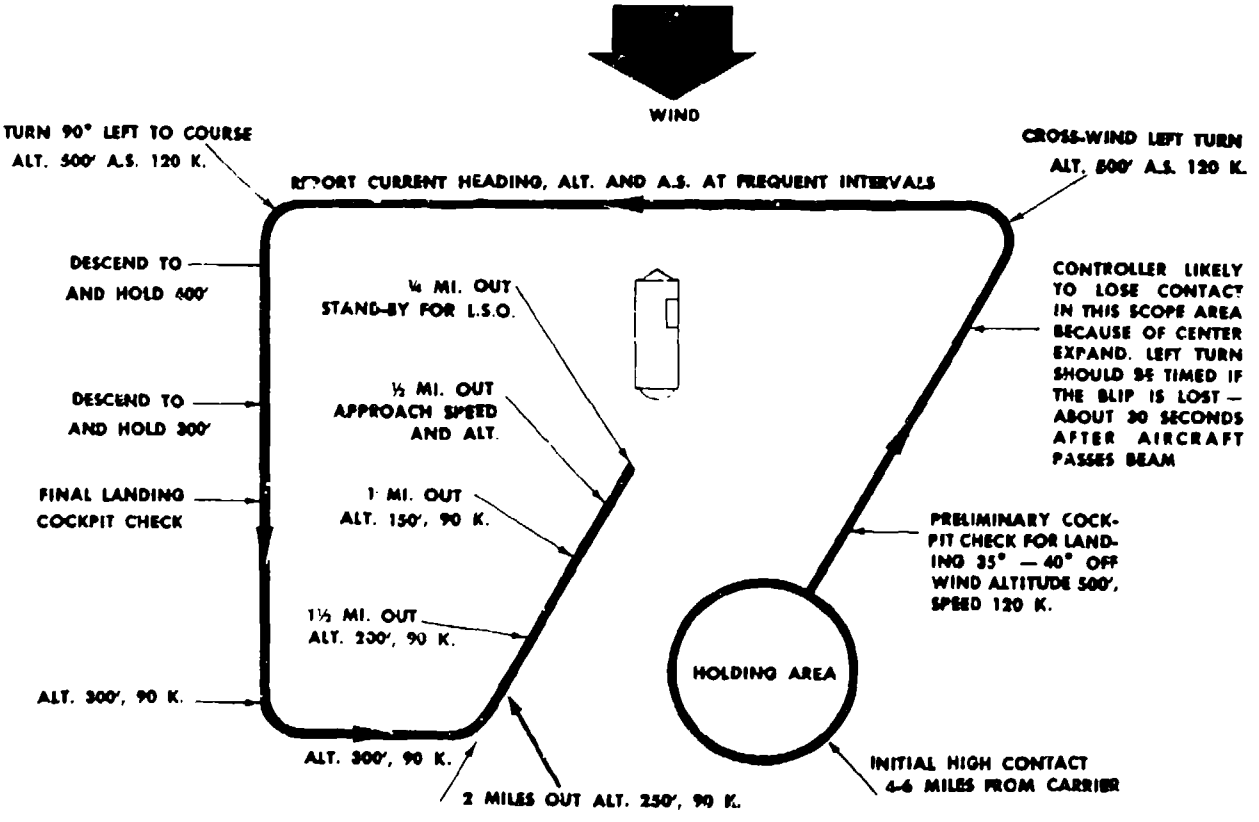


Figure 25--9. Standard hooker approach.

orders another aircraft to break off and gives him the same vector. As each separate aircraft reaches point A (Figure 25–8), the pilot is ordered to start a fast descent and switch to another radio channel for the Traffic Controller. Each aircraft in the entire division is switched in turn to the same Traffic Controller.

Traffic Control

The Traffic Controller mans a radarscope similar to that manned by the Pickup Controller. There are two Traffic Controllers, each on the separate radio channel. Experience has shown that a single Traffic Controller can control four consecutive aircraft and give them corrective vectors and speeds to maintain proper intervals better than he can control alternate aircraft. Successive divisions are vectored in in this way every four minutes.

In case of excessive wave-offs or a fouled deck, the Pickup Controller has the next division orbit at the break-up point until the Traffic Controller reports "Ready." In this way, there is enough altitude to stack aircraft in case of a fouled deck.

When the aircraft is switched from the Pickup Controller to the Traffic Controller, the Pilot calls the Traffic Controller on the assigned radio channel. If he can't get Traffic Control, he returns immediately to the Pickup Channel and requests further instructions. On his first transmission to the Traffic Controller, the pilot gives him his call, heading, and any other information that might affect the safety of the approach. The Traffic Controller acknowledges and corrects the vector as necessary. Since the Traffic Controller is handling four aircraft, every transmission has to be brief and pertinent.

The Traffic Controller keeps all aircraft

evenly spaced, approximately one minute apart. To do this, he may have to order individual aircraft to increase or decrease speed by up to 20 knots. If two aircraft get dangerously close, he orders one of them to pull up and vectors him out of the line of traffic. As conditions permit, he vectors waved-off aircraft back into the line of traffic.

The pilots prepare to make the letdown to 2,000 feet. Upon reaching 2,000 feet, he reduces his rate of descent to 500 fpm and slows down to approach speed. The Traffic Controller instructs the pilot to descend to 500 feet and gives him a complete landing check-off list. When the aircraft reaches point B (Figure 25-8), the Traffic Controller instructs the pilot to switch to another radio channel and call the Final Controller.

In case of a fouled deck, the Traffic Controller immediately orders the aircraft to resume an altitude above the overcast and vectors them in a controlled square at various altitudes until the deck is ready. If the aircraft are below 5,000 feet when the deck becomes fouled, the Traffic Controller keeps them under positive control and does not send them to the top of the overcast. The Traffic Controller must have aircraft ready to turn over to the Final Controller immediately after the deck is cleared.

Final Control

The Final Controller takes over the individual aircraft from the Traffic Controller and controls them one at a time. On switching to the radio channel for final control, the pilot gives his call, heading and any additional information that might affect the safety of the approach. The Final Controller acknowledges this transmission and instructs the pilot to acknowledge no further transmission. The Final Controller talks the aircraft down as in GCA.

He reports to the pilot when the aircraft is at distances of 2½ miles, 2 miles, 1½ miles, 1 mile, ½ mile, 900 yards, 800 yards, 700 yards, 500 yards. During this time, he gives the pilot assurance of progress and corrective vectors as required to maintain the proper approach track. He tells the pilot to start his descent at 250 fpm and at each mile gives the pilot a reminder of the proper altitude. When the aircraft reaches a point 500 yards

from the carrier, the Final Controller checks whether the LSO gives "contact." If the contact is given before minimum range or if deviation is beyond the limits of a successful approach, he gives the pilot a wave-off and instructs him to climb to 400 feet and call the Wave-Off Controller on the assigned radio channel.

During CCA operations, the LSO guards the radio channel of the closest aircraft on final approach. He observes the aircraft descending on final approach and gives warning of dangerous altitudes, airspeeds, and hazards of collision. When the aircraft is 500 yards astern and sight contact is made, he says, "LSO contact on his assigned radio channel." From this time on, the aircraft is under the control of the LSO. He notifies the Final Controller by light system or by telephone when he has visual contact. He also passes his comments concerning the pass to the Final Controller. He waves pilots off by radio or visually whenever it is apparent that continuation of the approach is dangerous or undesirable.

Wave Off

If the pilot has received a wave-off or has taken a wave-off himself, he switches to the Wave-Off Controller on the assigned channel. It is optional whether the wave-off is to starboard or port. Once the pilot has passed the carrier, he assumes a heading relative to the course. As soon as practical, he calls the Wave-Off Controller and gives his heading, altitude and, if possible, his approximate position from the carrier. If possible, the Wave-Off Controller avoids assigning aircraft to altitudes above 500 feet or in the overcast. Once the pilot is below the weather and is flying contact, he is kept contact. If there are many wave-offs, the Wave-Off Controller assigns each aircraft a separate altitude. He vectors waved-off aircraft in a racetrack pattern until they can be vectored back to final approach.

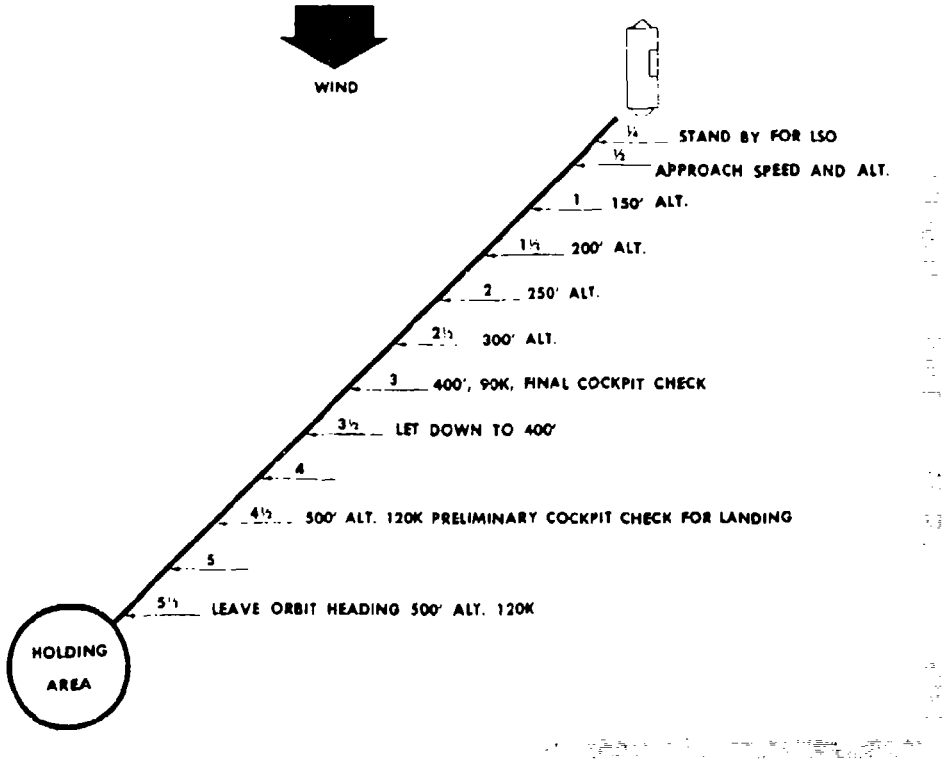


Figure 25-10. Straight-in Hooker approach

HOOKER CONTROL

Hooker Control was evolved to aid recovery in instrument or marginal conditions. It is not as complete as CCA, but can serve satisfactorily where traffic requirements are light. There are two Hooker approaches—the Standard and the Straight-In. The Standard Hooker Approach takes longer than the Straight-In Hooker Approach but is better suited to poor weather conditions. The Straight-In Hooker Approach is like the final phase of the Standard Hooker Approach but is more efficient.

Standard Hooker Approach

In the Standard Hooker Approach (Fig. 25-9), returning aircraft are vectored by CIC to a position on the ship's stern or port quarter where they can be kept under surveillance by the Hooker Controller when on the proper radar scale and also by the Air Controller in CIC. This position is at a range of about 6 miles. Here the aircraft are stacked in a standard rate turn orbit.

The aircraft to be landed is vectored toward the ship by the Hooker Controller so as to pass about 1 mile off the starboard quarter of the carrier at an altitude of 500 feet and a speed of 120 knots. Here the aircraft is vectored 35° to 40° from the direction of the true wind, parallel to the final leg at an altitude of 500 feet. This allows the Hooker Controller to check drift. While on this leg the pilot is also directed to go over his preliminary check-off list.

When the aircraft is 1 mile ahead of the ship, the Hooker Controller directs it to turn to the left across the wind. The next turn is to a downwind course to a heading that places the aircraft on the reciprocal of the recovery course. This track passes about 1½ miles on the port beam of the ship. When the aircraft is steady on this course,

the Hooker Controller directs it to descend 400 feet.

When the aircraft is level, the pilot is directed to perform the final cockpit landing check. He is then directed to descend to and maintain 300 feet until he is on the final approach leg, which is 2½ to 3 miles in length and 35° to 40° to the right of the recovery course. This offset affords the pilot maximum visibility in the direction of the ship and, at the same time, allows the aircraft to pass over the after starboard edge of the flight deck in case he can't complete the landing. When the aircraft is steady on the final leg at a speed of 90 knots, the Hooker Controller directs it to descend in 50-foot increments to an altitude of 150 feet. This procedure allows the pilot to establish a desirable rate of descent and to find the best power setting for the approach.

Straight-in Hooker Approach

The Straight-in Hooker Approach (Fig. 25-10) is like the final phase of the standard Hooker approach, but is more efficient. On the other hand, it is not as suitable under poor weather conditions.

The Straight-in Hooker approach starts at the holding area stack which is located approximately 6 miles on the port quarter of the carrier. The aircraft to be landed is vectored to the ship on the final leg heading, which is 35° to 40° to the right of the recovery course. As in the standard approach, a CIC area controller keeps the stack under surveillance.

When the aircraft is detached from the stack, the Hooker Controller gives the pilot his altimeter setting and preliminary final leg heading. He instructs him to descend to 500 feet and conduct the preliminary landing cockpit check. When the aircraft is steady on the course of the final leg and approximately 4 miles from the carrier, he directs the pilot to set the gyro and not reset it and to descend to and maintain 400 feet. At 3 miles, he directs the pilot to reduce speed to 90 knots and to descend in 50 foot increments to an altitude of 150 feet. This permits the pilot to establish a proper power setting and rate of descent. After the aircraft closes from a distance of 2½ miles, the controller announces each ½ mile to the pilot and directs him to assume the approach speed and prescribed altitude. When the aircraft is ¼ mile away, he directs the pilot to stand by and to contact the LSO visually.

If the pilot can not establish visual contact, he should take an automatic wave-off and climb ahead of the ship to 500 feet on the final leg heading. The Hooker Controller will then direct him into a Standard Hooker Approach or will return the aircraft to the stack.

CHAPTER 26

FLIGHT PLANNING FROM AVAILABLE WEATHER DATA

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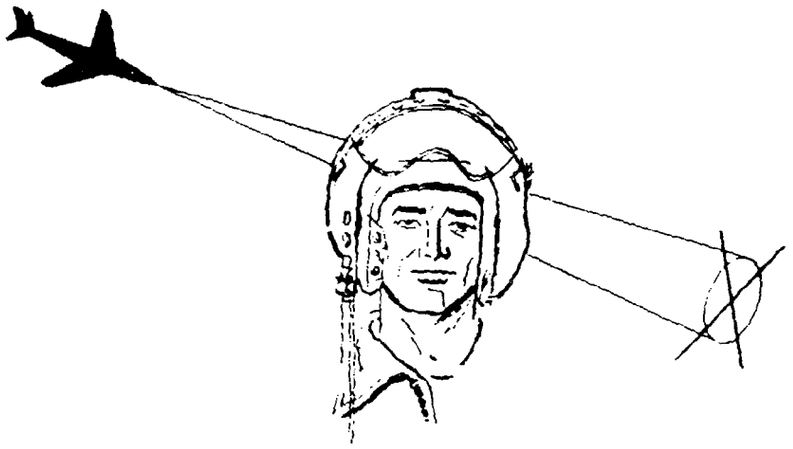


CHAPTER 26

FLIGHT PLANNING FROM AVAILABLE WEATHER DATA

OBVIOUSLY, all-weather flying requires knowledge of weather. Of course, that does not mean that you must become an aerologist. Weather analysis and forecasting is a complex science, and it takes far more training than a pilot has time to give it.

As a pilot, however, you must have:

1. Enough technical knowledge to be able to interpret the weather maps and forecasts provided for your information in the Aerology Office.

2. Enough knowledge of the theory of the changes of weather conditions and enough ability to recognize weather phenomena as you see them from your aircraft to interpret whether the forecast data was correct, and, if not, to make a reasonably capable interpretation of the changes which have occurred during the course of the flight.

This chapter concerns the analysis of the weather information provided by Aerology for *pre-flight* planning. It assumes that *you* have a basic knowledge of aerology. If you don't, a reading of *Aerology for Naval Aviators* would be helpful to you. The following chapters of this manual can also help provide you with the basic information. They discuss briefly the theory and development of wind belts, air masses, frontal weather, fog, icing, turbulence, and thunderstorms. These are some of the weather phenomena which you will encounter.

After planning your flight, you must know how to recognize and how to penetrate such weather conditions safely. As the flight pro-

gresses, you must analyze what has transpired weatherwise by relating what you see outside your aircraft to the forecast data.

PILOT ANALYSIS

Naturally, when you plan your flight, you will get your weather information from the duty forecaster. He is a trained expert with many sources of information at his disposal. The information on which his forecasts and charts are based is standardized, in the sense that he receives both factual data and forecasts from a central source which he adapts to the local requirement. He draws his own maps and prepares forecasts, but he is assisted also by facsimile maps and various types of forecasts transmitted through a network of weather communication facilities. His information, therefore, is complete and reliable, and you can depend on his advice.

Still, as a pilot, you have the duty not only to understand aerology well enough to comprehend what Aerology tells you, but also to be able to read and interpret weather data for yourself. The easy way to do this is to study and analyze weather data on the display boards and at the counter before discussing the situation with the forecaster.

The objective of your own analysis of weather is to get a complete picture of the weather conditions and developments that will affect flight along your route. This will enable you to discuss intelligently any possible discrepancies in the forecasts. What's more, once you are in the air, you cannot further consult the forecaster or the maps and see explanations for unexpected changes. However, pilot to forecaster service is available to military pilots at some Air Force Bases. This service is listed in the Radio Facility Charts. As a rule, though, you must rely on your own weather knowledge and experience and on information you have obtained before leaving the ground.

WEATHER INFORMATION

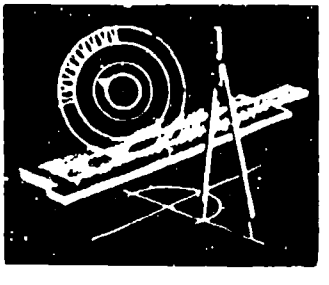
All weather offices, whether Navy, Air Force, Weather Bureau, or commercial airline, have access to approximately the same weather information. In all weather offices, you will find displayed a series of current *synoptic maps* which you can use to get a quick general picture of where weather is located, with what it is associated, and its direction of movement. The *sequence reports*, which indicate the latest weather and are used to determine the trend of weather conditions, are also available in weather offices.

In most offices you can find *upper air soundings* from which you can get a vertical cross-section of weather with regard to the stability conditions of the respective levels. You can use *winds aloft charts* to assist in determining the best flight levels. From *constant pressure charts* you can determine winds aloft over water areas and over land areas when winds aloft charts are not complete enough, usually because of low cloudiness, to give an accurate picture of upper level winds. Constant pressure charts also give important clues to future surface weather.

The weather information available to you in the weather office is compiled from observations over a large network of Weather Bureau, Navy, and Air Force stations. Within the continental United States, the Weather Bureau is the principal source of observational data. It is the job of the Weather Bureau to observe weather, compile this information, and distribute it to agencies and organizations concerned with weather, via teletype and radio communications.

Most weather offices are now equipped with facsimile recorders, which reproduce synoptic maps, prognostic maps, 850-, 700-, 500-, 300-, 200-, and 150-mb constant pressure level charts, as well as winds aloft charts and other charts.

It is important that you become familiar with these facsimile (FACS or FAX) charts for two reasons: first, they represent the weather picture as determined by experts at the National Weather



Analysis Center (NWAC), and second, they may be the only weather maps available at some airports. Here is the information they provide:

1. Surface weather analysis which shows existing conditions as of the time and date shown.

2. Forecast positions of pressure and frontal systems both surface and aloft.

3. Constant Pressure Charts (also called Upper Air Maps or Contour Charts), which show the observed wind, temperature, dew point, and altitudes of the various pressure levels (except that the dewpoints of the higher pressure levels are not shown). Numerical values of altitudes are shown in hundreds of feet on the isohype (contour) lines. The approximate altitude for each such pressure level chart is as follows:

850 mb chart: 5,000 feet (written "050").
700 mb chart: 10,000 feet (written "100").
500 mb chart: 18,500 feet (written "185").
300 mb chart: 30,000 feet (written "300").
200 mb chart: 40,000 feet (written "400").
150 mb chart: 45,000 feet (written "450").

These charts have a plane of one *pressure* (as contrasted with surface maps which have a plane of one altitude—mean sea level—MSL). This one-pressure value plane fluctuates in altitude with changes in weather. The given values above are the "average altitude" for each type chart.

4. Winds Aloft Charts (often called Pibal Maps) are made for various altitude levels up to 25,000 feet and show actual wind observations at various stations. There are two such facsimile charts: one for 0, 4, 7, 10 thousand feet, and one for 14, 16, 20, 25 thousand feet MSL.

5. Tropopause charts are analyzed radiosonde (upper air sounding) data at the height of the dominant "leaf" of the tropopause in the area of North America which is under consideration.

6. Composite Charts (sets of two or four sent together) include

a. 12-hour pressure changes, precipitation amounts for the last 6 hours, cloud cover areas, maximum and minimum temperatures for the past 12 hours. On the cloud cover chart, a dotted line outlines precipitation areas.

b. Freezing levels and snow cover on one chart and stability on another. Freezing level lines for every 2,000 feet altitude are shown, with areas where the surface temperature is below freezing plotted as "B. F." Dotted lines outline 1- and 6-inch snow depth areas. The stability chart uses a mathematical "stability index." Plus values indicate stable areas and minus values unstable areas.

7. Extended forecast charts: On Tuesdays and Fridays, there are 5-day observations and two groups of charts to cover the next five days. On the Wednesday or Saturday before the 15th and 30th of the month, there is a 30-day forecast chart group. Extended forecasts cover 700 mb contours, temperature and precipitation, and principal low and high pressure centers and their predicted tracks.

Most of these facsimile charts are discussed in more detail later in this chapter, but some are omitted as of little value to aviators.

You can recognize a facsimile chart by the fact that it is gray and black in color. Since no colors can be used, the data must be indicated by symbols or lines (which would be in color on a locally drawn chart).

The various facsimile charts (or their local counterparts) and the teletype reports and forecasts for the intended route comprise the data which you must study before beginning your flight. Make this study before you talk to the Aerology Officer or duty aerographer about flight weather conditions. Generally, all such facsimile charts are posted where you can study them.

SURFACE WEATHER MAPS

The best place to start your weather analysis is with the surface weather map. Note the valid time and date. Observe the general picture over the entire map area, then study conditions along your projected route and to alternates, including an area to each side. Check the older surface maps and then the prognostic maps to find the trend of movement. Local maps will not vary greatly from the facsimile, although some differences in analysis by the local aerologist may appear in the location of fronts, shape of pressure systems, and so on, based upon his interpretation of the data given in the station models. The station model tells the observed conditions at each station in detail.

Your detailed analysis of these charts should include the following steps:

1. Note any low-pressure system located in the general flight area.

2. Note the position of any fronts that might be located in the general flight area.

3. Check the station models over the entire section where the flight is to be made. Do not check only the station models *along* the proposed flight path. Remember, weather many miles away from the flight path may move into the flight area during the time of the flight. Note the type and height of clouds, states of weather symbols, temperatures, dew points, and winds.

Wind may be helpful in deciding the future movement of weather. With a small spread between temperature and dew points, fog or stratus may easily be formed, especially after sunset when radiational cooling takes place. Most low cloudiness with a frontal system is not caused directly by the overrunning condition, but by increases in dew point through evaporation of precipitation; by decrease in temperature at night. Either condition may cause formation of fog or low stratus if there is little wind.

4. Repeat the same steps on the previous surface charts and the prognostic (forecast) surface charts. The principal purpose of the comparison is to determine tendencies and trends in order to try to determine what to expect during the flight. If a prognostic map is not available, try to make your own forecast, bearing in mind changes in time of day between the latest chart and the time of flight. Low pressure systems and fronts, in particular, are important factors.

In order to perform this surface weather map analysis, you must be able to understand the symbols, color systems, and indications of fronts and pressure systems on both facsimile and local synoptic or prognostic maps. For detailed information, consult the publication, *Aerology for Naval Aviators*.

Following are some definitions which will prove useful:

Definitions

Isobars (*Iso* means equal; bar stands for barometric pressure) are lines of equal sea level pressure. The forecaster draws lines (isobars) connecting points of approximately equal pressure.

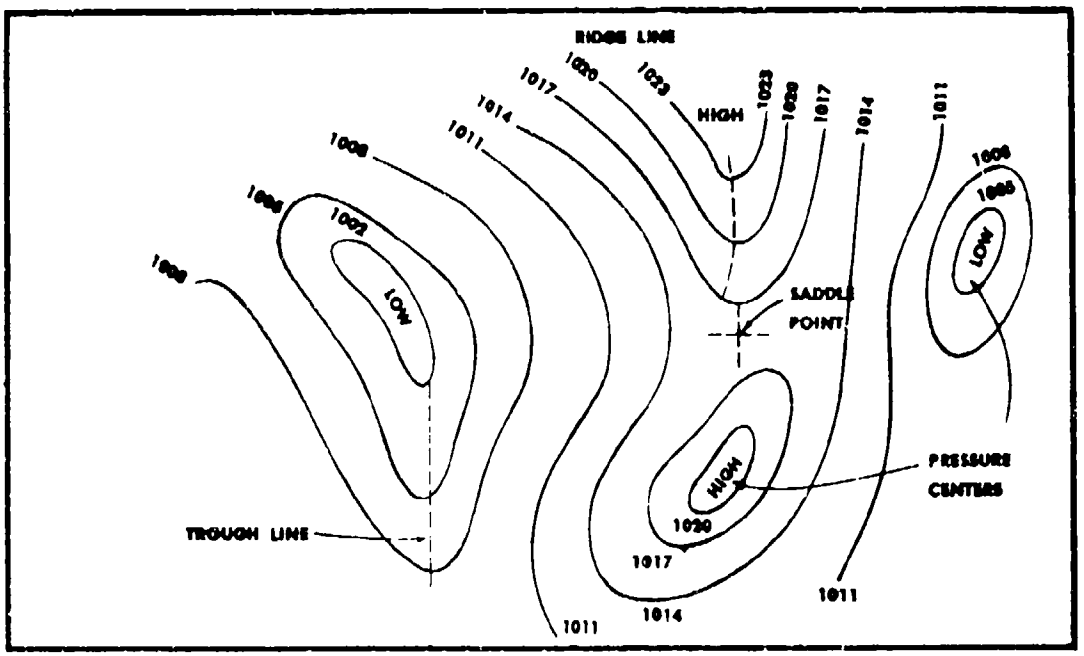


Figure 26-1. Pressure systems

Surface weather maps show isobars for every two or four millibars of pressure, depending upon location. Facsimile chart isobars are drawn every four millibars.

Pressure Systems. Isobars on a weather map show areas of relatively high pressure and other areas of relatively low pressure. Various common types of pressure systems, as outlined by isobars, are illustrated in Figure 26-1. Note that isobars outline pressure systems in exactly the same way that contour lines outline terrain features on a contour map. Pressure areas are referred to as High, Low, Ridge, and Trough.

Low pressure centers are marked with the letter L, and Highs with H. As you know, the Low is the center of storm development in almost every case. The High is an area of generally good weather, especially on the eastern side.

A High is characterized by upper air rotating clockwise around the center and by surface air flowing outward (Fig. 26-2). As the surface air goes outward, the pressure drops and air is drawn in from above. This air is cooler and drier, although it warms up somewhat through sinking to lower levels. Thus, a High is an area of Divergence and Subsidence. As surface air diverges, upper air subsides (sinks) to fill the space. Relative humidity is low because the air from above contains less moisture. A High is therefore usually cloudless or nearly so.

A Low pressure center also involves upper air rotating around it, but the wind direction follows the isobars counter-clockwise. At the surface, however, winds tend to converge toward the center (Fig. 26-3). This Convergence causes Lifting or ascendance of air. Convergence and Lifting go together. Lifting cools the air through expansion under lower air pressures aloft and cooling causes condensation into clouds and eventual precipitation. As the moisture condenses (changes physical state), the latent heat (locked up as heat energy of motion) of the water vapor is released (latent heat of condensation). This heat is energy and is transformed into weather phenomena: further thickening of clouds due to added lifting and turbulence—and some form of precipitation usually occurs. This is how changes of physical state result in either additional or lesser amounts of energy available for turbulent lifting.

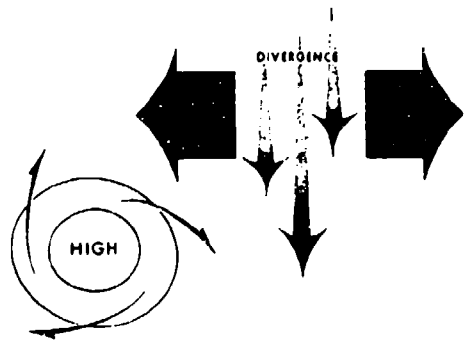


Figure 26-2. High-pressure cell (anticyclone) showing divergence

Facsimile surface analysis charts show isobars at 4 mb intervals. The central pressure of Highs and Lows is indicated under the letter H or L by a two-digit number, the units and tens of millibars. The anticipated motion of the center is shown by a vector or arrow indicating the direction and distance it is expected to move during the following six hours. These pressure centers move in a more or less easterly direction and their associated frontal systems move with them.

Never regard a surface weather map as static. It shows conditions as of its verifying time (V. T.), and that is necessarily a past time. As you study the chart, consider what has happened since that verifying time.

Pressure gradient. On a surface weather map, isobars are spaced at 4 mb intervals; the linear distance between isobars varies in parts of the system. This linear spacing is known as the pres-

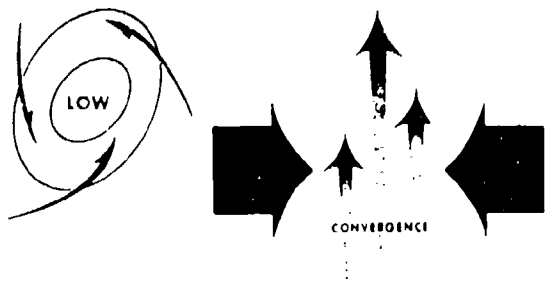


Figure 26-3. Low-pressure cell (cyclone) showing convergence

sure gradient and is defined as the rate of change of pressure per unit of horizontal distance. It may be 4 mb per 100 miles or 4 mb per 200 miles. The distance is measured perpendicular to the isobars. Areas of strong pressure gradient have closely packed isobars and stronger winds, while weak pressure gradients are characterized by isobars which are spread apart, causing light to variable surface winds.

It is possible to consider isobars as if they were contour lines, thus making a topographic map of the atmosphere. In this concept, a high would be a hill and a low would be a depression or valley. A trough would be a long valley or ravine, and a ridge would be what its name implies. This concept is not only possible, but reasonable and useful.

Wind Direction from Isobars. There is a relation between wind direction and the azimuth or direction of an isobar. At altitudes above about 2,000 feet, winds flow approximately parallel to the isobars clockwise about high pressure systems and counterclockwise about low pressure systems in northern latitudes. (It's the reverse in southern latitudes.) At the surface, the wind direction crosses isobars at about a 30° angle toward lower pressures. Thus, a low at the surface involves winds converging toward the center of the low, and a high involves winds diverging away from the center.

The natural tendency of air is to move from high to low pressure. As a result, high and low pressures would tend to disappear. In fact, at the equator, there are no high and low centers of any significance for that very reason. At higher latitudes, however, the Coriolis Force of the earth's rotation deflects the high-to-low pressure movement of air to the right of its direction of flow. Thus, air which tends to travel from high to low pressure ends up travelling parallel to the isobar aloft. It begins to follow a rotational course about the high or low centers, and centrifugal force helps prevent it from moving toward the low pressure side. Therefore, everywhere but at the equator, there is a tendency for winds to flow around high and low pressure centers. The effect of surface friction, however, is to reduce velocities of wind below 3,000 feet and thus reduce the centrifugal force so that winds begin to flow somewhat toward low pressure centers.

With this knowledge of the direction of air flow around pressure centers, wind direction in flight above 3,000 feet offers you a positive clue to further in-flight weather. If the wind is dead astern, the low pressure is on the left, and the high is on the right, a rule known as Buy Ballot's Law. The more important corollary is that when the wind is on the port beam or port quarter, you are heading more or less toward the center of any well-defined low pressure system, hence into an area of poorer weather. Similarly, when you are flying with the wind on the starboard beam or bow, you are tending toward better weather.

Fronts are usually associated with well-developed low pressure systems. The convergence and lifting phenomenon produces cloud formation, and converging air masses of different temperature differentials form fronts. Frontal weather is the subject of a later chapter; therefore, only the indications on the weather map are considered here.

The three most common fronts on a weather map of temperate zones are cold fronts, warm fronts, and occluded fronts. These usually form from the development of "waves" on a stationary front. A stationary front presents a line of demarcation between two air masses in which each air mass features minor difference in temperature and humidity characteristics from the other. Stationary fronts usually run more or less east and west and appear as alternating red and blue lines on a local synoptic map or as a solid black line with triangles on one side alternating with hemispheres on the other facsimile charts, as shown by Figure 26-4.

A Low, which is itself a trough or valley of low pressure, appears on this front. Immediately, the frontal line is broken into a sort of wave. The leading or easterly slope becomes a warm front; the trailing or westerly slope becomes a cold front. The warm air of the wave is then lifted by the cold frontal surface, and the Low increases in depth. The cold front overtakes the warm front, and a process called occlusion takes place where cold and warm front meet. This wave development is shown in Figure 26-5.

The warm front lies in a trough of low pressure, generally in the quadrant to the southeast of a low pressure center. It is caused by southerly

WBAN WEATHER ANALYSIS SYMBOLS

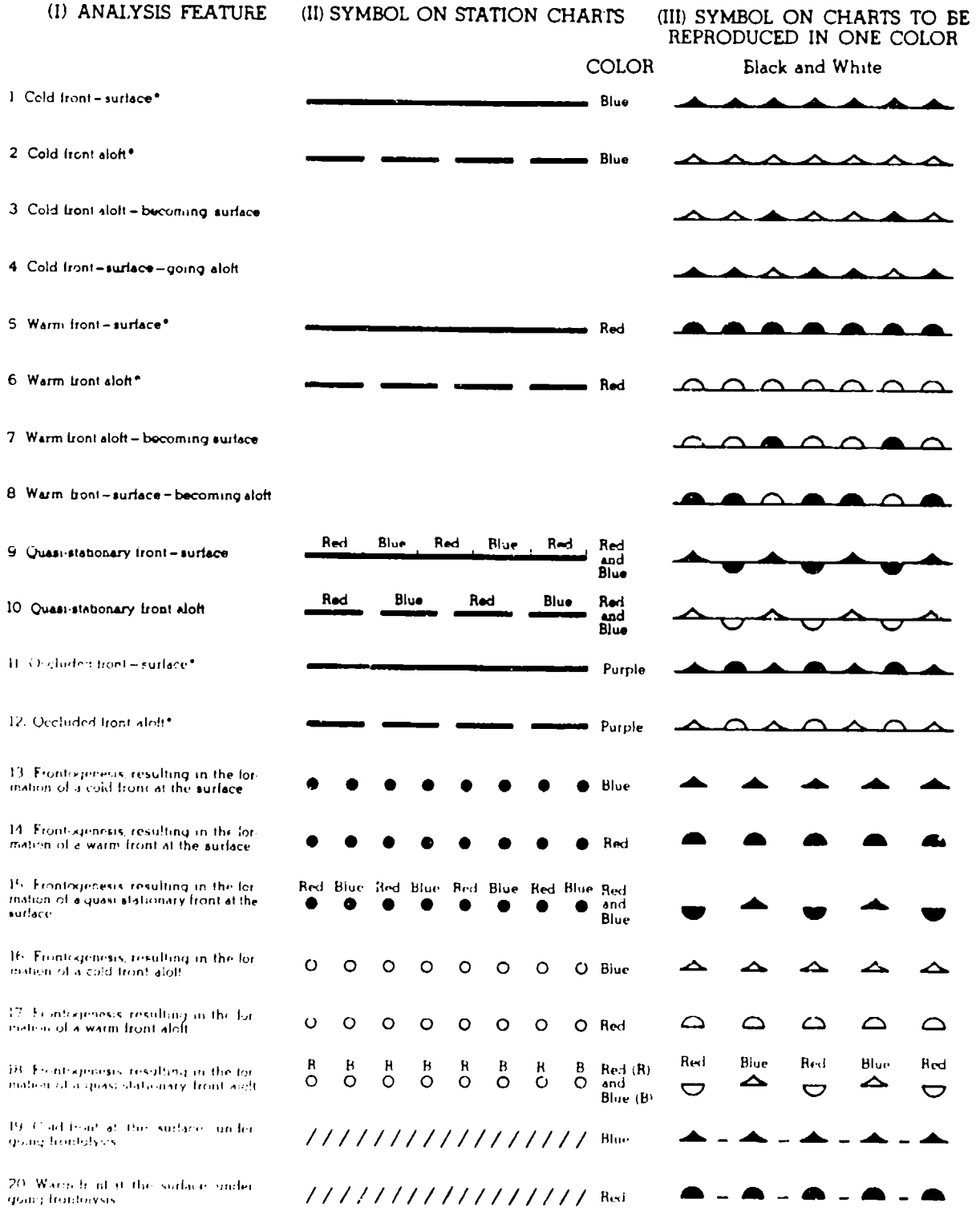
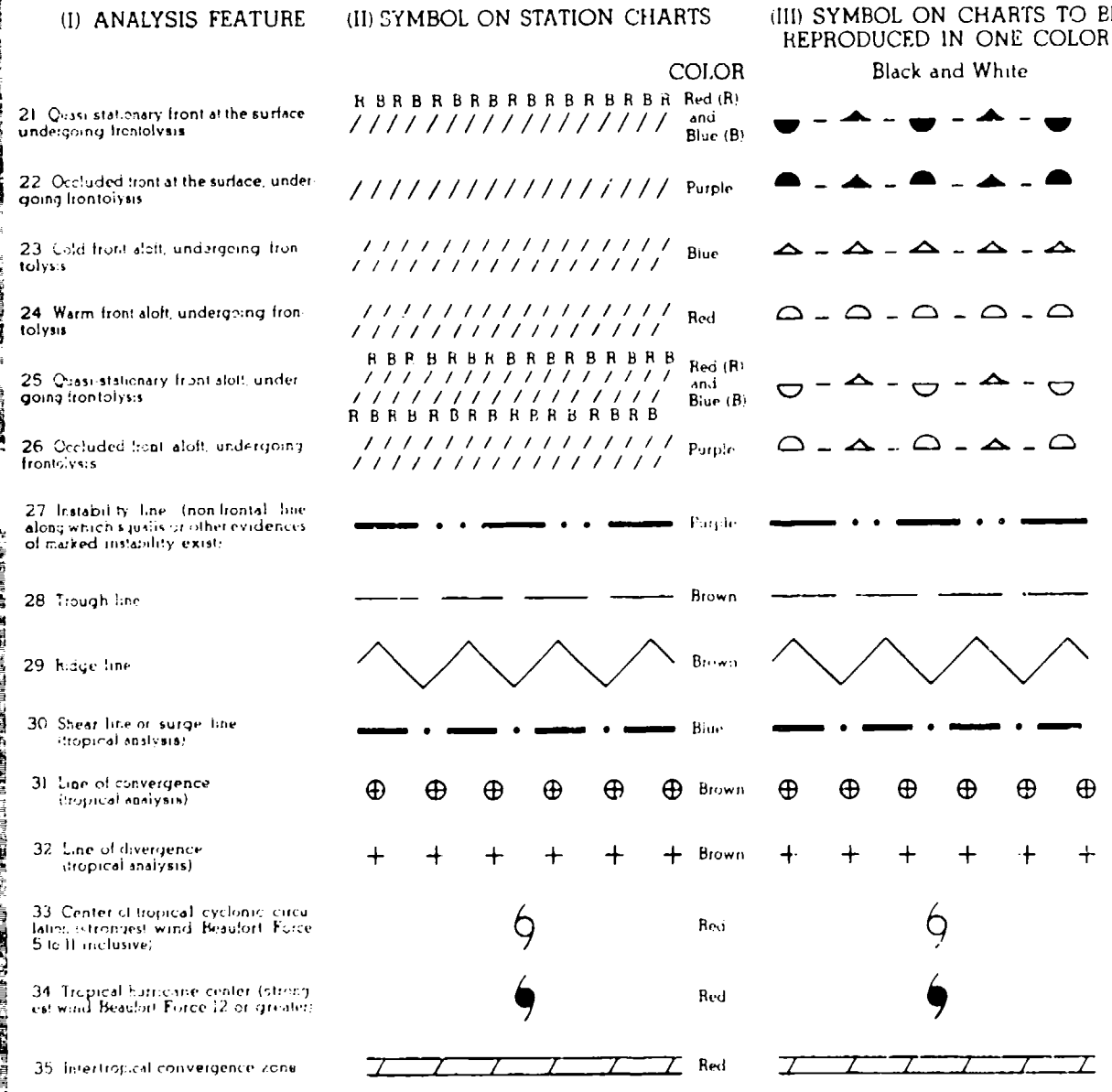


Figure 26–4. WBAN weather analysis symbols

WBAN WEATHER ANALYSIS SYMBOLS

(Continued)



NOTES

1 In symbols 1-12 inclusive, Column III, barbs may be separated more than shown, but a continuous line will always be drawn through the bases of the barbs.

2 In symbols 13-18 inclusive, Column III, the barbs will always be separated and will always be drawn without a connecting line.

3 In symbols 19-26 inclusive, Column III, the barbs may be spaced a greater distance than shown here, but the length of the dash between barbs should equal the space between the dash and each adjacent barb.

4 In symbol 35, Columns II and III, the spacing between the continuous lines will normally be about ⅛ inch, but may be greater when the intertropical convergence zone is broad.

Figure 26-4A. WBAN weather analysis symbols

warm air overrunning cooler or cold air. It is characterized by ever-thickening and lowering clouds with steady and often increasing precipitation. The frontal line (that is, the point where the temperature change occurs), passes a given point at higher altitudes before it passes at the ground surface. Passage of the frontal line at the surface marks the approximate end of the precipitation from warm fronts at a given station. Figure 26-4 shows how a warm front appears on a weather map (a heavy red line on a local synoptic map and a black line marked with hemispheres on facsimile surface maps). Look for precipitation to the north and east of a warm front line on a surface map.

Cold fronts follow warm fronts. At a given station a cold front is generally briefer, but with more intense precipitation, and it often features a more marked temperature change. Precipitation may occur both before and after the actual passage of the line of temperature change over a station. Unlike the warm front, the surface map position of a cold front usually represents the location of the band of the heavy weather. Figure 26-4 also shows the lines used for cold fronts, a heavy blue line on local synoptic maps and a black line broken by triangles on the leading edge on a facsimile chart.

Occluded fronts occur when a cold front has overtaken a warm front. Warm air has been lifted between the fronts and is being carried to higher, less dense, and colder levels. The water vapor condenses in vast amounts, causing widespread heavy precipitation. Occluded fronts present the characteristics of both warm and cold fronts. The sequence of surface front and upper front varies with the two types of occluded fronts. Cold occluded fronts feature first, the *surface front* (the occlusion line), then the upper *warm* front. Warm occluded fronts feature first, the *upper cold* front, then the surface front (occlusion line). Aircraft usually encounter two frontal zones in an occluded front. When the occlusion process occurs, it destroys temperature and moisture differences. This flattens the pressure gradient, and the system moves off as a weak, flat Low. Occluded fronts appear on local surface maps as a heavy purple line and on facsimile charts as a black line with alternating triangles and hemispheres *on the same side of the line* pointing toward the direction of movement. Compare occlusions with stationary fronts on facsimile charts, and note the difference of plotting.

These fronts are considered moving fronts because they move along with the low pressure center, with the cold front usually overtaking the warm front in most cases. The track of the low center varies with the seasons. In general, in the northern hemisphere, lows over a continental land mass move from the western shore southeast to mid-continent, and then move northeast to the ocean area. The winds at high tropospheric altitudes are generally westerly. Therefore, surface weather phenomena tend to move from west to east. In short, a low may move north, south, or usually eastward, or any intermediate direction, but rarely westward of the north-south directions (except in the case of low centers of hurricanes and typhoons). Thus, if a strong cold front lies over a station on the 0600 map and you are approaching from the west, you may expect that the front and associated weather will be clear of that station and your route by 1200. As a rough rule of thumb when a low center moves, its frontal system moves with it. Remember this basic, simple rule of motion of frontal and low pressure systems; it will make it easier to understand and interpret weather maps.

Other Weather Map Symbols

Troughs are valleys of low pressure. These are shown by heavy dashed lines along the area of lowest pressure. On facsimile charts, this is a black, dashed line. Long dashes are used to prevent confusion between other symbols. On local, colored surface maps, a solid brown line denotes a trough. Troughs are often the only indication of fronts aloft and are much more significant on constant pressure charts than on surface maps. Troughs on surface maps often denote conditions which might be described as very weak fronts. They are elongated areas of low pressure, a region of convergence and lifting, and are featured by increased cloudiness.

Ridges are areas of high pressure, as their name implies. They appear on facsimile charts

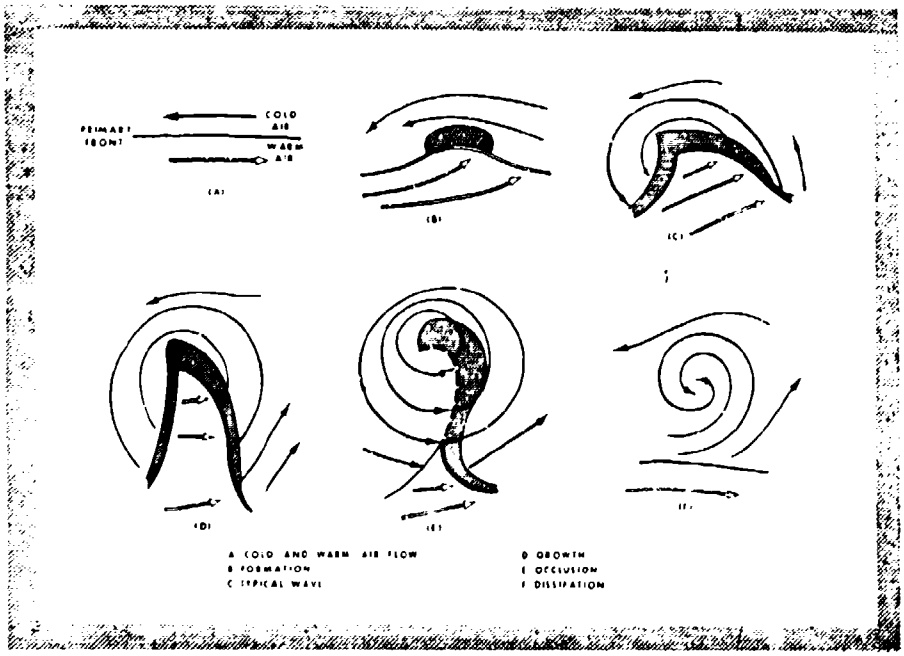


Figure 26-5. Development of a frontal system from a wave in a stationary front. Note that the cold front overtakes the warm front, becoming an occluded front

as zig-zag lines, and on local colored maps as zig-zag brown lines. Ridges are not particularly significant, and are often not shown on weather maps.

Easterly Waves are the curved lines of convergence on which a hurricane (typhoon) is occasionally formed. Easterly waves appear in the sub-tropical area between the equatorial front and 25 -28° north latitude. They usually cross a station in an average period of between three to five days. Easterly waves are troughs of low pressure and convergence, and move from east to west. They appear as a band of heavy cumulus (cumulo-nimbus clouds with heavy showers and thunderstorms. Passage of an easterly wave brings air of higher moisture content that extends to higher levels, and surface winds shift from north or northeast to east or southeast. Significant pressure falls (net 24-hour rise or fall) precede a wave, while rises are found behind a wave. On a colored surface map, easterly waves are shown as a curved blue line. (See Figure 26-1, item 30.) On a facsimile chart, they appear as a trough, or curved black line.

Tropical Cyclones (hurricanes and typhoons) are shown by a sort of pinwheel symbol on all surface maps (Fig. 26-1). Usually past 6-hourly positions of the "eye" or center of the storm are shown to assist in estimation of future movement.

An Intertropical or Equatorial Front is a common name for what is more properly called the Intertropical Convergence Zone (ITCZ). This is a trough of convergence and intense solar heating of very moist air. It is more or less parallel to the Equator, and may be stationary or slow moving. Often it bulges north then south with the wave form moving to the west slowly; it resembles the form caused by whipping a rope up and down and causing a snake-like movement. The width and strength of the ITCZ varies in different parts of the world (oceanic or land), with the seasons and amount of convergence between the northern hemisphere and southern hemisphere trade winds. In the northern hemisphere, the ITCZ moves northward in spring and summer and southward in fall and winter. On local colored maps, the intertropical convergence zone is shown as red hatching between two parallel lines. On facsimile charts, look for the usual stationary front indication in areas of definite frontal type weather.

Squall Lines are often found in front of an advancing *"fast moving"* cold front. Extremely

intense thunderstorm activity and occasional tornadoes accompany such squall lines. They are particularly common in summer. Squall lines may be indicated by an upper cold front paralleling the leading edge of cold fronts, or by a blue line of dashes and pairs of small dots as shown in Figure 26-4. On facsimile charts look for black dashes alternating with pairs of dots.

Upper Fronts are fronts which do not reach the surface of the ground. The frontal line is the line of meeting between different air masses. Occluded fronts usually have upper fronts associated with them. The location (ahead or behind) of the upper front is determined by the type of occlusion. The upper front on local synoptic maps is a broken line of the same color as used otherwise; on facsimile maps, it is an open or unshaded version of the same frontal symbol. Figure 26-5 shows a typical occlusion.

Frontogenesis, the forming of a new front or the strengthening of a weak front, is indicated by small red or blue circles of appropriate color on local synoptic maps and on facsimile by the appropriate front symbols with spaces between symbols.

Frontolysis, dissipation of a front, is shown by diagonal hatching across the usual frontal line as shown by Figure 26-4.

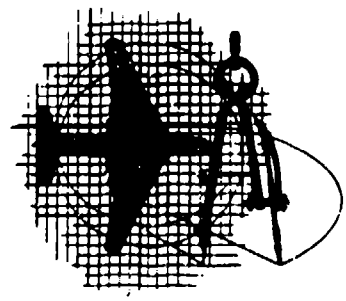
Shading and Hatching is used to indicate reduction of visibility from precipitation or obstructions to vision. Fog is shown by yellow shading on Air Force and Weather Bureau maps. On Navy weather maps, red is used to indicate fog. Suspensions of sand and dust are indicated by brown shading. Precipitation is shown by green *hatching* when intermittent, and by green light *shading* when continuous. Symbols are often used to designate the type of precipitation except rain. Smaller areas of dust, fog, or precipitation may be indicated by symbols drawn in large size. Particularly common in this category are indications of showers and thunderstorms. These are drawn in red on local surface maps when hazards, and in green when the weather is not severe. Shading and hatching are not used on facsimile charts, but the symbols for significant weather phenomena are often used, and precipitation areas are outlined by a dotted line.

Air Mass Symbols are sometimes shown on local surface maps. Three letters identify the air mass or high pressure area; for example "mPw" would indicate polar air from over the oceans north of 40° latitude which is warmer than the surface over which it is travelling.

Geographically air masses are classified according to the latitudes over which the mass of air originates. If the mass of air is from an area near or north of the Arctic Circle, it is called "arctic air" and is identified by the blue letter A on the synoptic maps. Air originating over an area south of the Arctic Circle to around the 40° latitude is called "polar air" and is identified by the blue letter P. Air originating over tropical and semi-tropical areas is called "tropical air" and is identified by the red letter T. Air from over the equatorial sources is called "equatorial air" and is identified by the red letter E.

Masses of air are also classified according to the type of terrain over which they originate. If the mass of air originates over a water area, it is termed a "maritime mass of air" and is identified by the letter M. Maritime air normally needs only a small amount of cooling to become saturated; therefore, more weather is apt to form in this type of air as it is cooled at night or when a front or terrain lifts it. If the mass of air originates over a land area, it is called a "continental mass of air" and is identified by the letter C.

Masses of air are also classified according to the temperature of the air relative to the temperature of the surface over which the air is passing. If a mass of air is warmer than the surface over which it is passing, it is called a "warm air mass" and is identified by the letter W (stable). If a mass of air is colder than the surface that it is passing over, it is called a "cold air mass" and is identified by the letter K (unstable).



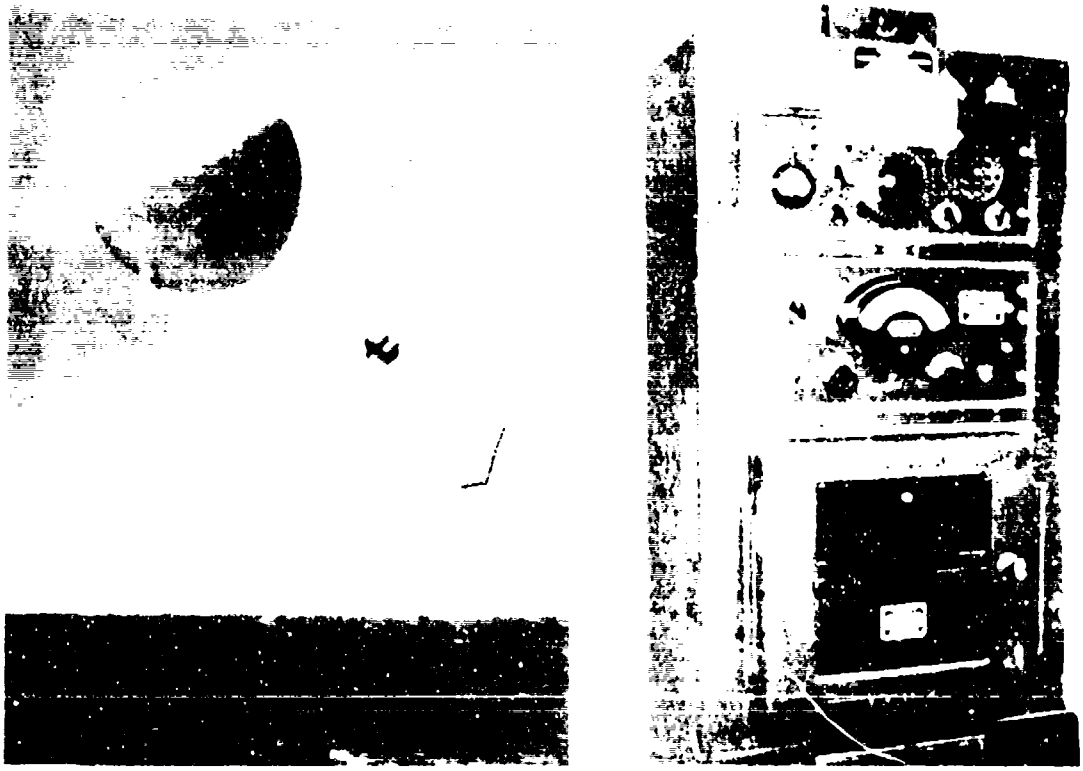


Figure 26–6. Radiosonde rising, with balloon, parachute and transmitting instrument suspended below (left). Radio receiving and automatic recording instrument (right)

When a mass of air has remained over an area for several days, it acquires temperature and dew points that are characteristic of the area. Then it is classified as A, P, T, or E air. If the mass of air moves out of this area, it keeps its original classification until it has remained over another new area for several days. When it acquires new temperature and dew points that are characteristic of this new region, it is reclassified.

UPPER AIR INFORMATION

As important as the surface weather map may be, it doesn't tell the full story on weather for pilots. A surface map will tell something about current weather and terminal weather, but you also need data on winds and weather en route at flight altitudes for flight planning. Conditions far above the earth become vital to aviators. With jet aviation, there are three primary sources of upper air information:

Radiosonde soundings provide data for preparation of the Arowgram (pseudo-adiabatic chart). Pressure, temperature, and relative humidity data are used to make this chart, which gives valuable information on temperature at flight altitudes, icing layers, bases and tops of clouds, and atmosphere stability.

Winds aloft data is presented to the pilot by means of winds aloft reports on the teletype and winds aloft charts (pibal maps, local or facsimile).

Constant Pressure Charts (or Contour Charts) provide a picture of winds, temperature, and dew point at standard pressure surfaces at common flight altitudes. If jet stream winds exist, they are shown on these charts.

In flight planning, you should consult this upper air information.

Radiosonde Soundings

A radiosonde is a minute radio transmitter which transmits radio signals indicating the values of pressure, temperature, and humidity. The transmitted data is received and recorded by an automatic machine at the surface station, and evaluated for information. (See figure 26-6.) Upper air soundings are observed twice a day—at 0300 and 1500 GCT (Z).

Data Shown in Upper Air Soundings

Radiosondes are plotted on at least two types of charts—the USAF Skew-T, log p diagram, and the Navy Arowagram, or NavAer 448T. The various chart forms used are very similar. You should be able to identify the various lines: free air temperature, dew point (wet bulb or saturation temperature), pressure level (isobars), standard atmosphere, temperature scale (isotherms), dry adiabats (potential temperature lines), moist (saturation) adiabats, saturation mixing ratio, and, in some cases, virtual temperature. You can find information concerning stability and upper air soundings in an aerology textbook such as *Aerology for Naval Aviators*.

In many cases the forecaster will be prepared with cross-sections and forecasts on cross-country flights, or will give you oral data on flight altitude temperature, icing levels, cloud tops and bases, cloud types, and so on, which are developed from his study of soundings. Often ask to see the soundings from which this information is derived to learn how to interpret such charts. If you can read important data from a sounding, it will reduce the time required to discuss the soundings at major stations.

STABILITY

The importance of determining the stability of various layers in the atmosphere cannot be overemphasized because there is a direct relationship between stability and such weather phenomena as turbulence, cloud types, and icing conditions. It has been shown that the degree of stability or instability of the air in the warm air mass is one of the primary determining factors for the type and intensity of the weather produced by both warm and cold fronts. It is apparent also that the type and degree of stability will determine the weather within the boundaries of any given air mass. Pilots have learned from experience that stable layers of air tend to have stratus-type clouds rather than cumuliform, rime icing in clouds rather than glaze, smooth flying

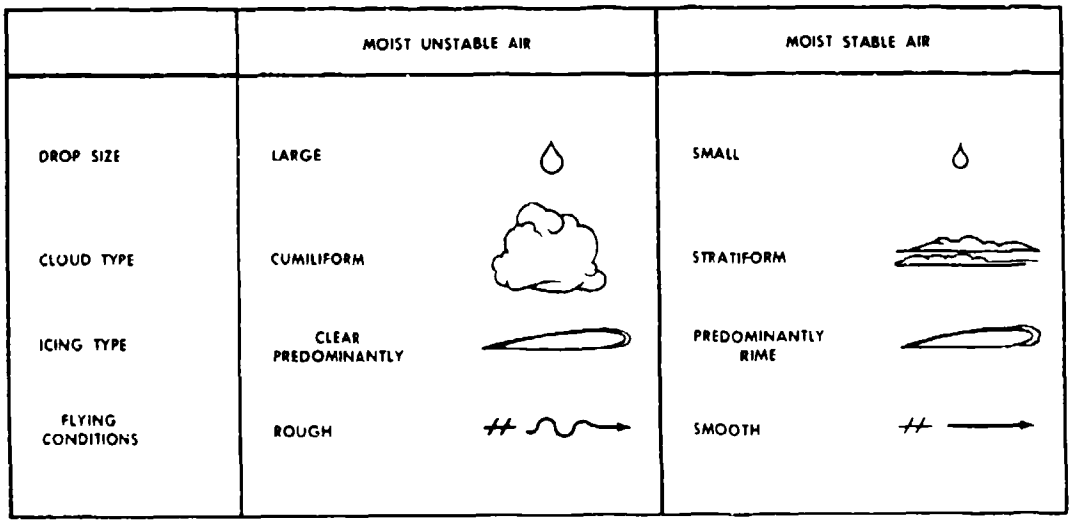


Figure 26-7. Relationship of stability to weather

rather than rough, and poor visibilities due to fog or smoke in layers rather than the clear air typical of turbulent, unstable air. (See Figure 26-7.)

Inversions

An inversion is defined as a reversal of the general or normal change of temperature with height. Thus, in the atmosphere below the tropopause, where normally the temperature decreases with increasing height, an inversion is defined as a layer of air throughout which the temperature increases with increasing height. You can find an inversion by referring to the virtual temperature curve alone. The lowest altitude of the inversion layer is called the "base of the inversion," and the highest is called the "top of the inversion."

As the name implies, a surface inversion would be one where the base is at the surface of the earth. A subsidence inversion is due to a layer of air descending and becoming abnormally warm relative to the layers above and below it. The word "subsidence" comes from the word "subside." The temperature-dewpoint spread at the top of a subsidence inversion is generally greater than at the base. When this type inversion occurs above the surface, it can usually be distinguished from a frontal type inversion because of the greater temperature-dewpoint spread.

Frontal inversions have the opposite characteristics of subsidence inversions. In a frontal inversion, the temperature-dewpoint spread is generally smaller at the top that at the base. In fact, the top ordinarily has very little spread.

Inversions are frequently characterized by clouds immediately above or below the inversion. Subsidence inversions are often associated with radiation fog conditions. Frontal inversions determine the height of the frontal slope over the location in question. As you know, the surface map shows the frontal position at the surface. However, the overrunning air mass above the surface is sloped, and the frontal line at altitude may be as much as 200 miles away from the surface frontal line. Therefore, it is important to note the altitude of inversions and examine the dew point spread above and below the inversion to establish what type of inversion it is and whether clouds exist above or below the inversion level. An inversion layer is usually relatively thin, and

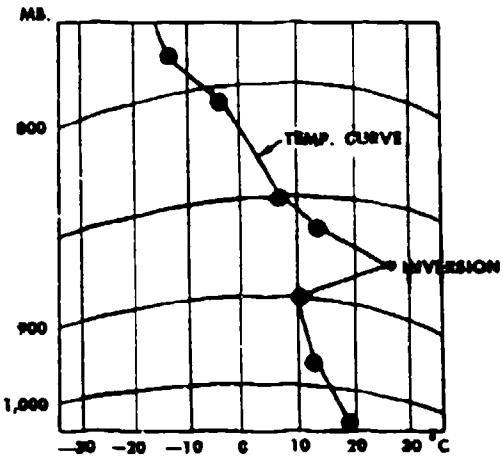


Figure 26-8. Inversions appear as layers where the temperature curve slopes to the right of the vertical; i. e., temperatures become higher with altitude and reduced pressure

the temperature curve generally maintains a slope to the left of vertical above and below such areas. Figure 26-8 shows the general appearance of inversions on a sounding diagram.

Turbulence

Generally, stable air provides smooth flight conditions, and unstable air creates turbulence. When a condition of neutral stability occurs (dry air with temperature curve parallel to dry adiabat, or moist air with temperature curve parallel to moist adiabat), you may expect moist air to be somewhat turbulent and dry air to be slightly turbulent.

Turbulence is more pronounced when clouds are present, and is greatest during rain conditions. Therefore, determination of turbulence from a sounding depends not only on stability or instability, but also on humidity as shown by the temperature-dewpoint spread. Some turbulence is possible in unstable, dry air, but the more destructive and strong turbulence is found where there is unstable, moist air and particularly where there is a considerable vertical depth to this condition.

WINDS ALOFT

Winds aloft data is observed every six hours at selected stations over the country (Fig. 26-9).

This information is transmitted to the field either by teletype code about two hours after the observation, or by facsimile winds aloft charts about 3½ hours after the observation. While the map format may be easier to read and visualize, the data is less prompt. The choice of whether to use the map or teletype therefore depends on whether the teletype data is more recent at the time of flight planning, and on personal preference.

Winds Aloft Chart

Winds Aloft Charts are often known by the name, "Pibal Maps." These maps may be locally prepared or facsimile, but usually the latter. Though they are not available as quickly as teletype data, they are easier to read and interpret, and most pilots prefer to use these charts when they show the latest information.

Facsimile Winds Aloft Charts are transmitted in two sets of four small charts. The lower level group shows winds at the lowest standard reporting level above the surface (usually 1,000 feet at naval stations), 850 mb or 4,000 feet, 7,000 feet, and 700 mb or 10,000 feet. The upper level group shows winds at 14,000 feet, 16,000 feet, 500 mb or 20,000 feet, and 25,000 feet. In cases where wind is shown for the pressure level instead of the altitude level, the station model includes the actual level by tens, hundreds, and thousands of feet, as shown in Figure 26-10. For example, the Key West wind shown is East 10K 20,000 feet, but the Tampa wind is SSE 10K at 500 mb which is at 19,480 feet (coded "948"). Note the temperature and dew point for stations which show the 500 mb wind. Tampa has a 500 mb temperature of −5° C. and dew point of −22° C.

Be careful to note the *time* of winds aloft charts. If the latest maps are 3 hours old or more, you should read the latest coded winds aloft reports to get the most accurate information on winds.

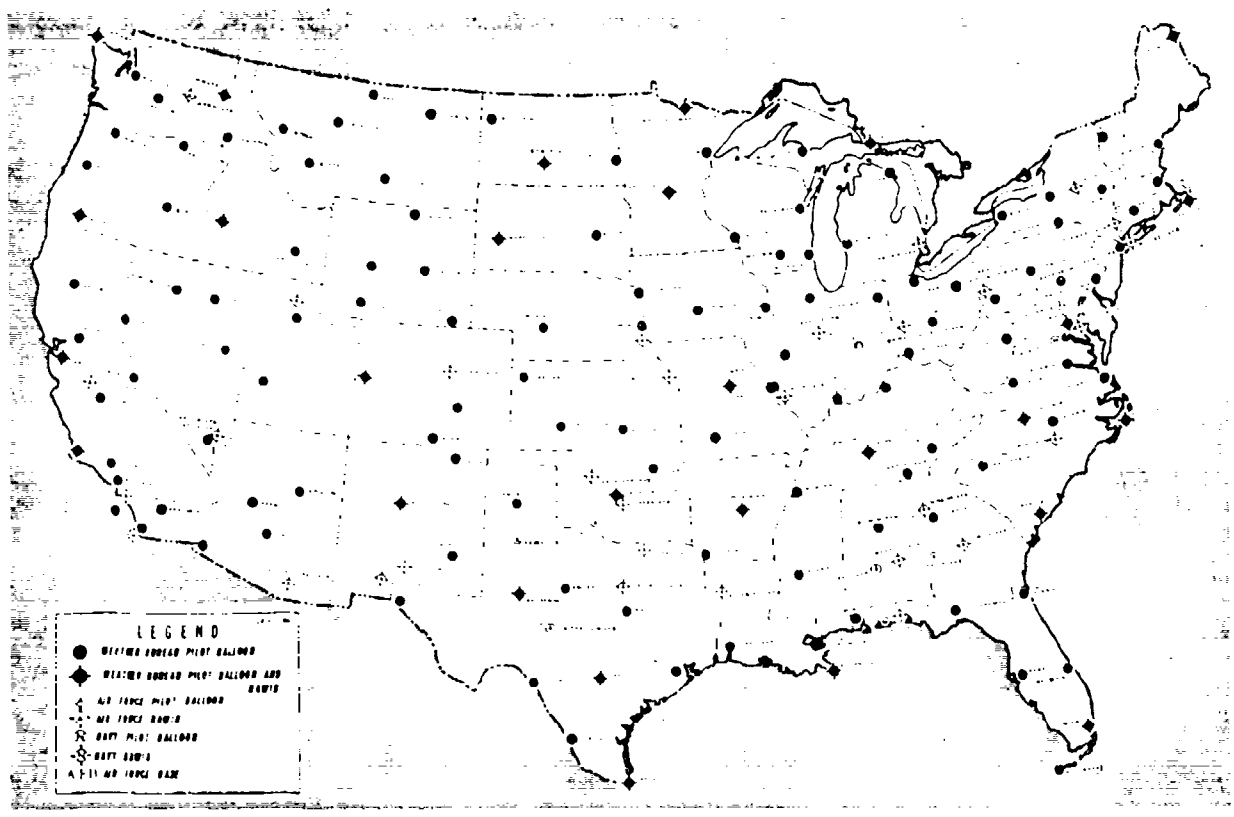


Figure 26-9. Winds aloft stations in U. S. from which reports are available on nation teletype services

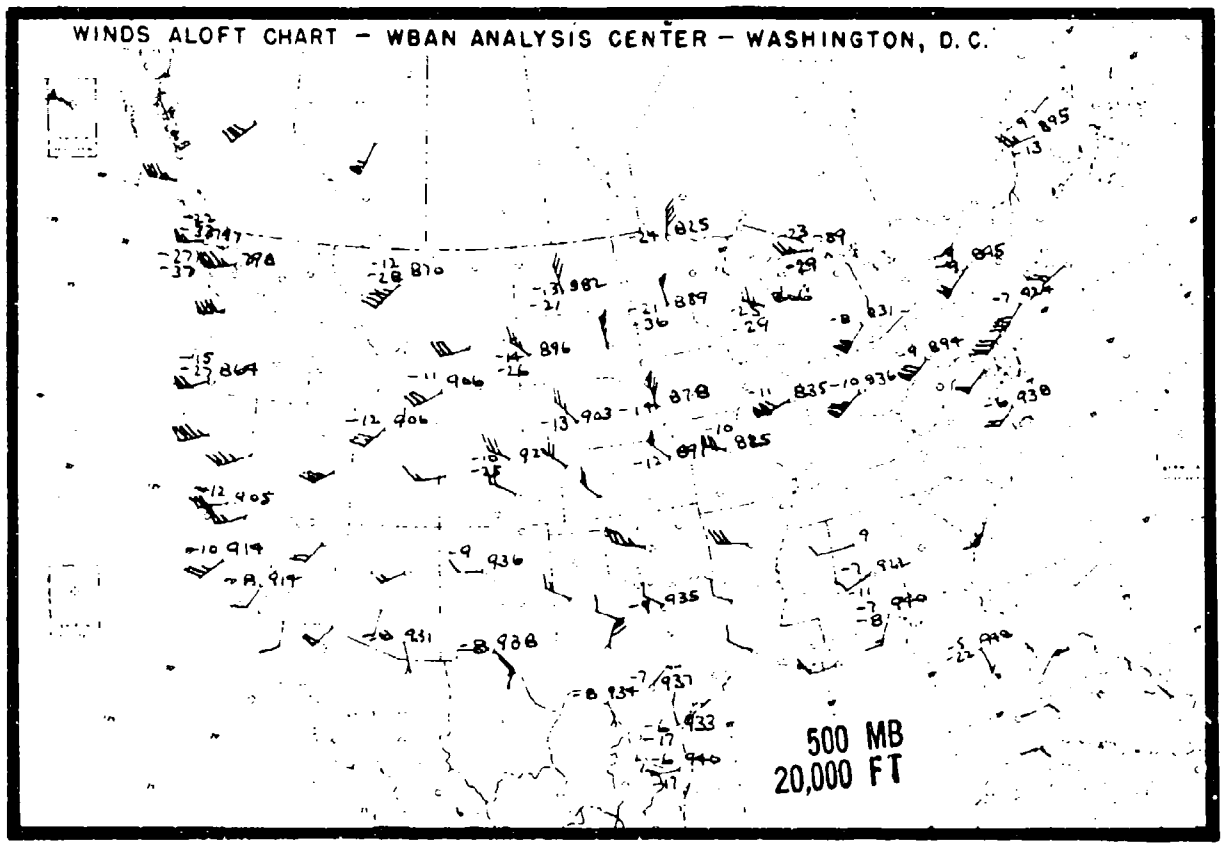


Figure 26–10. Facsimile winds-aloft chart. This chart is for 500 mb (20,000 feet) 0300Z, Oct. 8. It is one of four charts sent as a unit to show upper-level winds. Another set of four charts was sent at about the same time for four lower levels. Winds are at 20,000 feet here, excepting those marked with the level of the 500 mb contour, temperature, and dew point

Wind direction is indicated on the charts by a straight arrow shaft from the station circle, extending outward in the direction *from which* the wind is blowing. Wind velocity is indicated by barbs attached to the wind shaft, as shown in Figure 26-11. Each full barb represents 10 knots and each half barb represents 5 knots. Fifty knots is indicated by a triangular flag which takes the place of five full barbs. Calm is indicated by a concentric circle around the station circle.

CONSTANT PRESSURE CHARTS

The last source of upper air information to be discussed is perhaps the most important, the constant pressure charts (sometimes called upper air charts or contour maps). Study of these charts is essential for jet aircraft because of the difference in conditions and the extreme winds sometimes found at their high flight altitudes. All pilots, however, should study them. More skill in reading such charts will result in better flight planning.

Constant pressure charts reveal the circulation of air aloft by indicating, among other things, the variations in height above mean sea level of certain selected "standard" pressure levels. The levels chosen are 850, 700, 500, 300, 200, and 150 millibars. Standard charts and their approximate average altitudes are:

850 mb: 5,000 feet MSL.
700 mb: 10,000 feet MSL.
500 mb: 18,500 feet MSL.
300 mb: 30,000 feet MSL.
200 mb: 40,000 feet MSL.
150 mb: 45,000 feet MSL.

Although some weather stations may prepare their own high level charts, the charts are normally prepared for each of the standard levels by the National Weather Analysis Center and transmitted via facsimile every 12 hours. All data presented on the constant pressure chart are obtained from rawinsonde and Pibal observations made on a country-wide basis daily at 0300Z and 1500Z. Constant pressure charts, in combination with atmosphere sounding diagrams, present a three-dimensional coverage of weather elements aloft. They are important tools for actual forecasting as well as for obtaining winds and temperatures, since weather tendencies and trends are sometimes more representative and more evident aloft than at the surface because the air aloft is affected less by terrain, less by diurnal heating and cooling, and considerably less (at high altitude) by friction with the earth's crust.

For an understanding of what constant pressure charts are, it's best to start with a brief discussion of the data which is plotted on the charts. In Figure 26-12 there is plotted data observed simultaneously at 850 mb over stations A, B, and C.

The Station Models resemble those of the surface charts but with some important differences. Figure 26-12 shows the pattern used for station models on constant pressure charts and also the various types of wind arrow used.

TT: Temperature (C.): (Fahrenheit is used only for surface temperatures.)

TdTd: Dew Point (C.): Note that the relative position of the temperature and dew point data is the same as on the surface station models. Dew Point is usually omitted at 30,000 feet (300 mb) levels and above.

HHH: Height of Pressure Level. All data on a constant pressure chart is for the stated pressure, so, where a surface station shows barometric pressure at sea level, the constant pressure charts shows the altitude above mean sea level (MSL) of the chart pressure surface. Data is given in tens of feet, using 3 numerals. See the nearest isohype for altitude in hundreds of feet.

Wind arrows are drawn four ways to indicate the height at which that wind was observed. This situation results because circumstances often prevent observation of wind at the precise instant the radiosonde reaches a specified level, and, even at assigned winds aloft levels, data may be missing as to wind. Figure 26-11 shows samples of wind arrows with their meanings. Wind velocities are shown by the same system as previously discussed for winds aloft charts.

Isolines

The forecasters who analyze the data plotted on the various charts draw various isolines (lines of equal value) for pressure height, temperature, moisture, and windspeeds so that the cumulative meaning of the data is usable.

Isohypes. Contours or height lines known as "Isohypes" connect points of equal altitudes (of the pressure surface). They are normally drawn for values of even hundreds of feet, and for intervals of 100, 200, and 400 feet, depending on the pressure surface. They are solid lines, labeled in hundreds of feet. For flight planning purposes, winds blow parallel to the contour lines, with low

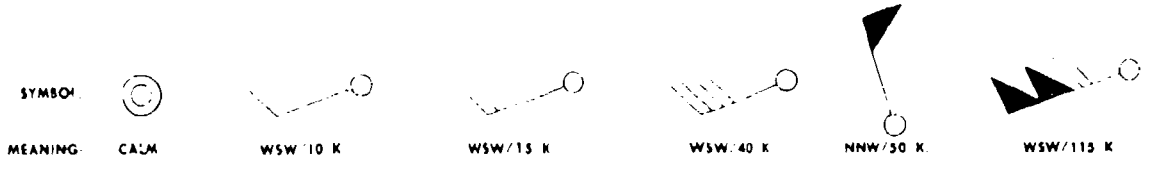


Figure 26-11. Wind indicators on facsimile weather charts

pressure to the left and high pressure to the right.

Isotherms. Just as points of equal height are connected by contour lines, so points of equal temperature are connected by isotherms (lines of equal temperature). These are normally drawn for even 5° C intervals. In the case of facsimile maps, they are long dashed lines. For the transmitted facsimile symbol, see Figure 26-13.

Isodrosotherms. Isolines of dewpoint, usually called moisture lines, connect points of equal dewpoint. These are dotted lines drawn for every 10° C. intervals (colored green locally.) Isodrosotherms appear only on the *850 mb* chart. On higher level charts of 300, 200, and 150 millibars, the dotted line is used for Isotachs.

Isotachs. On the higher level charts, 300 mb and higher, lines of equal wind speed, called isotachs are drawn. These are dotted lines labeled in knots, and are normally indicated for intervals of 25 knots, where space permits. Isotach lines outline the areas of low wind speeds and highest wind speeds (jet axis and jet streams).

Fronts

Fronts are indicated in the same symbolic manner as they are on surface charts, provided, of course, that the frontal surfaces extend upward to the pressure levels involved. It is important to remember that fronts are practically always displaced geographically at a given level from their positions at other levels because of frontal slope. Fronts are found only on the 850 and 700 mb charts, and then only if well defined at that altitude.

Ridges and Troughs

Pressure patterns at higher altitudes become a series of ridges and troughs moving from west to east (north latitudes).

Ridges are areas of relatively high pressure and feature improving weather, often with light winds. Troughs are valleys of low pressure. These troughs at upper levels may be said to form valleys for the movement of air masses. Therefore, as a trough aloft moves over a land area, a surface low and its frontal system tends to develop there within a few days after the trough appears. A regular succession of troughs pass a station, one every four days or so. Trough motion and the path of the jet stream have characteristics in common. Long-wave troughs tend to move surface weather further south, and also to distort a

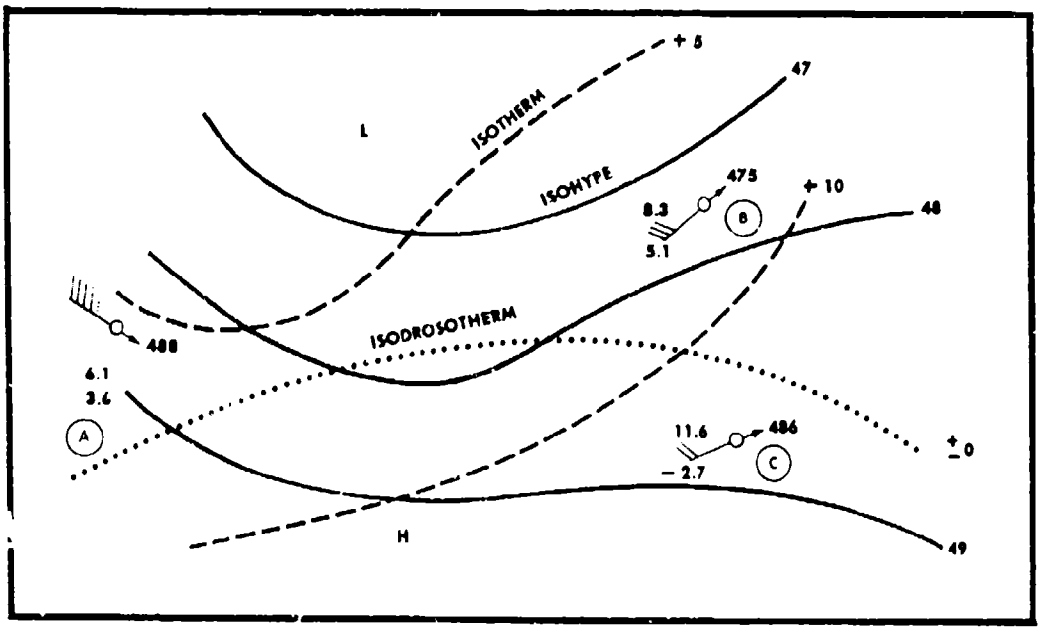
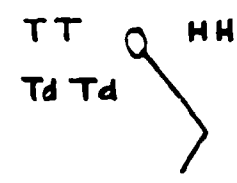


Figure 26-12. Section of constant pressure chart at 850 mb

Figure 26-13. Facsimile chart symbols used on constant pressure charts

STATION MODEL PATTERN	STATION MODEL SAMPLE	DECODE OF SAMPLE
 (TdTd omitted at higher levels)	(500 mb. Chart)	300 mb level is at 18,840 ft. Temperature is −45° C. Dew point is −60° C. Wind at 500 mb., 135°/65 knots at 18,840 ft.

ISOHYPES (lines of equal pressure) hundreds of feet MSL	186
ISOTHERMS (lines of equal temperature) C	−10
ISODROSOTHERMS (lines or equal dew point) C, 850 mb. chart only	−15
ISOTACHS (lines of equal wind velocity) knots (300-150 mb. charts only)	100

JET STREAM (max. axis) → TROUGH

RIDGE

jet stream to a large oval curl, instead of west-east orientation.

Uses of Constant Pressure Charts

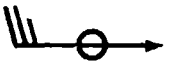
Constant pressure charts are actual slices through the atmosphere at various levels. Upper level conditions provide clues to further lower level conditions. You should make it a habit to regard weather conditions as being in motion, and consider the effects of such terrain features as mountains, seacoasts or low flatlands on the moving air masses.

The surface weather maps locate pressure centers, fronts, air masses, and terminal weather conditions on the surface. The 850 mb chart (5,000 feet) shows conditions for low-level flight, but is even more important because it shows a slice through the general level at which clouds associated with bad weather are most concentrated. It is valuable for forecasting thunderstorms, rain, snow, overcast, and heavy cloudiness. In this connection you can see the importance of the lines of equal dew point compared to lines of equal temperature to spot cloud areas. Lines of equal pressure heights define the pressure systems, and fronts are shown which are clearly defined at this level. This gives you some idea of how a front is oriented in relation to the surface front, and how intense it may be. Areas of precipitation and overcast associated with fronts and lows are easy to visualize.

The 700 mb or 10,000 foot chart gives data at normal flight levels for prop aircraft without pressurized cabins or oxygen, but are perhaps more important to show wind conditions associated with broad areas of heavy clouds and rain. Only well-developed fronts will appear.

The 500 mb chart shows conditions at about 18,000 feet. It represents average troposphere conditions. These, when used with wind arrows at stations around the country, show routes of weather motion and desirable routes to avoid headwinds. This is the level for most long-range prop aircraft flights.

The 300 and 200 mb charts show the structure and position of the jet stream, and are vital for

WIND SYMBOLS AND MEANINGS	When wind shown is at actual level of chart pressure	Where wind shown is at "average" altitude of chart.	Where wind shown is at a lower level.* If no numeral, means:
Wind Symbol → / Chart: ↓			
850 mb.	850 mb.	5,000′	4,000′ *
700 mb.	700 mb.	10,000′	9,000′ *
500 mb.	500 mb.	18,000′	16,000′ *
300 mb.	300 mb.	30,000′	25,000′ *
200 mb.	200 mb.	40,000′	35,000′ *
150 mb.	150 mb.	45,000′	40,000′ *

*_Note:_ This same wind symbol (broken barbs or pennant) means either next lower mandatory winds aloft reporting level (as shown by examples in this column) when no numeral appears, or else, if there is a numeral in parentheses underneath, that numeral shows the altitude in thousands of feet at which the indicated wind was observed.

Example: On a 300 mb. chart, (18) would mean wind at 18,000 ft. is NE/20 knots.

Figure 26–14. Wind arrows on constant pressure chart

jet operations and higher altitude prop flight.

The 150 mb or 45,000 foot chart generally shows conditions of the lower stratosphere. Even jet aircraft do not usually operate so high except on military flights. Aside from their use for high altitude flights by jets, these charts are also valuable to the forecaster.

WIND BELTS AND AIR MASSES

Modern weather forecasting is based on air mass theory. Even the weather forecaster who puts out a local area forecast must look at the big picture of the wind belts which move air masses together to produce fronts and then cause them to pass over the area. Fundamentally, all weather forecasting rests on the circulation of the atmosphere. This circulation is induced by the unequal distribution of the sun's energy on the earth.

Circulation of the Atmosphere

In its broadest form, circulation of the atmosphere results from the fact that the most direct rays of the sun hit the earth in the vicinity of the Equator and cause a net gain of heat at the Equator and a net loss of heat at the poles. The air at the Equator is heated, rises, and flows along the upper extremities of the atmosphere toward both poles. On reaching the poles, it cools and sinks back toward the earth, where it tends to flow along the surface of the earth back to the Equator where it started. (See Figure 26-15.)

Actual circulation in the atmosphere is far more complex because--

1. The earth is covered with an irregular surface of land and water areas.

2. The earth rotates, so that the area being heated changes constantly, and, further, *Coriolis deflection* enters into the picture.

3. The tilted axis of the earth causes seasonal changes in the amount of heat received by any specific area of the earth's surface.

According to the three-cell theory of atmospheric circulation, the earth is divided into six latitude belts—one belt in each hemisphere between the Equator and 30° latitude, one between 30° latitude and 60° latitude, and one between 60° latitude and the pole (Fig. 26-16).

The air at the Equator is heated and rises, creating a low-pressure area at the surface. When this warm air reaches the extremity of the atmosphere, it tends to flow toward the poles. About the time that this air has migrated to 30° latitude, the Coriolis force has deflected it so much that it is moving eastward instead of north. This results in a piling up of air near 30° latitude and, consequently, a descending current to the surface. When this descending air reaches the surface, part of it flows toward the Equator to replace that which has gone and part of it flows northward toward the pole in the Northern Hemisphere. (The converse is true in the Southern Hemisphere.) As a result of this piling up of air in the area of 30° latitude, a belt of high pressure is formed in this area, which is one of the three cells of circulation.

The second cell of circulation is located between 30° latitude and 60° latitude. The circulation pattern in this cell is much more involved than the pattern in the first cell, since the flow of air is complicated by traveling cyclones and anticyclones. Although the general flow of air in the second cell is toward the poles, it is deflected to the east by the rotation of the earth (Coriolis force). This cell is known as the belt of prevailing westerlies.

The third cell of circulation lies between 60° latitude and the pole. The circulation in this cell begins with a flow of air at a high altitude toward the poles. Air which is forced to rise by the circulation in the second cell and by the heating in this area adds to the primary flow of air from the first cell. This flow of air continues to the poles,

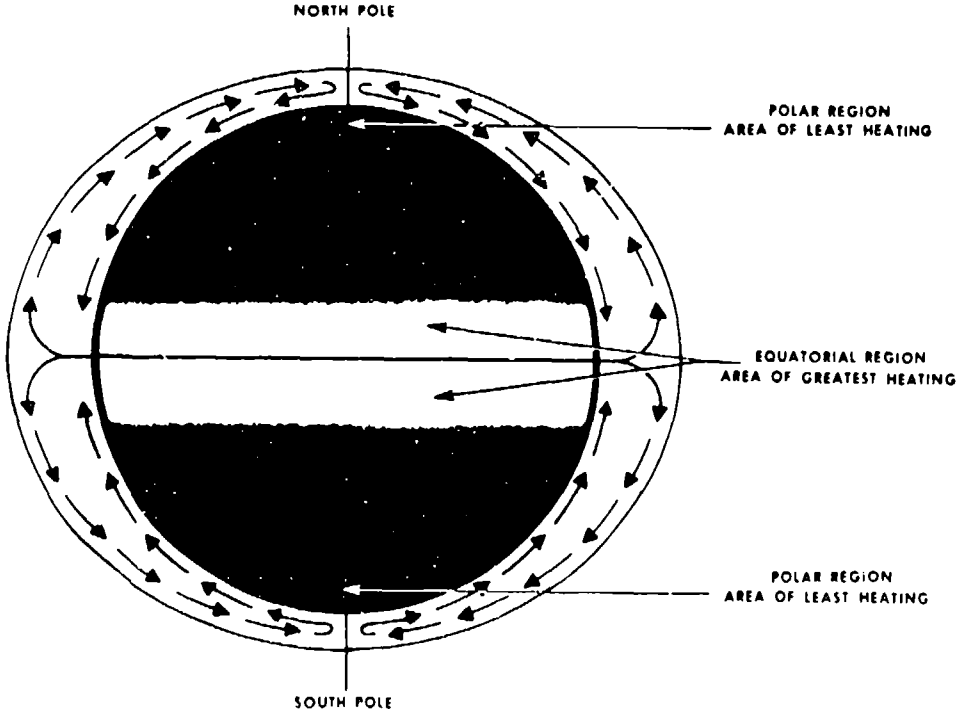


Figure 26-15. Simple circulation

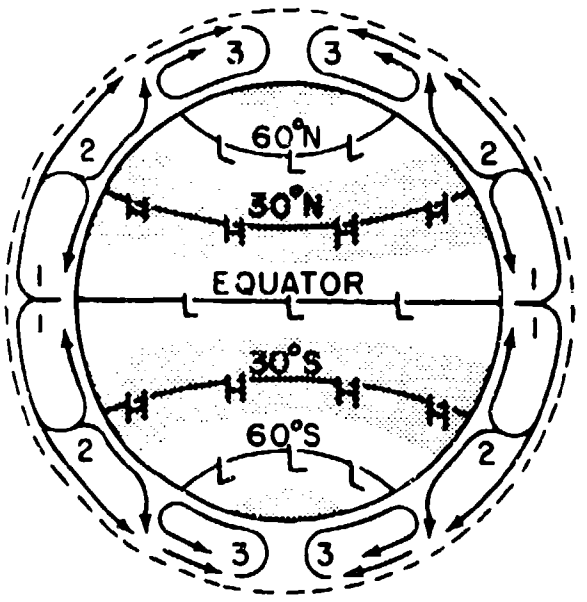


Figure 26-16. Three-cell world circulation pattern

where it is cooled, and descends, forming a more or less static high-pressure area in the polar regions. When the air reaches the surface of the earth, it tends to flow back toward the Equator near the surface of the earth. The circulation in this cell is completed by the southerly flow of air toward the Equator. The air here converges with the poleward flow from the second cell and is deflected upward. This convergence causes a semi-permanent low-pressure area (at approximately 60° latitude), and the discontinuity in temperature and density of the two bodies of air causes a front (called the Polar Front) to form in this area. In Figure 26-16 the circulation pattern is shown according to the three-cell theory.

As the earth rotates, circulation is affected by Coriolis force and winds are deflected to the right of the original direction of movement in the Northern Hemisphere and to the left of the original direction of movement in the Southern Hemisphere. (See Figure 26-17.)

The revolution of the earth about the sun introduces another set of variables—the seasons. All of the earth's atmospheric circulation is based on a differential heating from the sun. As a result of the seasonal variation in the intensity of the sun's rays on the surface of the earth, areas of differential heating do not always remain in the same geographical location, but fluctuate with a change in season.

An even greater number of variables is introduced by the great differences in terrain types which cause many local deviations from the primary circulation theory. Friction with the surface of the earth and the barriers presented by great mountain ranges towering 3 to 5 miles into the atmosphere produce definite changes in the flow. The difference in specific heats of land and water surfaces is an equally important factor in accounting for local variations from the primary circulation pattern. All these variations from the basic meridional circulation pattern must be taken into consideration in studying the over-all picture of atmospheric circulation.

Look now at earth's general circulation pictured more or less as it really occurs. Figure 26-18 shows average pressure distribution on the surface of the earth during winter. Here you see in the Northern Hemisphere, near 30° N. latitude, two high-pressure cells, one over the Pacific and one over the Atlantic—uniform in substance. Near 60° latitude, are two high-pressure cells over continental areas—one over Canada, and the other over Siberia. Now note the two Lows—one over the Aleutians, and the other one over the Icelandic area.

You should be completely familiar with the location of these six semi-permanent pressure systems (the Siberian, Pacific, Canadian, and Bermuda high-pressure areas and the Icelandic and Aleutian low-pressure areas) because they play an important part in the origination and movement of air masses and frontal systems.

Air Mass Weather

An understanding of the characteristics of an air mass is essential to any study of flying weather phenomena in the temperate regions. The prevailing weather in a given location at a given time depends either on the character of the prevailing air mass or the interaction between two or more air masses. An air mass may be defined as any large body of air whose physical properties are approximately horizontally uniform. The basic

characteristics of any air mass are humidity and temperature, and it is by measurement of these properties that the various types of air masses are determined.

Air masses are classified according to a system based on two principal factors: geographical location of the source region, and stability of the air mass. The following designators identify air masses generally found in the northern temperate zone:

mPk (maritime polar cold) has its source region over an ocean north of 40° latitude and is colder than the surface over which it is traveling.

mPw (maritime polar warm) has its source region over oceans north of 40° latitude and is warmer than the surface over which it is traveling.

mTw (maritime tropical warm) has its source region over oceans south of 30° north latitude and is warmer than the surface over which it is traveling.

cPk (continental polar cold) has its source region over land areas near 60° latitude and is colder than the surface over which it is traveling.

cTw (continental tropical warm) has its source region over a land area south of about 25° latitude and is warmer than the surface over which it is traveling.

Because of the varying characteristics within the specific air masses, weather and flying conditions in one air mass are generally quite different from those in another. For this reason, it is necessary that you understand what type of weather to expect in any particular air mass. Here are some examples from the U. S. Continent.

Maritime Polar. The outstanding feature of mP air masses is that they tend to be moist, so that some type of precipitation is usually associated with them, especially when they first move inland. Most mP air masses which affect the U. S. enter from the west coast. In the winter the air mass is usually mPw since the ground is colder than the air. As the mP air is cooled in the lower levels, stratus clouds and fog often form along the coastal plains. The abrupt lifting of the mP air up the Cascade Mountains frequently results in cumuliform clouds. This "stacking up" of the clouds along the windward side of the mountains is sufficient to produce frequent IFR conditions in this region during the winter months. Frequently, the IFR conditions are accompanied by severe icing and moderate to severe turbulence.

As this air moves down the eastern slope of the Rockies, it loses its moisture and acquires heat so that the air becomes stable. Flying conditions in this mass east of the Rockies are generally the best to be found in the U. S. in winter, with little turbulence, good visibility (except in industrial areas), and unlimited ceilings.

In the summer, there is little or no heating in the lower layers of an mP air mass as it moves inland, so that it invades the continent as a fairly stable air mass. As this stable air is lifted at the coast, stratus clouds and fog are common along the coastal area and for some distance inland. After this air crosses the mountains in the summer its characteristics are similar to those of continental polar air.

Maritime Tropical. The mT air masses generally invade the U. S. by the way of the South Atlantic and the Gulf of Mexico. The mT air masses are always warm and moist. Extensive

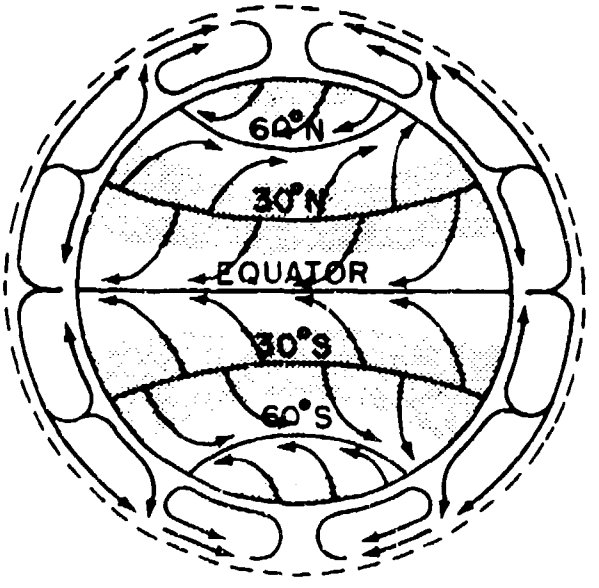


Figure 26-17. Direction of prevailing winds on earth's surface

precipitation and cloudiness are associated with these air masses, particularly in the winter when they are cooled from below (mTw), and cause low ceilings and visibilities. Even in the summer, the continental lifting and convective heating result in the formation of cumulus clouds, rain and thunderstorms. In general mT air masses present poor flying weather because of extensive cloudiness which may be cumuliform, stratiform, or both. Poor visibility is also associated with this type air mass because of heavy precipitation, frequent widespread advection, and prefrontal fogs. Turbulence is usually not a serious consideration in mT air masses outside of thunderstorms, but icing may be hazardous if the clouds extend above the freezing level, as they frequently do in the winter.

The mT air masses of Pacific origin affect only the California portion of the U. S. in the winter. Although invasion by this type air mass is infrequent, when it does occur heavy precipitation results. In contrast, the eastern half of the U. S. has frequent invasions of mT air masses in winter, and in summer these air masses represent the dominant form of weather in this region.

Continental Polar. The cP air is cold and dry and is heated by the underlying surface as it moves southward toward the U. S., consequently becoming unstable. Because of the dryness of this type air mass, the weather is generally clear. However, when it passes over a water source, such as the Great Lakes, it may acquire enough moisture to form cumulus type clouds. During the daylight hours, the air is generally turbulent and the visibility is excellent. At night the turbulence subsides and visibility is reduced by smoke, haze, and sometimes radational fog.

After crossing the lakes, the air again flows over a cold snow-covered surface. The surface cooling increases the stability and may produce fog at night. The air may be subject to forced lift in approaching the Appalachians. By upslope

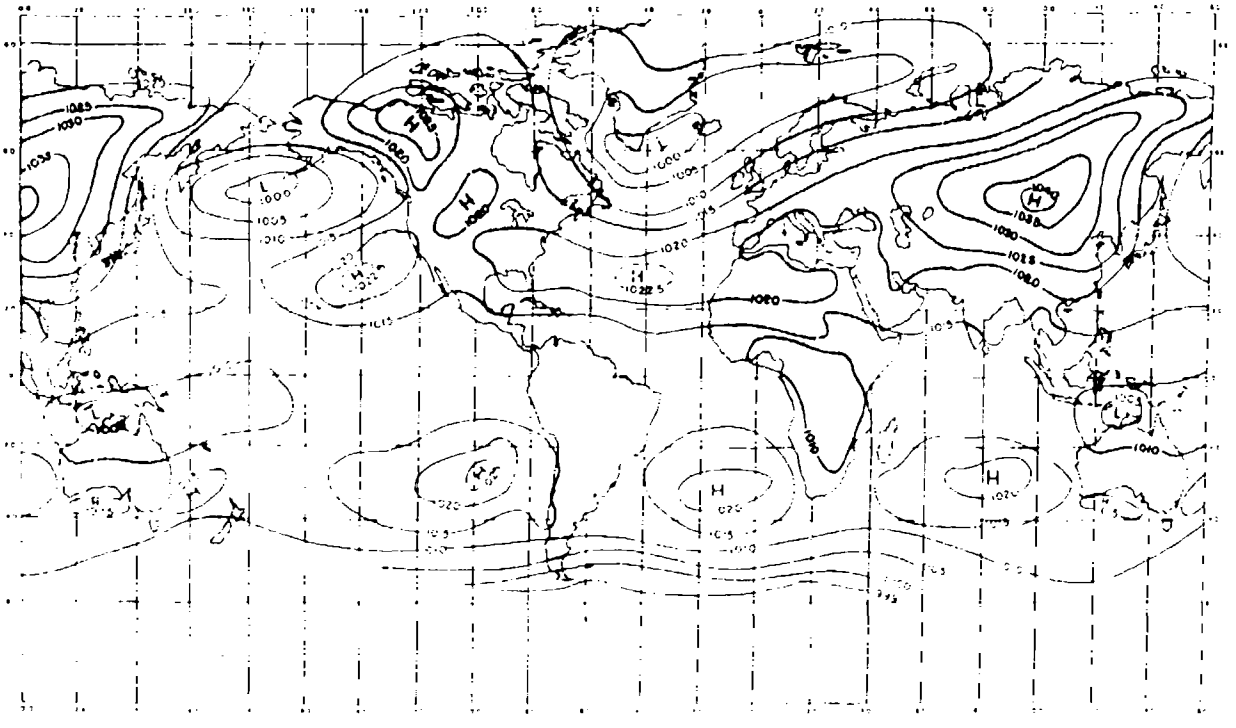


Figure 26-18. Prevailing pressure system of the world in winter

flow, instability is increased, and the resulting tower cumulus may develop into cumulonimbus. On the eastern side of the mountains, the air descends, is warmed adiabatically, and the clouds are partially or completely dissipated.

Continental Tropical. The cT air mass is characterized by high temperatures and low humidities. Little or no precipitation or cloudiness, as well as usually good visibilities, make for good flying weather. However, flying is often uncomfortable due to the large vertical extent of turbulence. Occasional dust storms present about the only significant flying hazard, as the dust or sand may extend to rather high altitudes and reduce visibilities for some time. The cT air masses are found over the U. S. in summer, when the source region is the Mexico-Texas-Arizona area.

THE JET STREAM

The jet stream is a narrow current or currents of wind over 50 knots, often as high as 300 knots, with varying intensity at different points along the stream or current. Wind velocities are greater when the stream is nearer the Equator. The jet stream is usually near the tropopause, at an altitude of 30,000 to 40,000 feet.

A jet stream can usually be found with an intense, rapidly moving cold front, separating a continental polar air mass from a tropical air mass. The jet stream appears to form near latitudes 60° or 70° (farther north in summertime than in winter) and frequently is identifiable as far south as 20° latitude.

The jet stream is not static or stationary. It is not a straight line current. It is not of constant width, depth, height, or velocity. It builds up and breaks down, being replaced by a new stream. It may branch out into "jetlets" or "jet fingers." These branches may or may not join up again. Generally there is a winding belt of maximum winds, with centers of greater velocity every now and again along the belt.

The jet stream can be pictured as a high speed meandering river of winds in an otherwise "normal" flow. The rate of change in wind speed as you move out of the core or axis of jet maximum is known as wind shear. Wind shear may be horizontal or vertical. The horizontal wind shear is how quickly the winds reduce in force to the left or right of the direction of the wind axis. Vertical wind shear is how fast wind velocities drop at altitudes above and below the core. For example, in Figure 26-19, the vertical wind shear is greater above the core than below it. Thus, to reduce the headwind effect of the jet stream during flight in the area, it would be more effective to climb above the jet stream than to go below it, disregarding considerations of airspeed change, time spent climbing, and total flight distance in relation to distance in climb.

Wind shear is important to flight planning, especially when the flight is in the opposite direction to the jet stream flow. It may be determined from constant pressure charts. Horizontal shear is established from the isotachs (lines of equal wind velocity) at the level of the jet maximum. Close-packed isotachs indicate a higher shear than widely separated isotachs. Vertical wind shear is determined by comparing values of isotachs along the axis of maximum velocity on the various charts for different levels.

Generally wind shear is greatest to the north side of the jet stream, sometimes dropping 100 knots in 100 miles. To the south, the shear rarely exceeds 100 knots in 300 miles. Each individual case should be determined from charts before take-off if possible. Vertical wind shear is greater, often 80 knots in only two miles (12,000 feet) of altitude. Usually the vertical wind shear is greatest and more constant above the axis of the stream. Vertical wind shears are greater when the jet stream axis is nearer the polar front.

The jet stream is indicated by a broad arrow on the constant pressure charts. Jetlets are also shown by this designation. This line on the chart is an approximation, because wind force measurements at these high altitudes are not especially numerous or accurate. However, this line itself does not tell you enough. What you want to know is the altitude of maximum velocity. To find it:

1. Compare the various constant pressure charts to find the probable level of maximum velocity.

2. Select points on the jet stream axis and look up the winds aloft for the levels between the standard constant pressure chart levels to find max-norm wind levels.

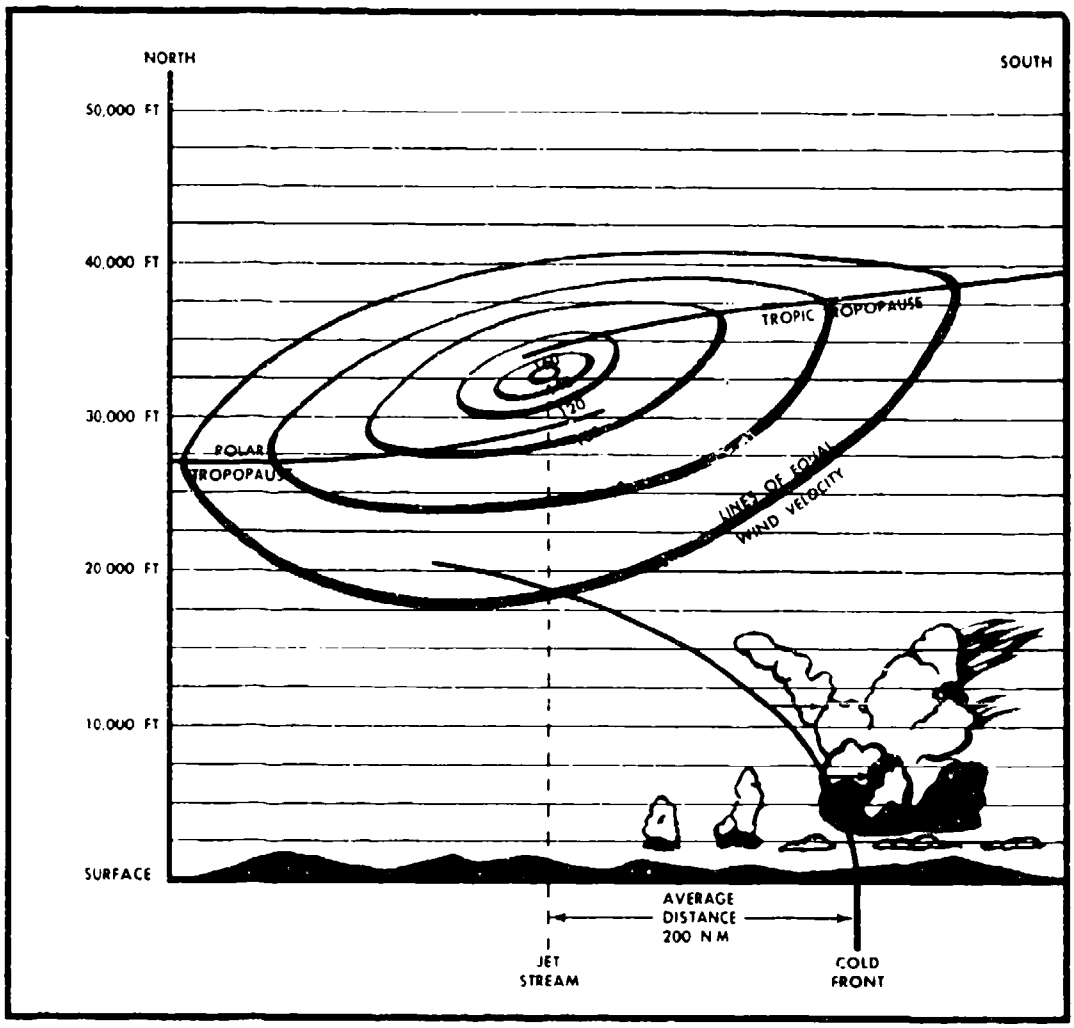


Figure 26–19. Polar front and the jet stream

3. In flight, check your ground speed or drift from time to time to make sure you have not left the jet stream or entered it when you did not wish to do so.

4. Remember the jet stream moves, its sideways rate of motion often being about 10 knots. Try to predict this.

Sometimes, you may wish to locate the jet stream from a 500 mb chart in the absence of charts for higher levels, or you may desire to find or avoid high winds for flight at the 500 mb (18,500-foot) level. Look for an area of strong temperature gradient (close-packed isotherms). The axis is often above this area. Frequently the jet axis more or less follows the −17° C (sometimes −18 to 20° C) isotherm, and it is often close to the 18,400-foot (number 184) contour. Isotachs (equal wind force) do not appear on the 500 mb chart. Of course, you should check the wind arrows at station models to confirm such rule-of-thumb determination to the extent available. Those with flags (indicating winds over 50 knots) are particularly easy to spot, but winds of only about 40 knots are not uncommon at 18,000 feet, below the jet axis.

The core of the jet stream is usually located

between the 200 mb and 300 mb levels (that is, in the thirty thousands). The stream is normally 100 and more miles wide and about 4,000 to 20,000 feet thick. Windspeeds are highest in winter, and the core at this time is usually at about 250 mb except lower over deep lows and troughs. In the winter, the jet stream moves farther south (which is the reason for the increased maximum velocities).

Location of the jet stream is an essential step in flight planning. Not only must the geographical position of the maximum axis be established, but the vertical structure must be determined by comparison of the various constant pressure charts and wind aloft information above about 500 mb. Flight planning must include computation of whether it will gain time to follow a devious route in order to gain jet stream tailwinds or avoid jet headwinds. Altitude selection must be made from comparison of ground speeds in climb and in cruise based upon airspeeds and the winds at different levels.

TELETYPE SEQUENCE REPORTS

The Teletype Network

Along the civil airways, and at important points off the airways, weather observations are taken and transmitted at hourly intervals. These transmissions begin at 28 minutes past each hour. It would be convenient if each station had available the hourly reports from every other station in the United States, but the time consumed would be excessive. To provide the maximum useful data in a minimum of time, a series of circuits and relays is used. Each station is part of a circuit, as this geographical division provides more rapid distribution of information. The United States is divided into 12 such regions.

Hourly weather reports are sent by teletype every hour at 28 minutes past each hour based on observations made between 20 and 25 minutes past the hour. Each station in a local circuit sends its own report in assigned order. Then the monitoring station on the circuit relays selected reports from other stations, beginning with the nearby circuits and following with circuits at a greater distance. The result is that stations on the local circuit receive reports from all stations on their own circuit and selected reports from other circuits, with fewer being received from the more distant stations.

These hourly reports are designated as Record Observations or Special Observations. The *Special* designation is given those which report a significant change in ceiling, sky cover, visibility, precipitation, or pressure—a change which is considered of importance to the safety of aircraft operations.

Moreover, at 10 and 50 minutes past the hour, a station may send an additional special report using an abbreviated format. These specials are in two forms—specials to report changes occurring at an other-than-scheduled time, and single-element specials to report a single item of importance such as a tornado, waterspout, significant wind change, pressure jump, or (USAF only) certain radar reports.

A symbolic presentation is used to show the type of information and order of presentation in the teletype sequence report. You must be proficient in decoding these reports. For an explanation of these formats, see the publication, *Aerology for Naval Aviators*.

In addition to the Hourly Airways Sequence Reports, there are five sources of weather forecast information available to pilots for flight planning. These are transmitted over the teletype network. They are (1) Winds-Aloft Forecasts (2) Regional Synopses (3) Area Forecasts (4) Terminal Forecasts and (5) Severe Weather Advisories.

The pilot who can read sequences and forecasts rapidly without assistance and who understands weather map symbols thoroughly can reduce the time spent planning his flight. Of course, mere ability to read a weather map or teletype report is not enough. After reading to find out what weather conditions are being described, you must know what these mean to you in flight. You must know, for example, what a squall line is. Otherwise, recognizing the symbol —·· —·· — on a facsimile map or the contraction "SQLN" will mean little.

The following chapters discuss weather phenomena which affect all-weather flight. These chapters, however, assume you remember some of the basic aerology from flight training. For background information, refer to *Aerology for Naval Aviators*.

CHAPTER 27

FRONTAL WEATHER

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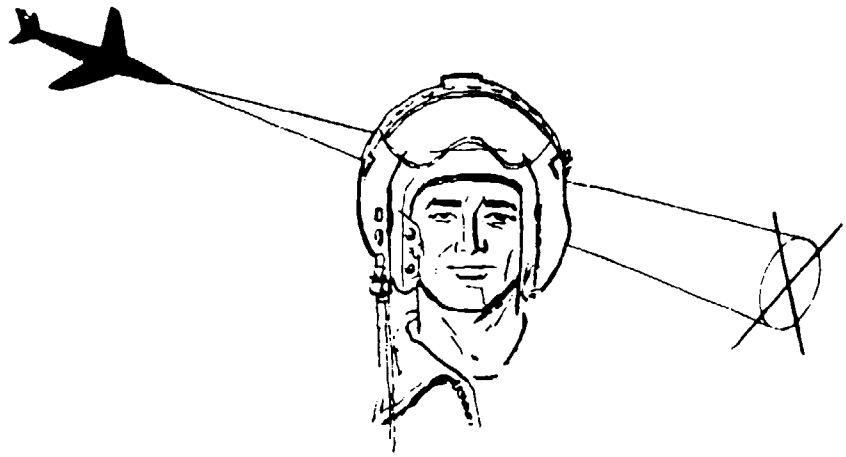

CHAPTER 27

FRONTAL WEATHER

MANY of the weather phenomena which we normally consider important or outstanding are associated with narrow zones where the properties of the air change markedly over a comparatively short distance. These narrow zones are the border regions of different air masses. When two different air masses come together, a discontinuity is formed between them. This is called a front. A front is a surface, like a thin elastic sheet, separating two air masses. It develops from a zone of transition through which there is a gradual change of physical properties to a "line" of real discontinuity. This process of development or marked intensification is called "frontogenesis." The opposite process, by which this discontinuity is dissipated or destroyed, is called "frontolysis."

CHARACTERISTICS OF FRONTS

A cold air mass, being heavier, will always tend to underrun a warm air mass. The front slopes upward over the cold air mass; thus, cold air is below and warm air is above.

In Figure 27-1 you can see that if you move from the front into the cold air, you are moving toward higher pressure. Similarly, if you move back into the warm air, you are also moving into higher pressure. Therefore, the front lies in a trough of low pressure. This is an important characteristic of all fronts. Whereas air masses are associated with regions of high pressure, fronts are associated with troughs of low pressure.

Near the ground, air crosses the isobars toward

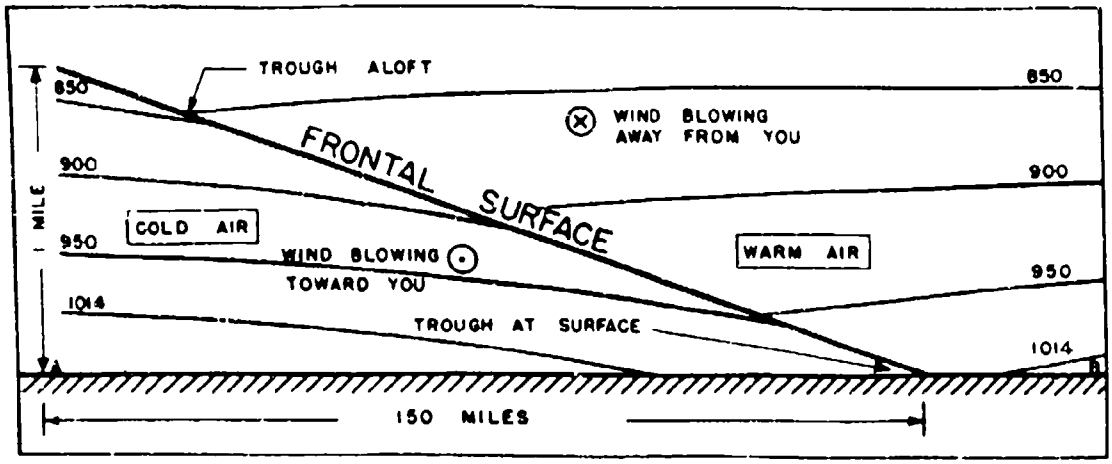

Figure 27–1. Frontal pressure field in profile

lower pressure. This causes a flow of air toward the front from both air masses. Since the air cannot disappear into the ground, it must move upward. Hence, there is always a net movement of air upward in the region of the front. This is another important characteristic of fronts, since the lifting of air causes condensation, clouds, and "weather." While air motion within an air mass (high-pressure area) is downward and outward (divergence), motion in a frontal zone is inward and upward (convergence). All fronts are areas of convergence and lifting, a condition which renders instability, condensation, and precipitation likely in the warm air mass.

A front may be either non-moving or moving. A non-moving front is called a *stationary front*. The moving front which results from a moving body of cold air advancing and replacing the warm air ahead of it is called a *cold front*. It brings colder weather as it passes. The moving front which occurs when warm air advances upward and over the retreating cold air is called a *warm front*. It brings warmer air as it passes.

FRONTAL SLOPE

The inclination of a frontal surface with respect to a level surface of the earth is called the "slope" of a front. A slope of 1 to 100, for example, means that at a point 100 miles ahead of the surface position of such a warm front the frontal surface would be at an altitude of 1 mile.

As a general rule, the values of 1 to 50 and 1 to 400 may be considered as the extremes of a frontal slope. Another general rule, and one with very few exceptions, is that a cold front has a steeper slope than a warm front. Average values for a cold front are from 1:50 to 1:150; for a warm front, 1:200 to 1:300. (See Figure 27-2.) In each case, the slope depends on a number of variable factors. Some of these variables which appear to be important are:

Roughness of the terrain over which the front is passing. Over very rough land, surface friction tends to retard the forward motion of a front in the lowest levels so that a cold front tends to have a steeper slope than under ordinary conditions and a warm front a more shallow slope. Other things being equal, the reverse is true when the underlying surface is very smooth; for example, a front which has traveled for some distance over a calm sea.

Wind speed perpendicular to the front. Other things being equal, the greater the component of wind perpendicular to the front, the steeper is the slope of a cold front, and the shallower is the slope of a warm front.

Unbalanced fronts. In general, fast moving cold fronts usually tend to be steeper than average, and fast moving warm fronts tend to be

shallower than average. This factor is closely allied to the previous two, inasmuch as fast-moving fronts usually have strong winds behind them and are also affected by the roughness of the underlying surface.

DISCONTINUITIES ACROSS A FRONT

Some properties which are discontinuous at a front, and therefore serve to identify it, are temperature, wind direction, pressure tendency (rate at which surface pressure is rising or falling), and dewpoint.

Temperature

One of the most easily recognizable discontinuities across a frontal surface is temperature. Since all fronts in effect consist of warm air overrunning cold air, a radiosonde passing through a frontal surface shows a relatively narrow region where the normal decrease of temperature with height is reversed. This is the frontal inversion, which indicates the height of a frontal surface over the particular station. The width of this inversion indicates the degree of frontal development. (See Figure 27-3.)

Wind

Wind discontinuity across a front is primarily a shift of direction. With either a warm or a cold front, if you stand in advance of the front with your back toward the wind, the wind will shift toward the left when the front passes. From the standpoint of an aircraft in flight through any front, the direction of wind shift is such that you must correct heading to the right in order to maintain the original course.

Wind velocity, however, is not necessarily discontinuous across a front. Nevertheless, in many cases, wind speed increases abruptly after the passage of a cold front and decreases after the passage of a warm front; in other words, wind speed is generally greater in the cold air mass.

Pressure Tendency

Pressure tendency is the tendency of a barometer to rise or fall over a three hour period. A front lies in a trough of low pressure. Therefore, as a front approaches a station, the pressure tendency will be shown on the weather map as a continuous fall. As soon as the front passes the station, the pressure tendency will be shown as an abrupt rise, then a continuous rise in pressure.

Dewpoint

The dewpoint of one air mass differs from that of the other across the front. The change of dewpoint is an excellent index of frontal passage and frontal position (both horizontal and vertical) because it is more constant than temperature through the day. In addition, the dewpoint is relatively constant throughout the horizontal extent of an air mass.

STATIONARY FRONT

A stationary front is one where there is little or no movement of the air masses involved and, therefore, there is no actual displacement of air

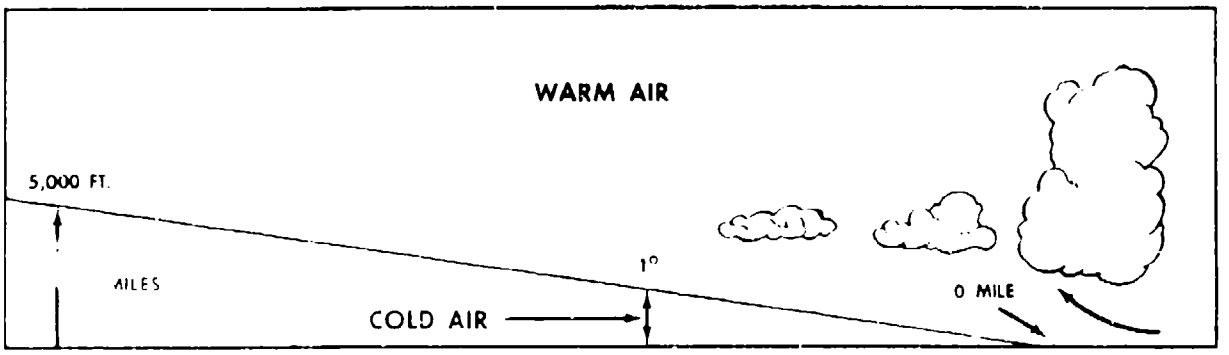

Figure 27-2. Slope of a steep cold front (1:50)

at the surface. There is a stationary front when a warm air mass and a cold air mass lie in adjacent positions at the surface with the warm air overrunning the cold air.

Since the cold air mass, as a whole, is not moving either toward or away from the front, the wind above the friction layer is blowing neither toward nor away from the front, but parallel with it. It follows that the isobars, too, are nearly parallel to a stationary front. This characteristic makes it easy to recognize a stationary front on the weather map. (See Figure 27-4.)

The frictional inflow of warm air toward the front causes a slow up-glide of air on the frontal surface. As the air is lifted to and beyond its condensation level, clouds form in the warm air above the front. If the warm air is stable, the clouds will be stratiform, and drizzle may occur. As the air is lifted beyond the freezing level, icing conditions prevail and light rain or snow may fall. At very high levels, above the top of the front, ice clouds will be present. (See Figure 27-5.) If the warm air is conditionally unstable, it can become unstable upon lifting. The clouds will then be cumuliform. If the energy released is great (warm, moist, unstable air), thunderstorms will result. Rainfall will generally be showery.

The cold air near the frontal surface of a stationary front may also be rising, but, since it normally carries less moisture because of its lower temperature, the clouds are not so thick or widespread. Where the cold air is saturated by rain or drizzle falling through it from the warm air above, extensive fog and low ceilings result, especially at nightfall. If the temperature is below 0° C, icing will be found but generally is light. The width of the band of precipitation and low ceiling varies from 50 miles to about 200 miles, depending on the slope of the front and the temperature of the air masses.

COLD FRONT

A cold front is the line of discontinuity along which a wedge of cold air is underrunning and displacing a warm air mass. Figures 27-6 and 27-7 illustrate cold front formation. The plan view shows a cold air mass converging with a warmer air mass. These air masses are separated by the front (low-pressure area). The cold air behind the front forces the frontal surface into the warmer air mass. As shown in the cross section, the cold air undercuts the warm air and the warm air is forced aloft.

Characteristics of Typical Cold Front

With a typical north latitude cold front, there are southwest winds ahead of the front and northwest winds behind the front. (See Figure 27-6.) There is warm air ahead of the front and cold air behind it.

The degree of instability and the moisture

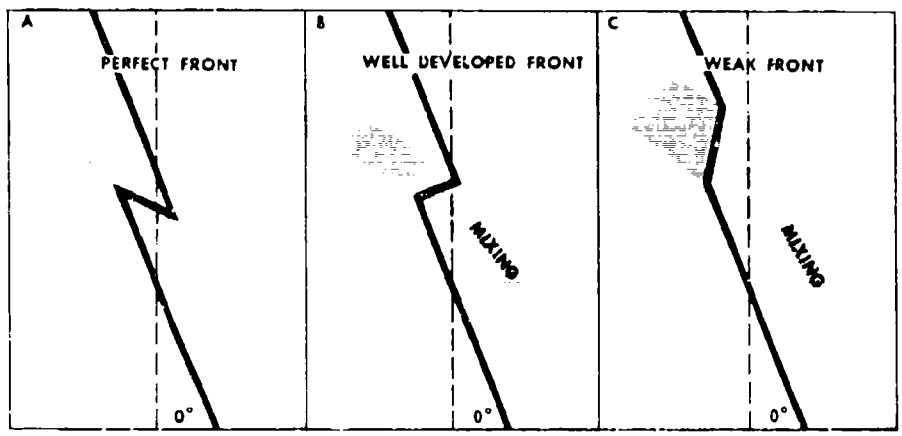

Figure 27-3. Soundings through frontal surfaces

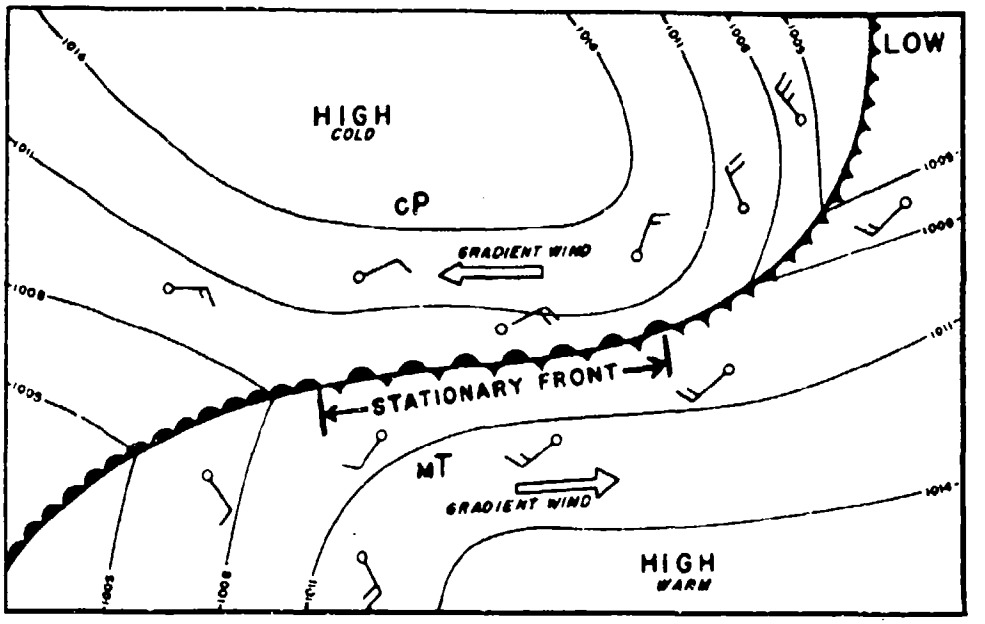

Figure 27-4. Stationary front on a weather map

content of the warm air which is being undercut by the cold frontal surface determine the intensity of clouds. Cloud formations occur in both unstable and in stable warm air masses. In an unstable warm air mass, the clouds ahead of the frontal slope are predominantly cumulonimbus mixed with fractostratus, nimbostratus, and altostratus. Tell-tale clouds showing definite instability aloft are: cirro-cumulus (cc), alto-cumulus castellatus (acc), and cumulonimbus mammatus (cm). Pilots should be able to recognize and interpret these important clouds. Behind the frontal slope, the clouds are stratiform in the rain area and cumuliform to the rear of the rain area. (See Figure 27-7, bottom.) In a stable warm air mass, there are stratiform clouds ahead of the frontal surface; behind it, there are stratiform clouds in rain areas and cumuliform clouds to the rear of the rain area. (See Figure 27-7, top.)

The extent of the precipitation area depends

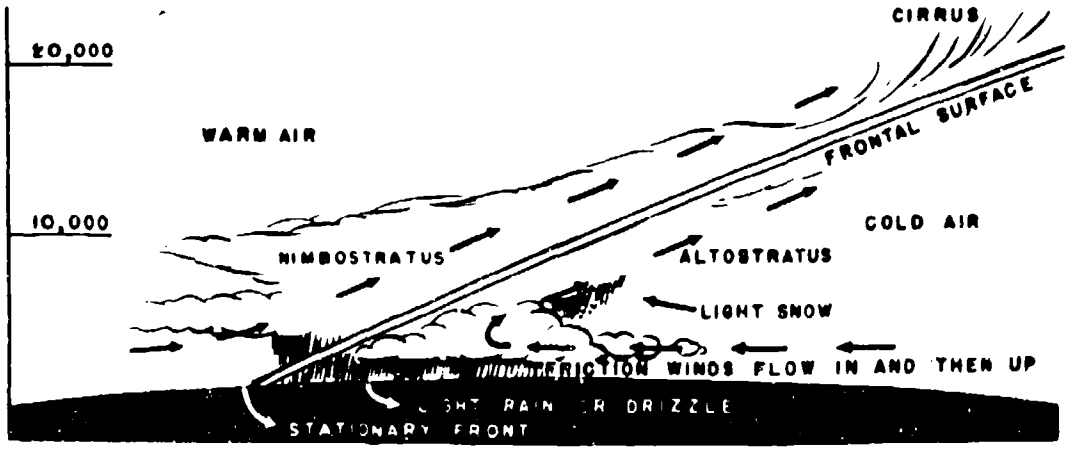

Figure 27-5. Cross-section of clouds on a stationary front

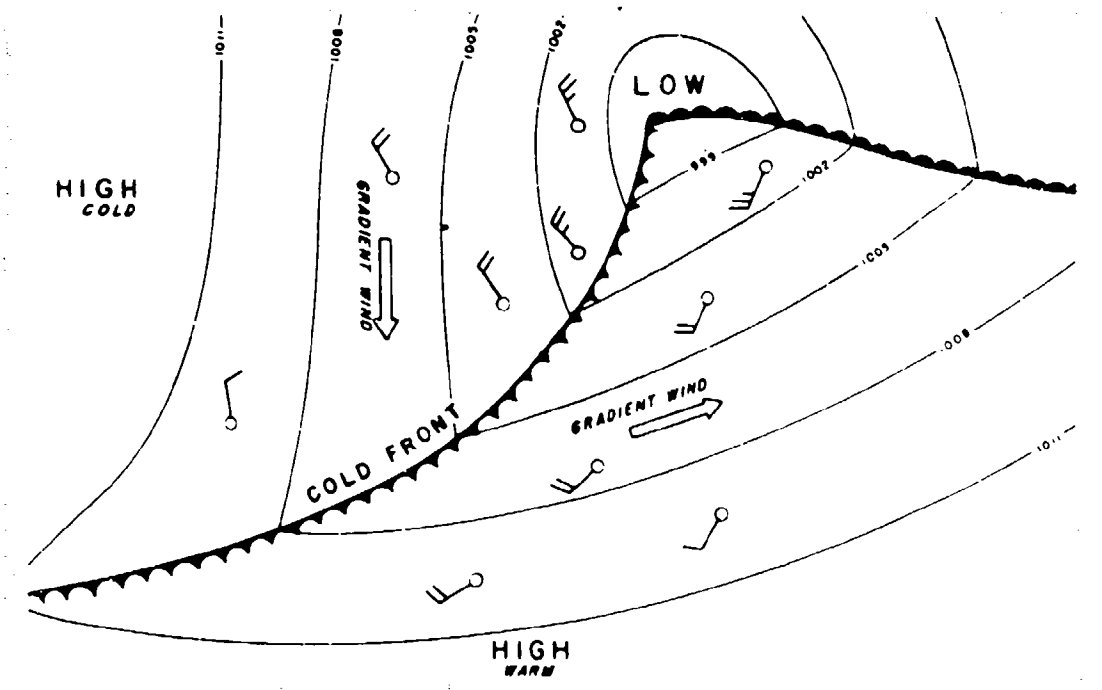

Figure 27-6. Cold front on a weather map

on the slope of the frontal surface, and the type of precipitation depends on the stability of the warm air being undercut. In an unstable warm air mass, there is light to heavy showery precipitation; in a stable warm air mass, there is light to heavy steady precipitation.

Cold fronts move predominantly *toward* the southeast in the middle latitudes (30° N. to 60° N.). Slow-moving cold fronts move at from five to 15 knots, and fast-moving cold fronts move at from 20 to 35 knots. The average speed of cold fronts is 20 knots. Cold fronts usually move faster than warm fronts.

The width of the weather band depends on the velocity of the frontal surface movement and on the stability of the warm air mass. It averages 50 to 150 miles measured from the leading clouds to the trailing clouds of the frontal cloud sequence.

Cold Front Flight Conditions

Flight conditions associated with a cold front, such as turbulence, icing, cloud tops, types and intensity of precipitation, vary from case to case. Each cold front must be studied individually to determine the degree of hazard which it presents to flying.

The cold air which is relatively close behind the surface cold front is ordinarily quite stable. Consequently, flight conditions behind a cold front are usually rather good, and are characterized by scattered cumulus clouds or clear skies, good visibility, relatively little water vapor in the air, and little or no turbulence.

However, as a cold front moves further past a station, or as an aircraft proceeds further into the cold air mass, flight conditions tend to become less favorable. This is due to the fact that, as the cold air passes over the ground which is moistened from frontal precipitation, its moisture content is increased and, at the same time, it is warmed from ground radiation. This combination of increased moisture and warming makes the air unstable at some distance behind a cold front. In this case, scattered to broken stratocumulus clouds and light to moderate turbulence are not uncommon.

WARM FRONT

A warm front is one along which warmer air overtakes colder air. The cold air, being heavier, ordinarily retreats only when the warm air blows against it with some force, causing an energetic upglide of warm air above the frontal surface. The isobars are then no longer parallel to the front, but cross it in a direction which carries the warm air toward the front. (See Figure 27-8.)

The lifting of air along a warm frontal slope is more rapid than the upglide over a stationary front. These same processes take place, but with greater intensity. The air is carried up past its lifting condensation level and past the freezing level, forming a thick mass of clouds from which much rain or snow falls and in which icing occurs.

If the warm air is stable, the clouds will be stratiform, and steady rain or snow falls. (See Figure 27-9, top.) When the warm air is conditionally unstable, it will become unstable if lifted sufficiently. Cumuliform clouds form, precipitation is showery, and thunderstorms may form. (See Figure 27-9, bottom.)

The warm air may start to rise, because of converging flow, before it reaches the front. Thus, some cloudiness, mostly as layers at middle altitudes, may be found in the warm air mass a short distance away from the surface front, and scattered light rain may occur.

Rain or snow falling through the cold air from the warm air aloft rapidly saturates the cold air producing low ceiling and poor visibility over a wide area in advance of the moving front. When strong winds precede the warm front, the fog is lifted to a low stratus. Icing will occur, and, in winter, will ordinarily extend all the way down to the ground.

The area affected by an active warm front may be very large; sometimes, it is 600 miles or more across. The first indication of the approach of a warm front can often be observed 500 to 1,000 miles in advance of the front. As the front approaches, clouds can be observed in the following sequence: long thin wisps of cirrus clouds, becoming thicker, and then merging to form cirrostratus. The cirrostratus thickens rapidly as the warm front continues to approach. The bases of the

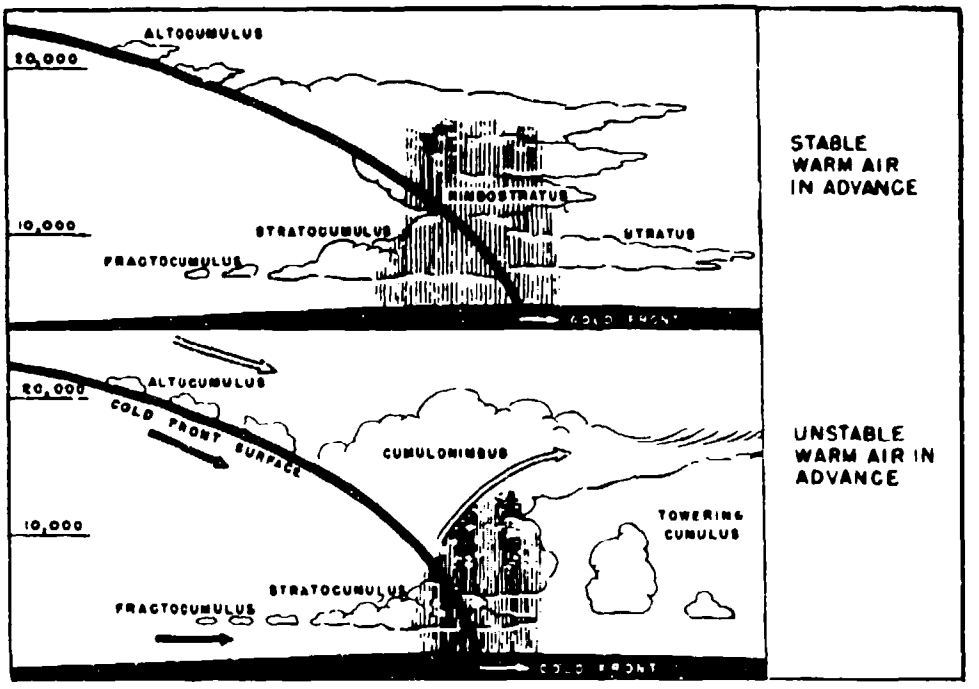

Figure 27-7. Cross sections of clouds on a cold front

clouds gradually change to altostratus, usually 300 to 500 miles from the surface frontal position. Light precipitation begins to fall from these altostratus clouds as they become lower and thicker.

As precipitation falls from the warm air, the relatively warm liquid moisture is evaporated into the cold air below the frontal surface, and lower clouds are formed. This precipitation soon begins to reach the surface and the ceiling lowers rapidly as several layers of lower stratus clouds form in the cold air and extend almost down to the surface. It is not unusual for the stratus to extend all the way down to the surface in the form of fog. Prefrontal fog is, in fact, often characteristic of a warm front.

As the front passes, a surface station would observe gradual clearing with a rise in temperature and a clockwise shift (veering) of wind direction. Frequently, the warm air to the rear of a warm front contains so much moisture that the air is "muggy." Stratus clouds and drizzle are not uncommon even after frontal passage.

Occasionally, the warm air which overruns the frontal surface may be unstable and the vertical motion may result in intense cumulus or thunderstorm activity. Such thunderstorms may be obscured by the stratus clouds and thus not be apparent from an aircraft approaching the front. In this case, a pilot may unexpectedly encounter icing, severe turbulence, hail, and marked tem-

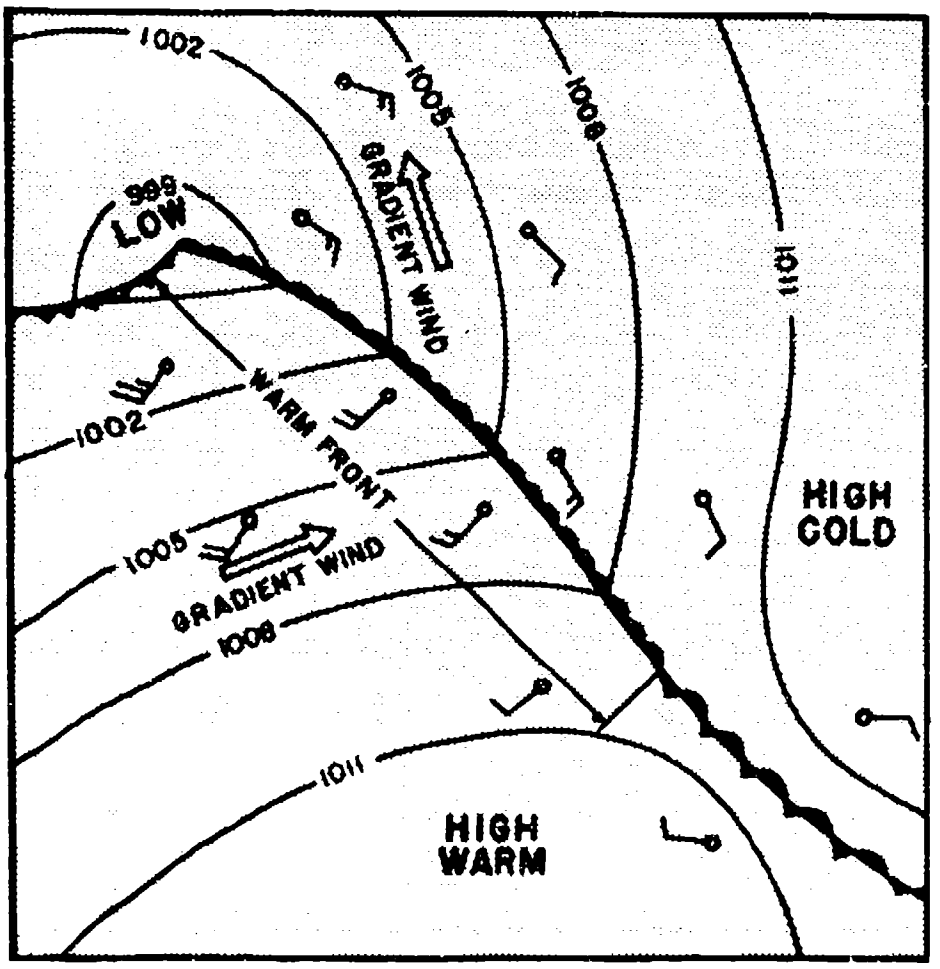

Figure 27-8. Warm front on a weather map

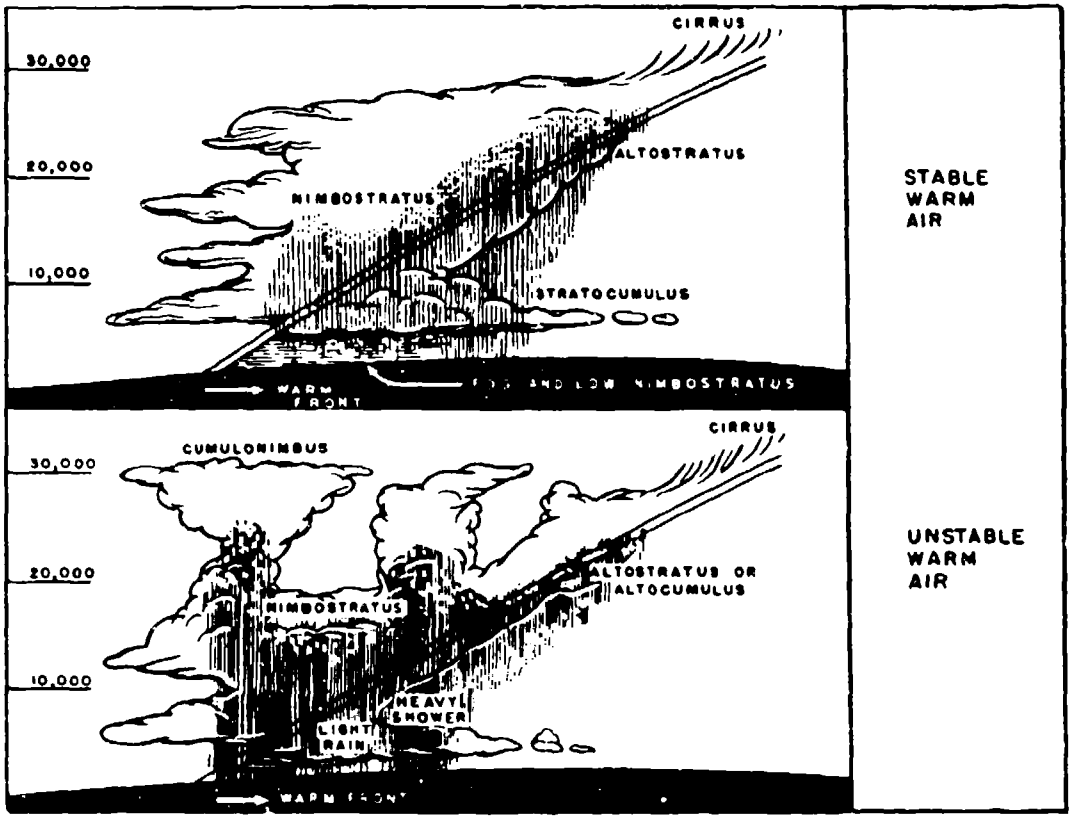

Figure 27–9. Cross section of clouds on a warm front

perature changes within the clouds. The frequency of thunderstorm activity associated with warm fronts is greater in summer than in winter.

OCCLUDED FRONT

An occlusion is defined as a line along which a cold front has overtaken a warm front. It starts with the development of a wave as shown in Figure 27-10. When a wave has formed, the cold front moves more rapidly than the warm front, and the air in the warm sector escapes by flowing up over the warm front. The cold front overtakes the warm front first at the crest of the wave and, later, a distance away from the storm center. This process by which the warm sector is closed off from the ground is called the occlusion process. The folded portion of the front, where the cold front has overtaken the warm front, is called occluded front, or simply an occlusion. Occluded fronts are of two types—cold front and warm front.

Cold Front Occlusion

If the air behind the cold front is colder than the air ahead of the warm front, the front which appears between them when they meet will be a cold front. This is a cold front occlusion, and is more common on the eastern side of continental areas. In eastern areas, advancing cold fronts consist of Polar Continental Cold (CPK), or Arctic (A) air masses which are colder, drier and more dense than the stagnant, older Polar Continental and or Polar Maritime air masses in ad-

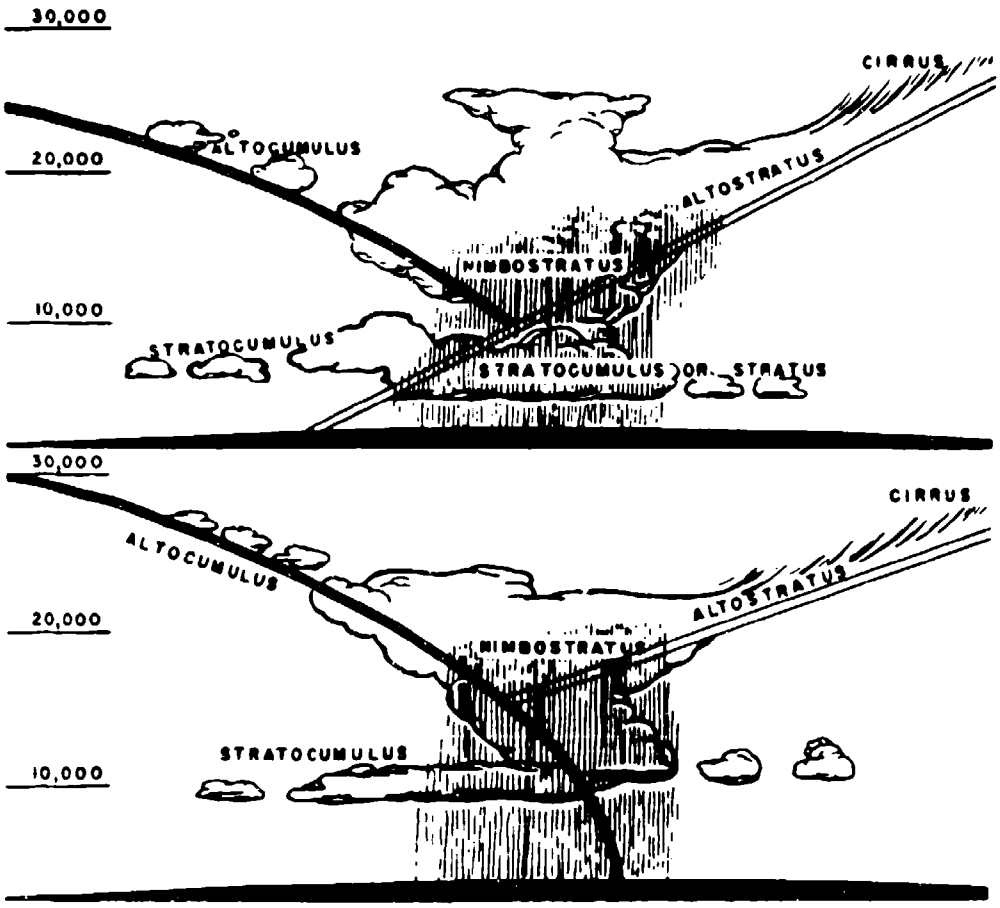

Figure 27-10. Cross section of clouds in occlusion

vance of the Warm Front. Therefore, not only the warm air over the warm front but also the cool air under the warm front, are lifted by the advancing cold front. It should be stressed that cold air masses originating over polar land areas are drier and consequently denser than polar air masses originating over maritime areas.

Warm Front Occlusion

If the air behind the cold front is warmer than the air ahead of the warm front, it will ride over the colder air which it overtakes, forming a warm front between the two cold masses. This is a warm front occlusion and is commonest on continental west coasts, where cP air moving inshore is usually warmer than the cP air ahead of it over the continent. (See Figure 27-10, top.)

Weather Associated With Occlusions

The weather accompanying an occlusion is a combination of the warm front and cold front weather types. The bad weather is most widespread and most active at the moment when the warm front is first overtaken. As the warm air is forced farther and farther aloft, and most of the moisture is squeezed from it by cooling, the weather abates somewhat. In the last stages of an occlusion in winter, icing is perhaps the chief hazard, because air warm enough to melt the ice can no longer be found on either side of the front. Occlusions cause widespread areas of heavy precipitation, lowered ceilings, and poor visibilities.

Carrying the wave cycle to its conclusion, eventually the warm air is forced to high levels, the low-pressure area fills up, the cyclonic whirlpool dissipates, and frontal activity decreases and fades away. The occlusion process is the beginning of the end of a storm and the last stage of its life cycle. Figure 27-11 summarizes wave development and occlusion.

PRINCIPAL WORLD FRONTAL ZONES

The general circulation pattern and the average position of world pressure zones are such that certain areas in the circulation system are more conducive to frontogenesis than others. The fronts that form in the three main zones or belts which may be termed frontogenetical are known as the "Polar Fronts" (northern and southern hemispheres) and the "Inter-tropical Convergence Zone (ITCZ)." (See Figure 27-12.)

The ITCZ is not a true front in the accepted definition of the word front, since the air masses on either side of it usually have nearly the same properties of temperature and humidity. In addition, the zone of "frontal" weather is usually considerably broader so that the ITCZ is even less like a line than the temperature zone fronts which are pictured as a line on weather charts. However, since the air masses in the tropics as a rule are conditionally unstable, the cloud and weather patterns associated with it often resemble closely those associated with fronts in the temperate zones. Thus it is often classed as a front and is frequently called (rather loosely) the tropical front or equatorial front.

Polar Fronts form and exist in regions where warm air from the temperate or tropical zones and cold air from the polar regions converge. In the Northern Hemisphere, the Polar Front advances southward as a cold front and sometimes recedes northward as a warm front. The advancements are frequently called "Polar outbreaks." The Polar Front in the Northern Hemisphere moves further south in winter than in summer, and its frequency of occurrence is also greater in winter.

The Polar Front does not constitute a single, more or less continuous, band of convergence and bad weather. It appears, rather, as a series of active, convergence zones, which move in a general direction from west to east. These convergent zones are the migratory low or traveling cyclones of the middle latitudes.

The formation of a cyclone along the Polar Front is first noted as a slight indentation of the front. This indentation or wave later deepens and moves along the front, rapidly at first, and then progressively slower. The waves nearly always move from west to east.

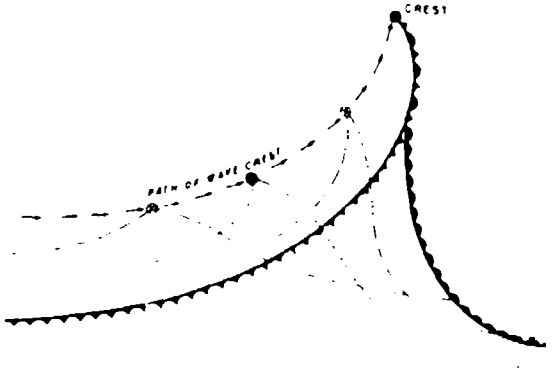

Figure 27-11. Wave development and occlusion

UPPER FRONTS

Fronts may also exist in the upper air. Frequently a front is forced up over the Rocky Mountains from the west and then proceeds for some distance to the east before again descending to the surface. Sometimes it does not reach the surface again, but seems to weaken or dissipate aloft. Such fronts may cause great trouble to aircraft. However, when such fronts advance into warm, unstable mT air, severe thunderstorms and sometimes tornadoes result. This latter condition is the squall line, which is discussed shortly.

TROUGHS

Troughs form as valleys of low pressure where there is not sufficient difference or motion between

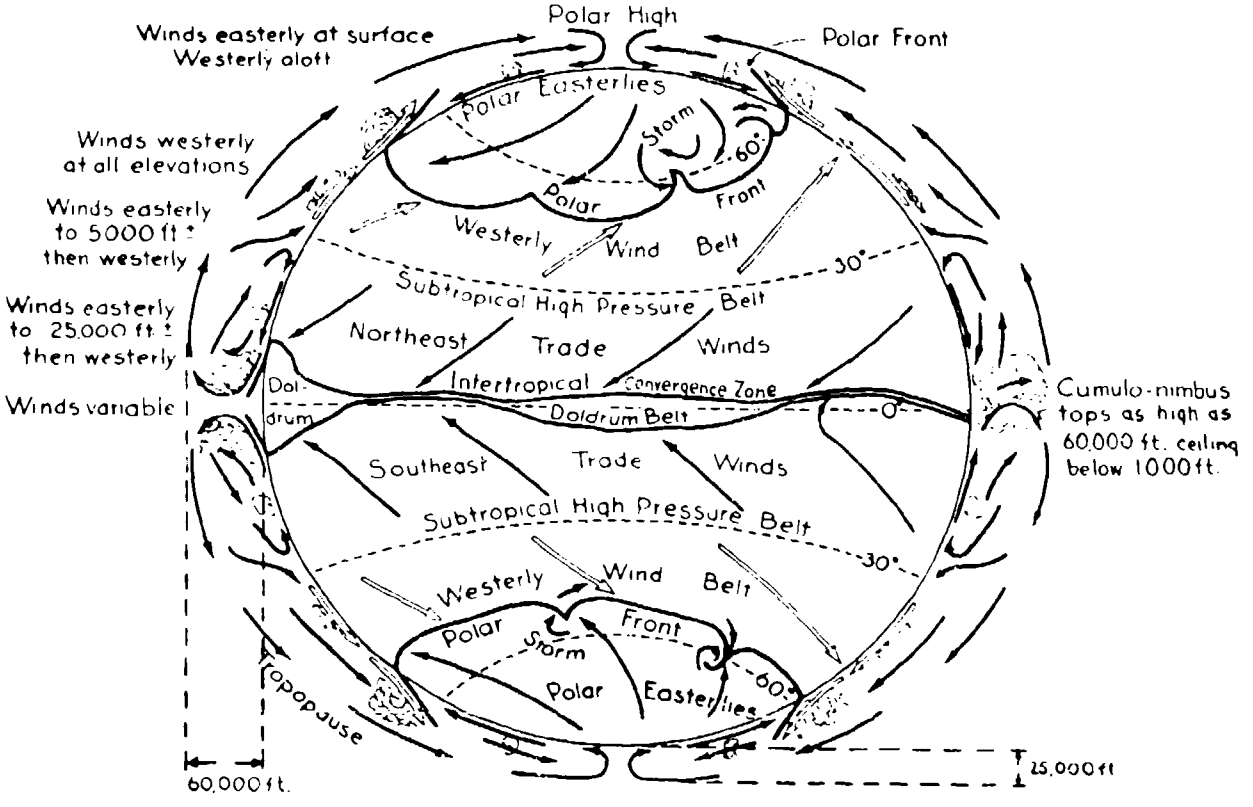

Figure 27–12. Idealized pattern of atmospheric circulation

the air masses to create frontal conditions. Often a cold front trails off to the south as a trough in low latitudes.

At altitudes above the top of a frontal situation there is a trough. In addition, troughs often form aloft in areas where a front will later develop. Thus the trough at high altitudes is of great interest to aerologists.

Troughs running north and south occasionally form in certain tropical regions and move to the west. These present weather similar to that of a cold front, and are also the frequent formation areas of tropical cyclones (hurricanes). This type of trough is called a wave in the easterlies or an easterly wave.

Easterly Waves

Easterly waves are trough lines appearing on the southern side of the oceanic high pressure cells. The waves move from east to west because they are situated in the northeast trade-wind belt. They feature falling pressure, wind shift, and along the trough line, convergence and cumuliform development with showers. It has been found that these waves occur in all seasons but are most intense in the summer and early fall. Tropical storms (hurricanes and typhoons) generally originate in closed circulation systems along the inter-tropical convergence zones (ITCZ) or on intensifying easterly waves, and develop at the season that the easterly wave is most intense and most commonly detected. The easterly wave is capable of rapid intensification and should be watched carefully.

An easterly wave generally moves along with the easterly current of air, its course being more or less at right angles to the trough line. Such waves appear about twice weekly, though the lack

of reporting stations in the areas where they develop often results in some scarcity of information. However, they may deepen and intensify rapidly, especially upon meeting the ITCZ. They may also swing away from the equator and produce a tropical storm. For this reason, you should get full data on any known easterly waves in your flight path. On surface maps, you recall, they show as a green line with arrows to show direction of motion. On facsimile charts, however, they appear as troughs. The code number alongside the trough symbol can be checked by the aerologist to identify troughs in the tropics to establish their character.

SQUALL LINES

Squall lines are associated with fast-moving cold fronts. They are a line of prefrontal thunderstorms which develop when surface friction retards the forward motion of the cold air at the surface to an extent that the cold air aloft is advanced many miles ahead of the surface front. Thus they are most common to leeward of mountainous or hilly areas. This causes the warm air ahead of the front to rise at a greater distance in front of the cold front, creating a cold pressure trough near the surface which parallels the advancing wedge of cold air. The lifting of the warm air forms convective thunderstorms more violent than ordinary cold front thunderstorms.

This prefrontal squall line usually consists of a band of cumulus and cumulonimbus clouds parallel to the front and 20 to 200 miles ahead of it. Flight through such a squall line would be similar to flight through an active cold front. In fact, it appears that prefrontal squall lines often present the worst known hazards to flight, with very intense thunderstorm activity, and even occasional tornadoes.

SUMMARY

It is essential to understand the wave development of the frontal system and how the three elements of the wave are arranged: the cold front generally southwest from the low, the warm front generally to the east, and the occlusion developing near the low center where the cold front overtakes the warm front. In addition, you should know the general course followed by the migratory Lows and their associated fronts in the operating area. This knowledge will give you valuable information for anticipation of frontal movement and development, and for interpreting flight conditions as you meet them. Fronts are stressed since the two greatest hazards to flight, namely icing and turbulence, occur most frequently in Frontal Zones.

This chapter mentioned certain bad weather conditions associated with fronts—fog, icing, turbulence, and thunderstorms. Although any of these may be found in frontal weather, they may also occur at other times. Since they are vitally important to flight, these phenomena are covered in the chapters to follow.

CHAPTER 28

FOG

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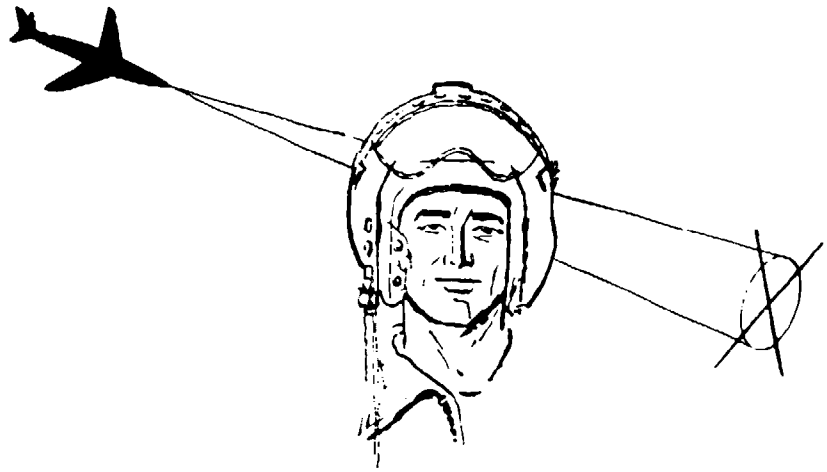


CHAPTER 28

FOG

FOG is one of the most common weather hazards encountered in aviation. It presents no problem en route, of course, but may be serious at the destination when you want to land. Fog is defined as any cloud which lies on the ground and reduces horizontal visibility. Like a cloud, fog may be defined as a suspension of water or ice particles in air saturated with water vapor.

Low stratus, which is formed by the same process as fog, is just as great a hazard, even though it does not lie upon the ground. If a low cloud is more than 50 feet off the ground, it is not fog, but low stratus. The mere change of name, or the difference in cloud base of a few feet, is insignificant to a pilot who finds his visibility close to the ground obstructed.

In the discussion of stability (Chapter 26), you learned that air becomes saturated and moisture condenses as clouds (and sometimes precipitation) when the temperature and dew point spread is less than 2° C or 4° F. Since fog is a surface phenomenon and surface temperature and dewpoint data is generally in Fahrenheit, 4° F is the spread to watch for in sequences and on station models.

FOG FORMATION

Fog may form any time the surface air becomes saturated. This will occur when the temperature and dewpoint are the same or may occur when there are particles such as smoke or dust in

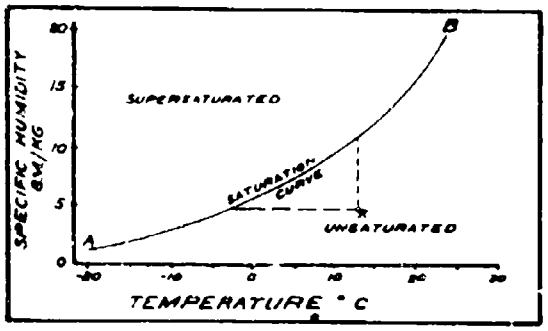


Figure 2-1. Saturation curve

the air which permit condensation with a dew-point spread of 4° F or less.

Figure 2-1 shows the amount of water vapor required to saturate a kilogram of air at sea level at various temperatures. Consider unsaturated air at "X" in Figure 2-1. Fog will form if the air is cooled to −4° C (point "A"). Fog will also form if the temperature is constant but the dewpoint is raised (moisture content increased) to 11 gm. kg. (point "B").

Usually, the amount of moisture in air remains fairly constant over a period of time. When moist air is cooled, therefore, the temperature dewpoint spread is reduced and relative humidity is increased. Cooling of moist surface air until the temperature dewpoint spread is less than about 4° F (or the relative humidity exceeds 85%) will often cause condensation which results in fog. This cooling occurs as a result of night cooling, flow of air over a cool surface, or lifting of surface air along an up slope. The fogs formed by cooling of the air are known as *radiation fog* (night cooling), *advection fog* (flow of warm, moist air over a cool surface), and *upslope fog* (adiabatic cooling caused by lifting of air over rising terrain).

Air may also become saturated if its moisture content is raised (that is, if its humidity and dewpoint are increased). Moisture may enter air from evaporation of warm bodies of water, from large steam industrial plants, and from evaporating warm lapse precipitation falling through colder air. Fogs formed by increasing the amount of moisture in the air are less common than those caused by cooling of air. Temperature fluctuations are common, whereas moisture content tends to remain fairly constant. Fogs of this type are *steam fogs* when they involve evaporation from bodies of water; they are *frontal fogs* when they involve precipitation falling from a warm air mass into a cold air mass.

There is usually a combination of formation factors. Conditions that favor formation of fog are high relative humidity (low temperature-dewpoint spread), very light wind, and condensation nuclei (such as dust, salt, or smoke particles). A light wind creates a mixing action which tends to extend the depth of fog formation. Condensation nuclei permit fog to form when the spread between temperature and dew point is slightly greater than zero (up to 4° F.). These nuclei provide a center around which moisture condenses. Almost all surface air in the atmosphere contains such nuclei, but they are particularly prevalent in city and industrial areas—hence at many airports.

Haze is very closely related to the formation of fog. Haze is a concentration of condensation nuclei which have already gathered dust and smoke particles in their first molecules of water. Before the appearance of fog, as the air approaches saturation, the haze becomes more dense. When you notice the thickening of the haze, you know that fog will soon form if other conditions are favorable.

Wind velocity also plays an important role in fog formation. If a complete calm exists and a layer of fog is formed, it is only a few inches deep. A light wind produces some turbulence which serves to mix successively deeper fog layers. However, winds of high velocity are so turbulent and tend to mix the air so thoroughly that the fog layer is either lifted and becomes low stratus, or the narrow zone of high humidity is broadened vertically until the relative humidity becomes too low for fog or low stratus formation.

RADIATION FOG

Radiation fog is caused by the radiational cooling of the earth's surface at night. It forms

only at night and over a land surface. It never forms over a water surface. (See Figure 28-3.)

After sunset, the earth does not get any heat from the sun, but it continues to radiate heat. The surface begins to cool because of this heat loss. As the earth cools, the layer of air close to the earth is cooled by conduction, and inversion develops. If the air beneath the inversion layer is sufficiently moist, it chills to its dew point, and fog forms. In the case of a calm night, this cooling by conduction affects only a very shallow layer (a few inches deep), because air is a poor conductor of heat. Wind of low velocity (3 to 5 knots) causes slight turbulent currents which are enough to spread the fog through succeedingly deeper layers. As the nocturnal cooling continues, the fog becomes deeper and more dense. Condensation on the ground (dew) sometimes thins the lowest few feet of a fog during the night.

After the sun rises, the earth is heated. Radiation from the warming surface warms the lower air, causing evaporation of the lower part of the fog, and makes it appear that the fog is lifting. Before noon, heat radiated from the

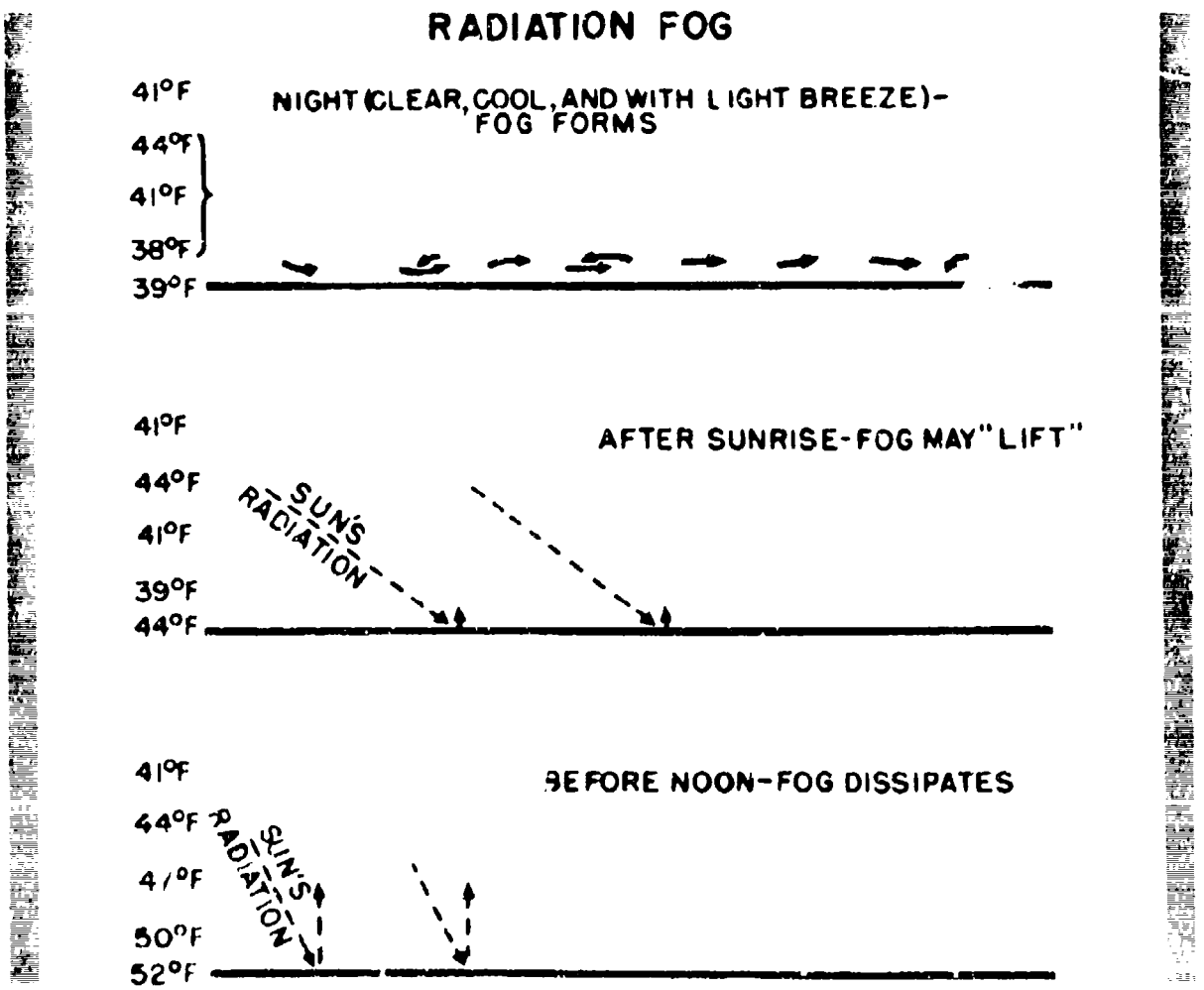


Figure 28-2. Formation and dissipation of radiation fog

warming surface of the earth destroys the inversion. The fog evaporates into the warmed air.

ADVECTION FOG

Advection fog is the name given to fog produced by air in motion, or fog formed in one place and transported to another (Fig. 28-4). This type of fog is formed when air is transported over a colder land or water surface. Cooling from below takes place and gradually builds up a fog layer. The cooling rate depends on the wind velocity and the difference between the air temperature and the temperature of the surface over which the air travels.

Advection fog can form only in regions where marked temperature contrasts exist within a short distance of each other, and only when the wind blows from the warm region toward the cold region. Advection fogs will usually be along coast lines or between snow-covered and bare ground.

Sea fog is always of the advection type and occurs when the wind brings moist warm air over a colder ocean current. Sea fog may occur during the day or night. Some wind is necessary, not only to provide some vertical mixing, but actually to move the air to the place where it is cooled. Sea fogs tend to persist for long periods of time.

Figure 28-3. Radiation fog is formed on clear nights when the earth cools most rapidly

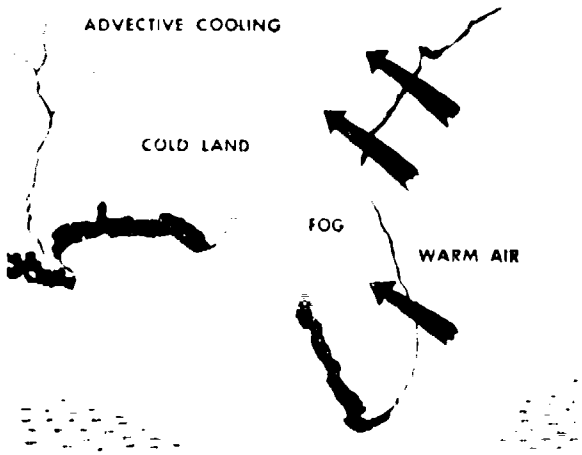


Figure 28-4. Advection fog is formed as warm moist air moves over cold ground

Land advection fog is found near large bodies of water; that is, along sea coasts and large lakes. Onshore breezes bring this maritime air in over a land surface which has cooled by radiation at night. Also, fogs may form over the ocean and be blown over the land, day or night. Another situation favorable to fog formation is one in which air flows from warm, bare ground to snow-covered ground nearby.

UPSLOPE FOG

Clouds are formed by the adiabatic (expansional) cooling of rising air. Upslope fog is formed by the same process. It is formed when moist, warm air is forced up a slope by the wind (Fig. 28-6). The cooling of the air is almost entirely adiabatic, since there is little conduction to the surface of the slope. The air must be stable before it starts its motion so that the lifting will not cause convection currents which would dissipate the fog.

Some wind velocity is needed, of course, to cause the upslope motion. The fog is usually found where the air moves up a gradual slope. This type of fog is deep and requires considerable time to dissipate. The most common fog of this type in the United States is caused by westward flow of

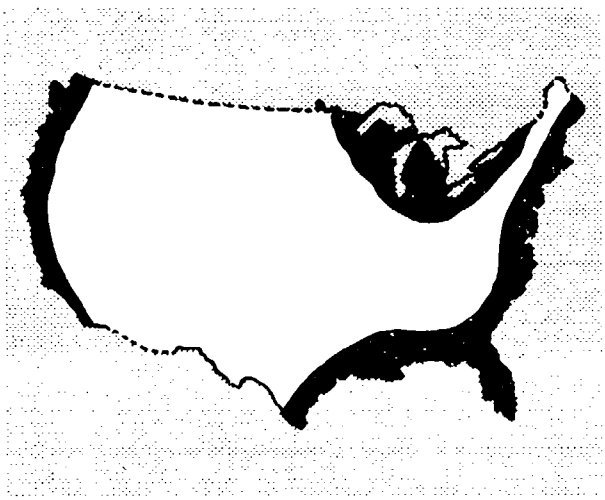


Figure 28–5. Land areas in the United States most often affected by advection fog

air from the Missouri Valley, which produces fog on the eastern slope of the Rockies.

STEAM FOG

Steam fog, or sea smoke, occurs within air masses; but, unlike other air mass fogs which are formed by the cooling of the air temperature to the dew point, steam fog is caused by saturation of the air through evaporation of water. It occurs when cold air moves over warm water. Evaporation from the surface of the warm water easily saturates the cold air, causing fog. It rises from the surface like smoke. Steam fog is most common in northern latitudes. Marsh or swamp mists are familiar examples of steam fog.

FRONTAL FOGS

Frontal fogs are another hazard which must be added to the list of weather troubles associated with fronts. The actual fog occurs under the frontal surface in the cold air mass. It is due the evaporation of falling rain which gradu saturates the air. Precipitation falls from the rifted warm air through the cold air and evapora tion continues as long as the temperature of the raindrops is higher than the temperature of the air, even though the cold air is already saturated. Naturally, the upper regions become saturated first because the temperature is lower at the higher altitude. Eventually, this cloud layer will extend down to the ground and become fog, as indicated in Figure 28-7. During the day, there may be enough turbulence caused by solar heating to keep this cloud off the ground. However, after dark, because of dying convection currents and the nocturnal cooling of the air, the ceiling drops very suddenly. It is this sudden closing in after dark that makes this type of fog so dangerous. Aviators may be confronted with zero ceilings almost without warning.

Cold fronts usually move so rapidly, and have such narrow bands of precipitation and high wind velocities, that cold front fog is comparatively rare. The warm front fog, however, is common and dangerous. Frontal systems are quite extensive, and warm front fog may cover a wide area. Since it extends from the ground to the frontal surface, it is also very deep. The clouds above the frontal surface also slow down the dissipating effect of solar heating. All these factors make warm front fog the worst possible type to encounter. Flights which terminate under warm fronts should be made only after careful inspection of the weather map, noting dew points and

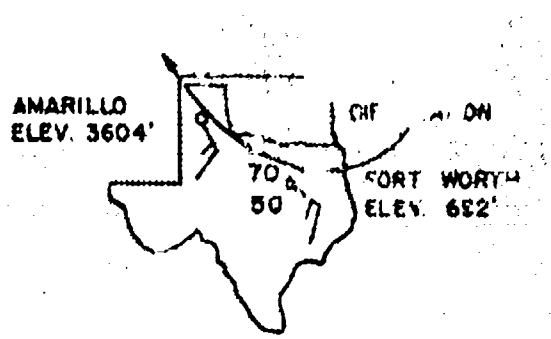


Figure 28–6 Upslope cooling

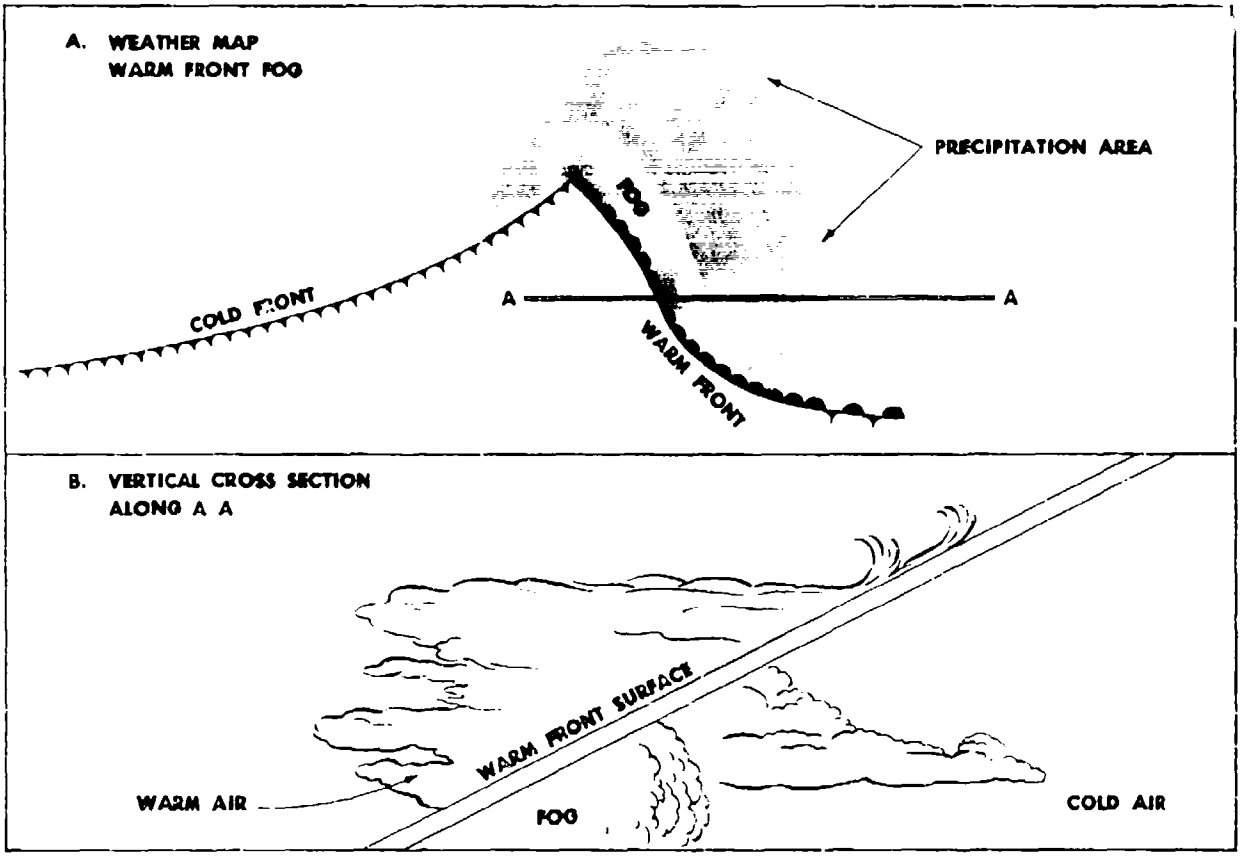


Figure 28-7. Warm front fog

rainfall. Conditions in this system get worse from sunset until some time after sunrise.

DISSIPATION OF FOG

Turbulence, resulting from strong winds, causes fog to dissipate by mixing warmer or dryer air from higher layers of the atmosphere with that at the surface, thus widening the temperature-dewpoint spread. Dissipation may also be accomplished by heating of the fog layer, either from the radiation of solar heat or from adiabatic downslope motion, both of which result in a widening of the temperature-dewpoint spread. Since an increase of the temperature-dewpoint spread is a manifestation of decreased relative humidity, the fog may be said to evaporate or "burn off."

In a few cases where fog lies more or less south of a stationary front or in areas where cold frontal passage is imminent, you may look for a cold air mass to move into the area and dissipate fog.

In the case of wind action, sometimes the vertical mixing caused by wind may destroy only the lower part of the temperature inversion. In this case the fog will dissipate at the surface, but low stratus will remain with the inversion marking the top of the low stratus and acting as a lid to retard further vertical mixing.

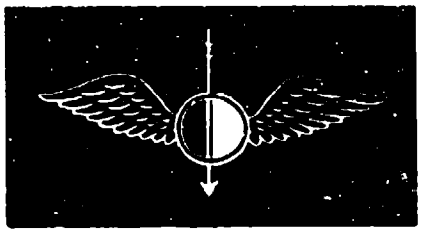
Solar heat, however, is the greatest enemy of fog, and therefore fog is most common at night and in the early morning before much warming

has occurred. Solar heat has a threefold effect. Heating produces convective currents, changes liquid moisture to vapor, and raises air temperature. The air can then accommodate this newly-formed vapor.

FLIGHT PLANNING

Flight planning must always include cautious consideration of possible fog at terminals and alternates. Since tolerances for fog formation are small, check w . the forecaster as to possibilities of fog. A few degrees drop in temperature, a few knots change in wind velocity, or a shift in wind may bring fog. Check sequences for a decreasing temperature-dewpoint spread, check weather maps and sequences for precipitation in the area, and check wind direction and velocity in relation to topography. Be particularly alert to possible fog at terminals on the coast or large bodies of water, which includes almost all Naval Air Stations. Select an alternate inland when going to a coastal terminal.

If you do encounter fog at a terminal, *don't wait for it to dissipate*. Proceed at once to an alternate which is clear while you still have plenty of fuel, because the conditions causing fog at the terminal may often spread to other stations in the area and close the alternates, too. The only exception is where the terminal forecasts its fog to lift soon and the time of arrival is after about 10 A. M.



CHAPTER 29

ICING

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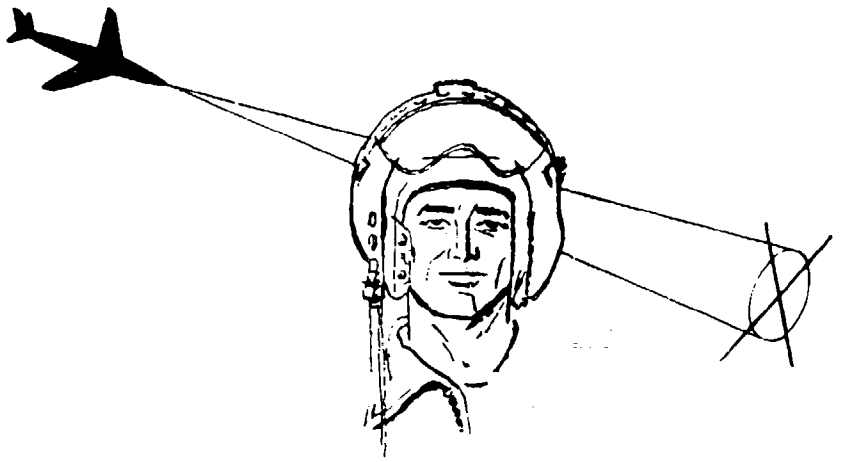


CHAPTER 29

ICING

ICING is an insidious flight hazard because it can sneak up on you when you are not alert. It doesn't always follow the predictions made for it. Under ideal icing conditions, an aircraft can pick up $\frac{3}{4}$ inch of ice all over in 50 seconds. Icing loads which can prevent maintaining altitude can accumulate in ten or fifteen minutes of flight. Yet many pilots report they have flown through all kinds of weather, in all seasons, into areas of forecast icing, and have never seen anything like that.

The answer seems to be that precise forecasting of icing is not possible. Icing conditions may vary sharply with small changes in location, altitude, or time. Because the worst icing effects are so serious, however, the rule must be to avoid areas where icing is forecast as possible or likely. Dangerous icing occurs only in clouds or precipitation. Therefore when outside temperatures are near or below freezing, it is wise to try to avoid clouds and falling precipitation.

EFFECT OF ICING ON AIRCRAFT

The presence of ice on an airfoil disrupts the smooth flow of air over the airfoil and thus decreases lift and increases drag, with a resulting increase in the stalling speed of the aircraft. Ice on the propeller results in a loss of thrust. The addition of ice to the various structural parts of the aircraft results in vibration, causing added stress on these parts. This is especially true in the case of the propeller, which is very delicately

balanced. Even a very small amount of ice, if not distributed evenly, can cause great stress on the propeller and engine mounts. The danger of added weight is not too great under ordinary circumstances, if too much of the lift and thrust are not simultaneously lost. Weight does become an important factor, however, in critically loaded aircraft.

Jet aircraft normally operate at speeds and altitudes that preclude flight in an icing region for any appreciable length of time. In most cases it is possible to leave the icing level before ice accumulation becomes dangerous. While in the icing region, however, the external surfaces of jet aircraft are affected by icing in the same way as prop aircraft. Severe structural icing, reported up to five inches in thickness, has occurred in regions considered by aerologists to be favorable for only light icing. This may be explained by the tendency of the thinner wing and tail sections to collect a larger than normal percentage of super-cooled water.

FACTORS NECESSARY FOR ICE FORMATION

Observations have shown that ice may form on a static object when the free-air temperature is as high as +4° C, as a result of evaporational and adiabatic cooling. When an aircraft is in flight, however, expansion of the air just above the leading edge of a wing causes a cooling of several degrees, so that the wing surface at this point and the air in contact with the wing surface is continuously several degrees below the free-air temperature. On the other hand the heating from skin friction and the impact of water droplets cause the temperature of the skin to rise. Thus, the heating and cooling effects cancel each other out, and structural ice can form at 0° C, or below.

At temperatures less than about −2° C or −4° C, the *frequency* of ice formation decreases gradually with lowering temperature, and the most severe icing is encountered generally between 0 and −15° C; however, under unusual circumstances dangerous icing conditions may be encountered at temperatures less than −15° C.

In addition to freezing temperatures, the second factor usually necessary for structural ice formation is the presence of liquid moisture visible to the naked eye.

FORMS OF VISIBLE MOISTURE CAUSING ICING

Clouds are the most common form of visible liquid moisture; however, not all clouds at temperatures below freezing give rise to ice formation. You don't have any way of knowing which clouds will present an icing situation, but you must be aware that the possibility exists if the temperature is below 0° C.

Freezing Rain or Drizzle

Rain or drizzle falling from warm air into a colder air mass below may become subcooled and form ice upon aircraft encountering this precipi-

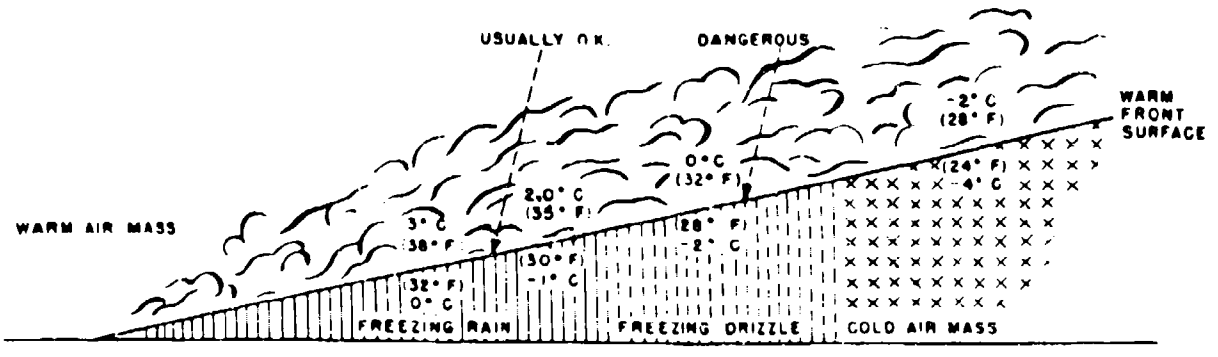


Figure 29–1. Icing in freezing rain or drizzle

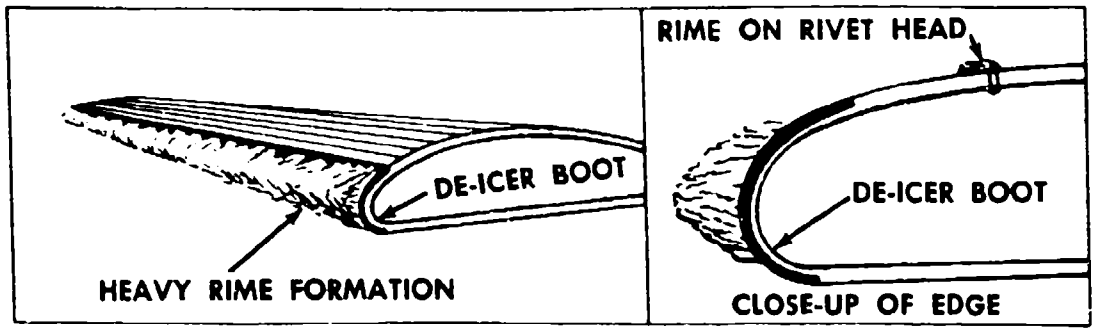


Figure 29–2. Rime ice on an airfoil

tation. The raindrops falling into the cold air freeze upon contact with the aircraft if the temperature is 0° C or below. Freezing rain is the most dangerous form of ice; it can build to enormous proportions in a few minutes and is extremely difficult to break loose.

Since freezing rain and drizzle are commonly the result of warm front activity, ice may be avoided by *climbing* when encountering freezing *rain*, but *not always* when encountering freezing *drizzle* (Fig. 29–1).

Wet and Dry Snow

Wet snow combined with freezing rain forms a very rough glaze that is not easily removed, and is usually associated with warm front weather. Wet snow alone is also a potential icing hazard. Partial melting of the wet flakes and subsequent freezing by expansional cooling or evaporation produce the necessary conditions to freeze them to aircraft.

Dry snow or ice crystals in flight offer no hazard, but when they collect on a warm aircraft recently drawn from a hangar for loading the flakes will melt and freeze if the air is 0° C or lower.

Sleet

Pellets of sleet alone will not form ice on aircraft, but remember that a sleet condition indicates the existence of subcooled rain drops just above the sleet. Above the level where this glaze is encountered, temperatures are usually above freezing. A very slight change in meteorological conditions at flight altitude may result in sleet changing to glaze.

Subcooled Fog

Some dense fogs contain a considerable proportion of subcooled particles which present an icing problem during run-up of engines or taxiing.

TYPES OF STRUCTURAL ICE

There are several types of ice which will adhere to the surface of aircraft. It is important to know the various types of ice since the characteristics of each vary, depending on the type. The *type* of ice that will form on any moving structure usually depends on 5 factors—the free air temperature; the skin temperature of the structure; the surface characteristics of the structure (configuration, roughness, etc.); the size and concentration of water droplets; and the amount of turbulence.

Rime Ice

Rime ice is a granular, whitish, opaque, rough deposit of ice formed from tiny supercooled water drops found in stratiform clouds of stable air. Rime ice usually occurs at the lower temperatures in the range of 0° C to −18° C, although it has been observed with temperatures as low as −40° C. It also occurs in cumulus clouds at temperatures below −9° C.

Each supercooled water droplet that strikes the aircraft freezes completely before another droplet comes along and strikes in the same place. The resulting ice deposit is in the form of tiny pellets frozen together in a spongy mass, which

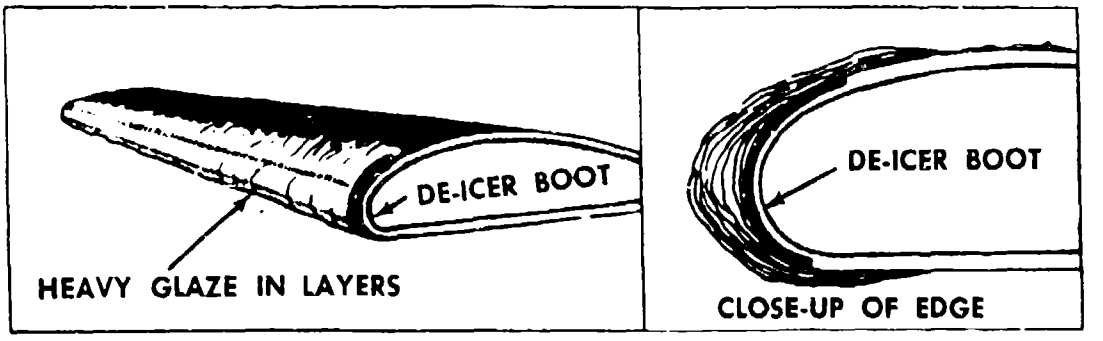


Figure 29–3. Glaze ice on an airfoil

is relatively easy to break off. Since the particles forming rime freeze where they strike the aircraft, rime builds principally on the leading edge of aircraft structures, although rivets, skin laps, and localized rough surfaces may become anchorages for small deposits of rime. Figure 29–2 shows the formation of rime ice on an airfoil. The greatest resultant danger is the added drag caused by the rough ice surface created.

Glaze (Clear Ice)

Glaze is considered to be the most serious of the various forms of structural ice. It is clear, dense, solid ice and adheres firmly to structures upon which it forms. It is the same kind of ice which brings down trees and telephone lines. Glaze is most likely to form in an unstable air mass, in or below cumuliform clouds, at temperatures from 0 °C to −9 °C.

If water droplets strike an aircraft in such rapid succession that none has a chance to freeze before the next strikes in the same place, the leading edges of the aircraft structures are kept covered by a film of liquid water. This film of water, cooled in contact with the colder air and by evaporation of some of itself, freezes from the inside out, forming a clear, dense, strong layer of ice attached to the wing or other surface upon which it is freezing.

Cloud droplets strike chiefly on the leading edges of structures, so it is there that the most severe glaze icing will occur. (See Figure 29-3.) However, if water is deposited faster than it freezes in the same place, some water will run back over the rest of the aircraft and freeze there. Over the top and bottom of the wing, where the friction action of the wind is strong, this free water will freeze into rough ice. This results in greatly increased drag and in a dangerous increase in the stalling speed, for it interferes with the airflow over a critical portion of the wing. Moreover, it spreads away from the de-icer boots and cannot be removed by them. For these reasons, the effect of glaze on the flying characteristics of an aircraft is serious and out of proportion to the weight of the ice deposit.

Combinations

A wide range of conditions may be encountered between those most favorable to rime and those most favorable to glaze. These produce any form in-between, ranging through dense rime to porous, white ice. There is also combined rime and glaze formed in mixed rain and cloud drops at sub-freezing temperatures.

Since the surface of rime formation is mostly dry, snowflakes do not adhere to it to any great extent. However, snow does adhere to the liquid film present when clear ice is forming. This results in a rapid accumulation of a rough deposit

of sticky snow and glaze, which may become dangerous.

Frost

Frost is a hazard very often underestimated. Frost may form on the ground or in the air. On the ground, frost is likely to form during the night when surface temperatures are below freezing. Frost forms in clear air by sublimation (change of state directly from gas or vapor to solid ice) when the moist air comes in contact with a very cold surface.

Frost may form in flight from a very cold air mass to a warmer air mass or during descent into warmer (but still freezing), more moist air. Frost causes added drag and offers a very real hazard at lower critical airspeeds. Ice accretion is very rapid on frost covered surfaces. For this reason, and because frost on windshield surfaces is a restriction to visibility, the aircraft should be checked thoroughly, and frost removed before take-off.

ANTI-ICING AND DE-ICING AIDS

An anti-icer is an item of equipment which prevents the formation of ice, and a de-icer is an item of equipment which eliminates ice after it has already formed. Anti-icing and de-icing equipment can be divided into three general classes.

1. Mechanical (de-icing boots which are used on wings, tail assembly, and radio mast).

2. Chemical (anti-icing paste, which is used on propellers and anti-icing fluid, which is used on the propeller, windshield, carburetor, and jet engine accessory section).

3. Thermal (electric heat, which is used on the pitot tube, propeller(s), electrical wingboot, and wingtip tanks, and exhaust or compressor heat, which is used on the wings and tail assembly, windshield, intake air, canopy, and carburetor).

The "hot wing" or exhaust heated wing (Fig. 29-4) may be considered as either an anti-icer or de-icer, depending on the time at which the unit is put into operation.

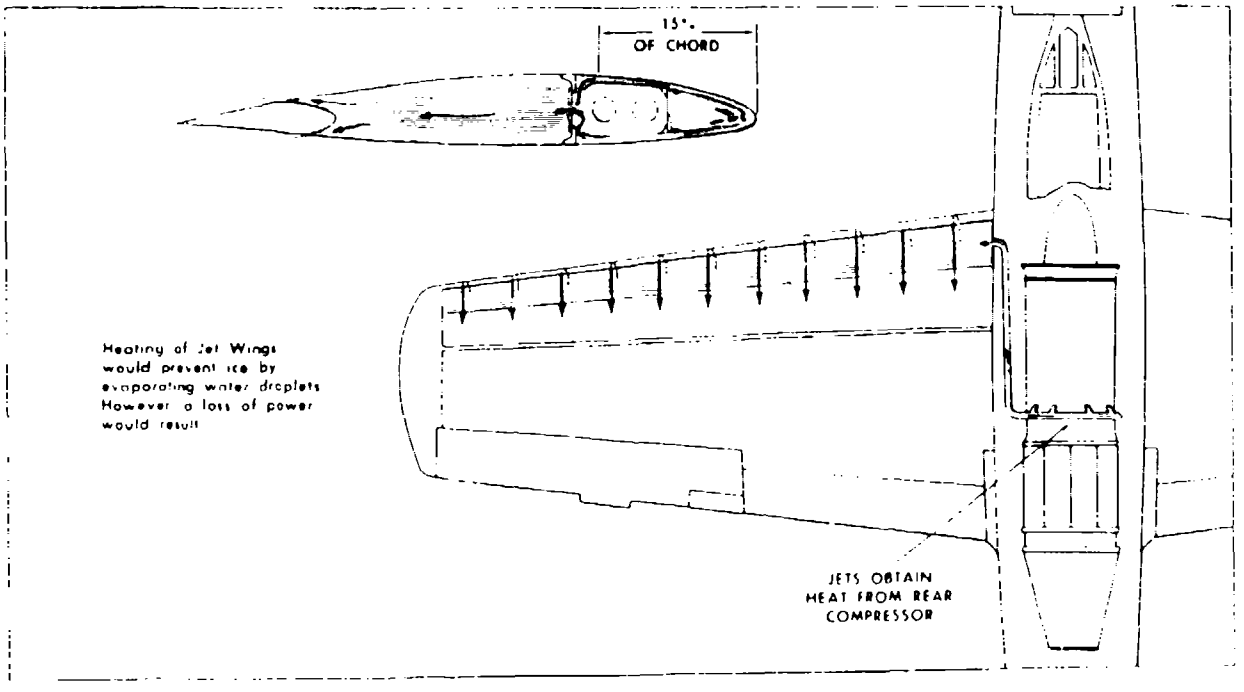


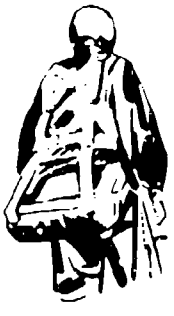
Figure 29–4. Typical installation of thermal anti-icing system

Anti-icers should be used before, or immediately upon, entering an icing zone and should be operated continuously until the aircraft is out of the icing zone.

De-icing boots should be used intermittently and only after an appreciable thickness of ice has accumulated upon the boot. Ice that does not cover two or more of the parallel tubes in the boot should be left alone. It will not be sufficient to cause serious consequences, and if the boots are turned on only a part of the ice is likely to be broken loose. The chunks that remain not only destroy the airfoil more than the original formation, but act as a rough base for additional ice to accrete to and build up unevenly.

Since rime ice usually forms on the wing leading edge, the aerodynamic efficiency of the wing is not greatly impaired. Because rime ice is granular in make-up, you stand a better chance of its breaking off in large chunks when you use the boots, if you allow it to build up properly. The strength of the boots generally will handle considerable rime satisfactorily, provided not too much clear ice is mixed with it to strengthen its cohesive qualities.

You have to be much more careful when clear ice forms on the wings. It is highly tenacious and it must be broken before it reaches a strength that the boot cannot break. If corrective action is taken too soon, the ice will merely crack along the line between the inflated and deflated sections of the de-icer and will not break off. Experience shows that about one-eighth of an inch to one quarter of an inch is the correct thickness to begin boot operation. It is better to begin too soon than too late. Once ice is thick enough to make the boot inoperative, you are at its mercy.



If you get either clear or rime ice for a short time only and you are certain you will be in clear air soon, leave it alone. Use the boots after you are through the icing area to break up all that will come off and let evaporation clean up the rest of the wing for you. Fly manually through icing and move the control surfaces from time to time if the air is smooth to prevent them from freezing at the hinges. De-icing boots should not be used during take-off or landing.

Before takeoff, remove snow, frost, sleet and any other foreign particles that have frozen to the aircraft. Never be satisfied with less than an aerodynamically clean plane.

THE RATE OF DEPOSIT OF ICE ON AIRCRAFT

Four factors govern the rate of ice build-up - the amount of supercooled water present, the temperature of the air, the area and roughness of the surface exposed, and the airspeed of the aircraft.

The first of these factors can be estimated in flight by the darkness of clouds encountered and their vertical development. Sharpness of the contour of clouds indicates active build-up and consequently larger amounts of water vapor in the air. In stratus clouds the lower levels contain the most moisture.

So far as temperature is concerned, remember that under normal conditions the lower the air temperature, the less relative amount of water present. However, remember also that as long as visible moisture is present there is a possibility of ice forming.

Any rough surface over which the air flows not only cuts down the aerodynamic cleanliness of the aircraft but also becomes an anchoring point for ice. Rough paint, rivet heads, and frost particles are especially bad. Frost is unquestionably the worst of the offenders, as ice forms on this base almost immediately.

Speed versus amount of ice accumulation is a highly controversial subject. This much is known, however -the rate of accumulation is always higher at higher airspeeds, but the amount of accumulation may be greater at slower speeds.

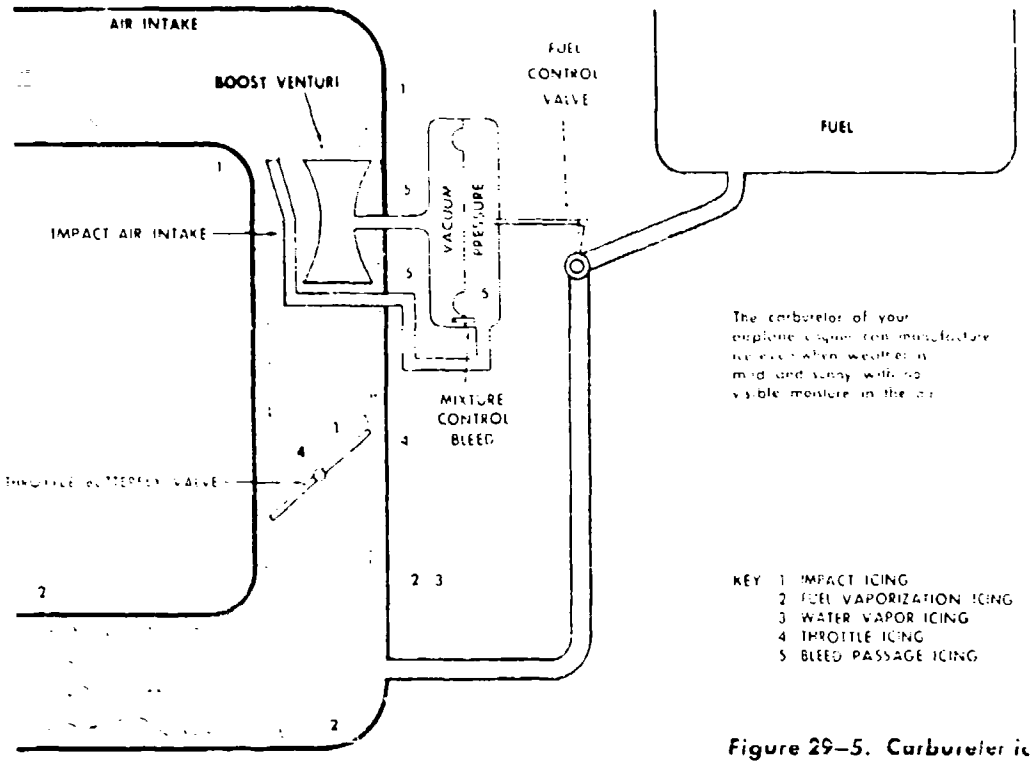


Figure 29–5. Carburetor icing

INDUCTION SYSTEM ICING

Carburetor Icing

Carburetor icing can occur under a wide range of temperatures and can result in complete engine failure. However, it is generally encountered only between 13° and 18° C outside air temperature in high relative humidity, rain, or overcast. Below 13° C, the danger of ice formation in the air is slight. However, once the ice begins to form in the carburetor, the power can be seriously affected in less than a minute's time.

Ice may be formed in a reciprocating engine induction system by two processes: (See Figure 29-5.)

Impact ice is formed when supercooled water strikes a surface that is at sub freezing temperature. It collects on scoop inlets, duct walls, carburetor inlet screens, exposed metering elements, and other protuberances in the induction system. These ice formations may reduce the airflow and thereby reduce the engine power.

Throttle ice is formed because of the cooling effect of the evaporating fuel after it is introduced into the airstream. This is the carburetor ice that probably occurs most frequently in actual operation, because it may form at carburetor air temperatures considerably above 0° C.

To combat carburetor icing, two basic types of carburetor heating systems are used in naval aircraft with reciprocating engines—the alternate air system and the preheat system. When flying in conditions conducive to induction system icing, use carburetor heat.

Jet Engine Icing

Centrifugal compressor type jet engines, such as the J-33 and J-48, are relatively free of icing difficulties. While it is possible for these types to ice up under extreme conditions, such cases are rare. Axial flow power plants, on the other hand, are seriously affected by icing. The initial indication of jet engine icing is increased exhaust gas (tail pipe) temperatures. This is all too often

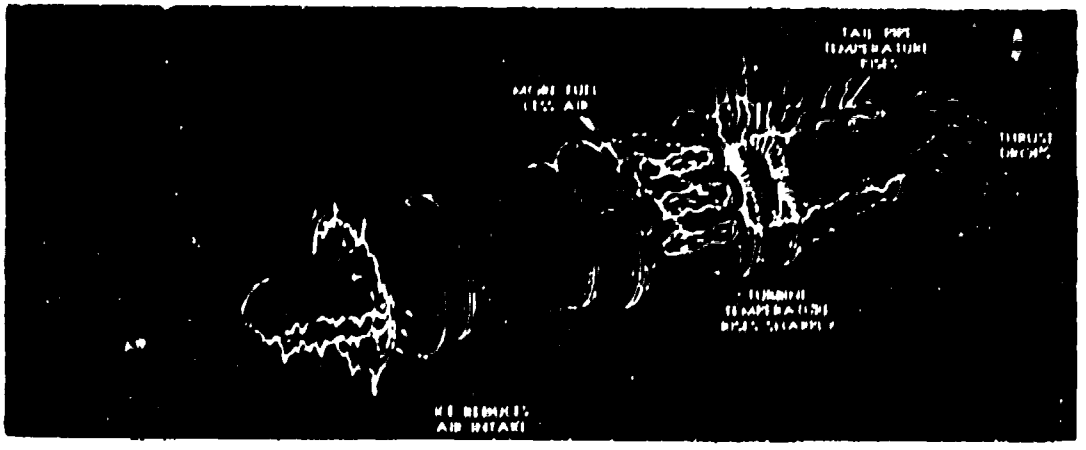


Figure 29-6. Effect of icing on axial-flow jet engine

the only indication before complete engine failure. Ice forms on the fixed or extended inlet screen and compressor inlet guide vanes (stator) and restricts the flow of inlet air. This causes a loss of thrust and a rapid rise in tailpipe temperatures. As the airflow decreases, the fuel-air ratio increases, which in turn raises the temperature of the gases going into the turbine. (See Figure 29-6.) The fuel control attempts to correct any loss in engine rpm by adding more fuel, aggravating the condition.

Complete turbine failure may occur in a matter of seconds after ice build up in the engine air inlet. Critical ice build upon the inlet screen can occur in less than one minute under severe conditions.

The conditions under which induction icing most frequently occurs result from a combination of factors: temperature near freezing, high relative humidity, low air speed, and high rpm. This combination frequently exists during an early morning take-off and climb. The combination may occur at any season of the year and is not necessarily limited to early morning hours. Not all the causes for cloud or other visible moisture are present for the formation of induction icing. Induction icing may result whenever the temperature and dewpoint are in proximity at, or relatively near, 0° C.

You can recognize the onset of induction icing by noting a loss of thrust and an increase of tailpipe temperature. Corrective action calls for retarding the throttle or leaving the icing area as quickly as possible. If you are taking off in conditions favorable to induction icing, accelerate rapidly and climb at higher than usual airspeeds. Layers of air which contain sufficient moisture to cause this type of icing are rare at altitudes greater than 20,000 feet.

DETERMINATION OF ICING REGIONS

Whenever you plan a flight, use the weather charts and all other facilities, including the knowledge of the forecaster on duty, to aid in anticipating possible icing regions.

Warm Front

The various surface and constant pressure weather maps indicate the positions of thunderstorm fronts, thus indirectly marking regions of possible aircraft icing. For example, the region of the cloud system of any warm front presents a potentially dangerous icing situation. This region may extend over a great area, vertically and horizontally, and severe icing conditions may be present at any point in it. In the smooth or stratiform clouds, icing tends to be predominantly rime in character.

Keep in mind that warm front icing is not necessarily confined to the freezing precipitation below the warm front surface, but is also to be expected within the warm air mass clouds *above* or *in* the frontal surface. Gradual lifting of the moist air mass may at times produce widespread condensation and sub-cooling. Above the frontal surface, flight to higher altitudes with lower temperatures (and less cloud) will generally be safer when flying *toward* the warmer air mass.

Warm fronts that have become stationary along mountain barriers furnish a persistent icing zone. The Allegheny and the Sierra mountain ranges are to be watched for this condition.

Cold Fronts

Just as lifting and cooling processes are stronger over mountains than away from them, so are all frontal surfaces zones of strong condensation and subcooling. A majority of serious icing conditions are those found in frontal zones (Fig. 29-8). Flight through an icing condition can generally be counted on to increase in severity as the frontal zone is passed through where turbulence and mixing is more pronounced.

Icing along cold fronts in the Mississippi Valley, either with cP or in mP air masses or both, is a fairly common occurrence during the cold season. Cold fronts crossing mountain barriers such as the Sierra, the Cascades, Rockies, or Alleghenies can frequently be counted upon as contributing to icing conditions of serious proportions.

Crossing a Front

One very important principle which must be kept in mind in connection with fronts is that if a front lies parallel to the course, it is possible for an aircraft to remain in the frontal surface during a long flight. By flying perpendicular to fronts, you may pass through quickly. In this connection, keep in mind a three-dimensional picture of the frontal surface so that if you find icing in a frontal surface, you won't try to climb above it in the direction in which the frontal surface slopes upward.

Effect of Mountain Ranges on Air Mass Icing

Icing within an air mass is frequently severe directly over large peaks or extensive mountain ranges. This zone may extend some distance on either side of the crest, principally on the windward side where upslope effect is predominant (Fig. 29-9). In general, when stable air flows over mountain ranges, the intensity of icing decreases rapidly above the tops of the mountains.

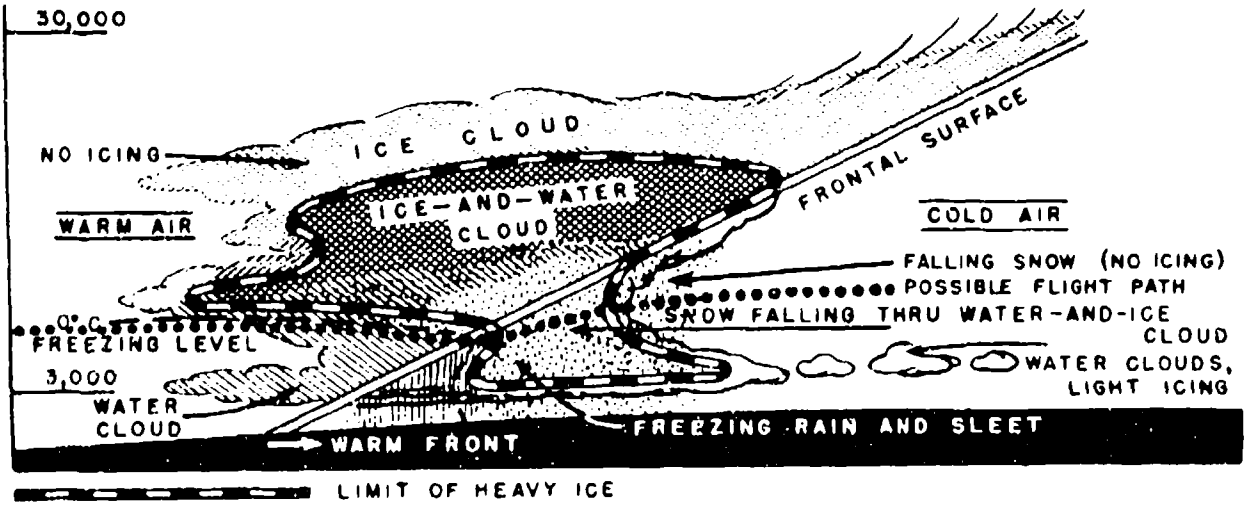


Figure 29-7. Icing zones along a warm front

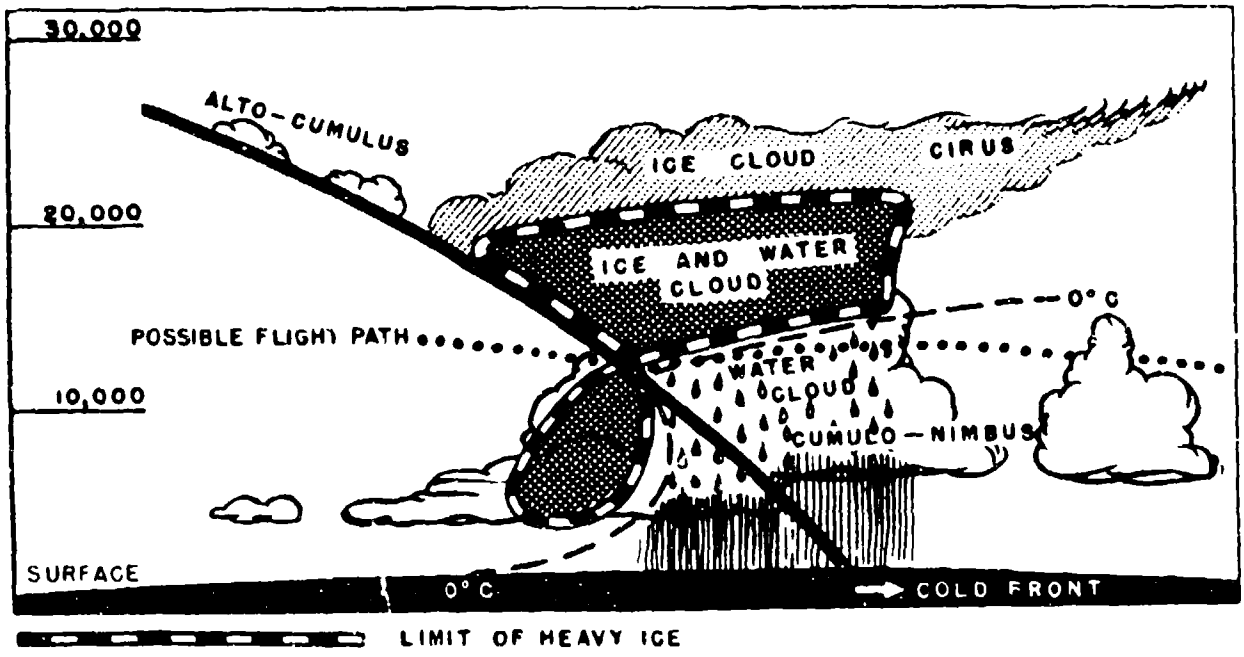


Figure 29–8. Icing zones along a cold front

Close to the crest, however, cloud layers tend to come together; because the upslope currents may carry large numbers of sub-cooled particles, this region should be avoided when temperatures are known to be at or below freezing.

In the vicinity of mountain ranges the icing zone may extend to considerable altitudes above the crest of the mountain if the air mass moving over it is conditionally or convectively unstable. Cumulous clouds developed over the mountains in unstable air frequently contain a large amount of sub-cooled droplets.

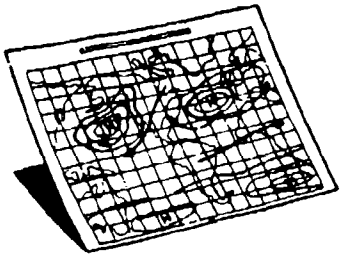
The mountains along the west coast of the United States, the Rocky Mountains, and the Allegheny Mountains in the East are all zones to be watched for potential icing conditions when stable or unstable air is forced up their windward slopes. Because of the higher frequency of unstable air masses in the east, the Appalachian Mountains are particularly critical regions at times, especially through Pennsylvania and New York when cP air modified by the Great Lakes is forced up the west slopes.

Occlusions

Icing in occlusions is typical of the warm and cold frontal surfaces making up the occlusion. The simple occlusion consisting of a trough of warm air aloft is frequently a producer of serious icing (Fig. 29-10). Occluded fronts present an icing hazard about the same as a warm front—particularly in northern regions such as Alaska and the North Atlantic. The extensive cloud cover may necessitate considerable flying time in clouds, with the type, severity, and zones of icing determined by considering each case separately.

Weather Forecasts

All types of weather forecasts give information on the height of the freezing level and regions in which the pilot can expect ice formation. The type and intensity of ice to be expected are usually omitted because of the difficulty in forecasting these details. Since it often is possible to fly in clouds at temperatures below freezing and not pick up any ice, the forecast may seem to be in error. These forecasts, though, simply indicate regions



always conditions are favorable for ice formation. Be prepared to encounter ice in those regions and consider yourself lucky if you don't.

Teletype Weather Reports

Pilot reports of icing are often included in teletype weather reports—PIREPS collection or individual special reports—and may be used as a source of much useful preflight planning information by other pilots. When planning a flight, note the areas where the free air temperatures are favorable to ice formation, and where clouds are expected.

Upper Air Soundings (Arowagram)

The upper air sounding diagram enables you to determine the height of the freezing level and the presence of clouds. It also shows the presence of an inversion. Temperatures of freezing or below may often exist at the surface, or at a particular level, while temperatures higher in the atmosphere are above freezing. Many times you can fly at the altitude of the inversion, picking up ice only during the climb and descent. Sometimes, however, the layer of warm air which essentially composes an inversion is relatively shallow, and icing conditions may exist in freezing rain or clouds immediately below the inversion. Be careful in selecting a cruising altitude and planning changes in it. Take the advice of the forecaster (both preflight and during flight) as a guide for the selection of a flight altitude which may eliminate or reduce icing hazards.

CHECK LIST FOR COLD-WEATHER OPERATIONS

Here is a winter check list that will help take the hazard out of cold-weather flying:

1. Check weather carefully; ask the pilot who just came through, and check PIREPS at origin and destination.
2. Check NOTAMS.
3. Remove frost and snow before takeoff. This must be done thoroughly.
4. Check controls for restrictions of movement.
5. Taxi slowly. Use brakes with caution.

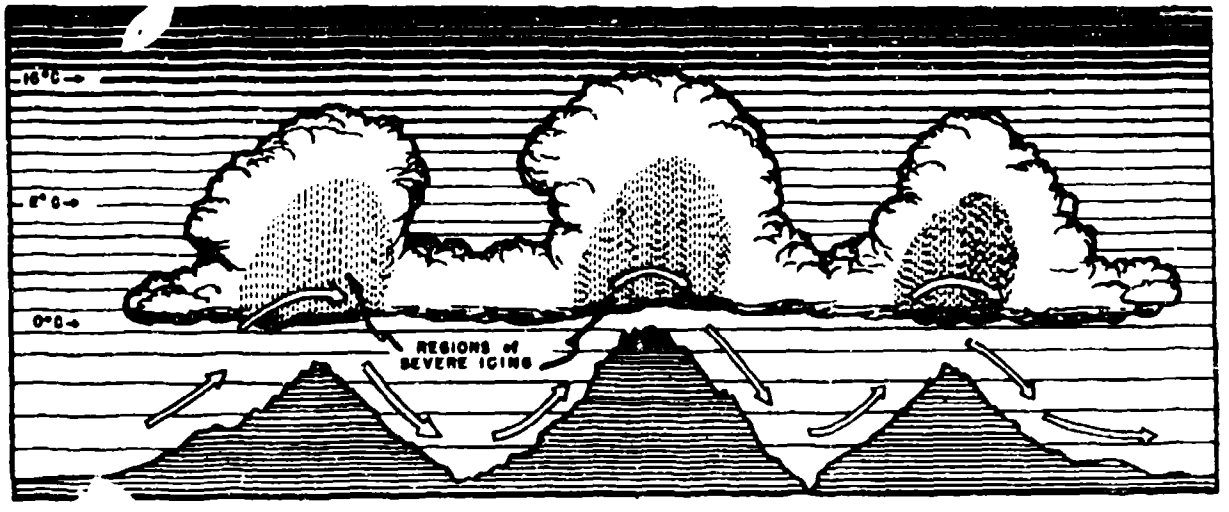


Figure 29-9. Icing over mountains

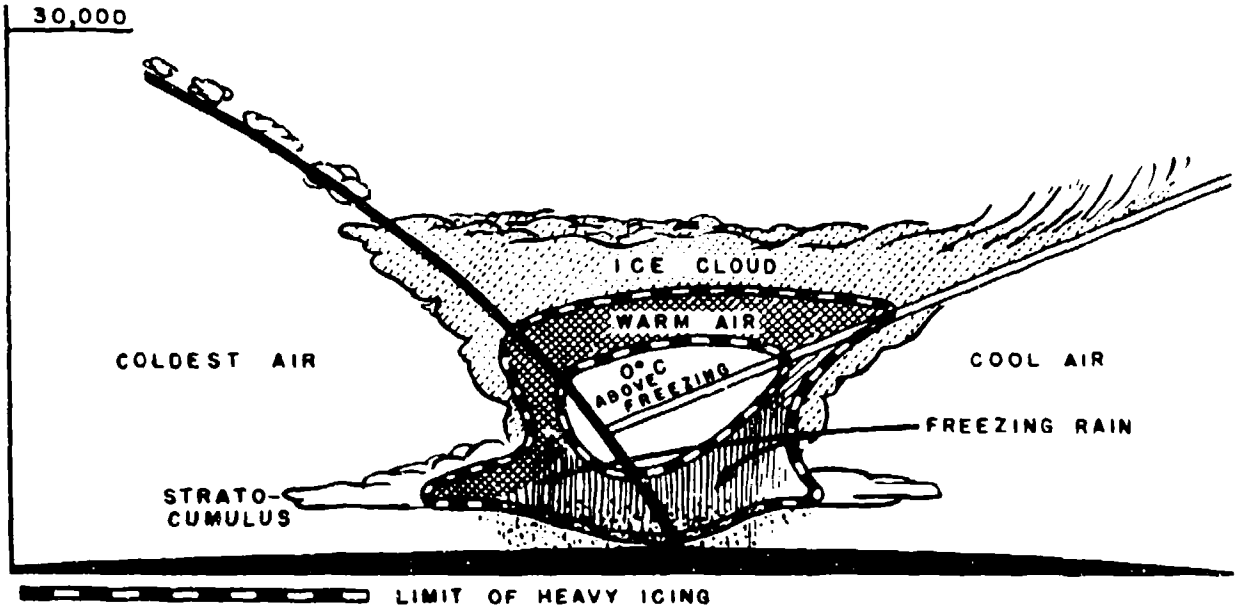


Figure 29–10. Icing zones along an occluded front

6. After run-up in fog or rain, check wing and empennage for ice in propeller blast area.

7. Wear sunglasses if glare is bad.

8. Before take-off, check anti-icing and de-icing equipment. Be sure it is in good operating condition. You might need all of your equipment.

9. Don't take off in slush or wet snow if it can possibly be avoided.

10. Be alert for snow banks during takeoff and landing.

11. Remember, when ice forms, you will use more fuel to get to your destination. Ice on the aircraft causes increased drag, and all types of ice prevention measures use up energy (fuel). Therefore, if you expect icing conditions, you must anticipate conservative cruise control.

12. Plan flights over mountains to clear crests or saddles by about 4,000 or 5,000 feet. Be wary of icing especially on the windward side of mountains.

13. Avoid flight at freezing level (0° to −9° C), especially in cumuliform (turbulent) clouds.

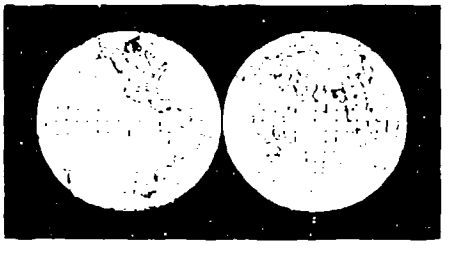
14. When flying in wet snow or freezing rain, change altitude if possible. (Climb to warmer temperatures or proceed out of the area.)

15. Choose the altitude of least icing. Clear ice is common in cumulus clouds; rime ice is common in stratiform clouds.

16. Do not fly parallel to a front through areas of possible icing.

17. Use pitot heat when flying in rain, snow or clouds, as well as in known icing zones.

18. Use full carburetor heat or alcohol to clear ice. Use alternate air or carburetor preheat for prevention. Don't wait to cure. Watch



your carburetor air temperature, especially between −5° C and +10° C (23° and 50° F).

19. Watch your airspeed—stalling speed increases with ice. Don't climb at a low airspeed.

20. Don't make steep turns if the surface of the aircraft is heavily coated with ice.

21. Report all inflight weather hazards.

22. Check wing de-icers—use them properly. Do not land with de-icers on; they act as spoilers.

23. Don't try three-point landings when iced-up in a propeller-driven airplane. Fly in with power. Before starting landing approach, move throttle back and forth slowly to make sure carburetor butterfly valve is free of ice.

CHAPTER 30

THUNDERSTORMS

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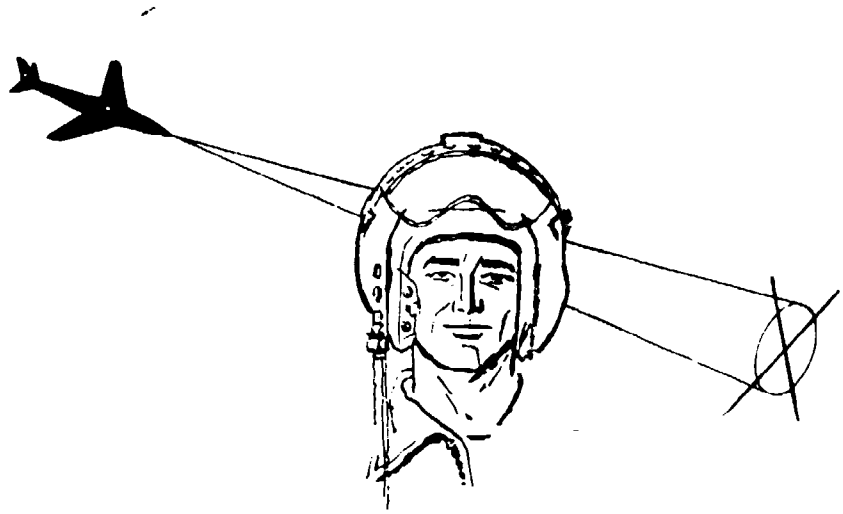

CHAPTER 30

THUNDERSTORMS

TODAY'S Navy pilot must be capable of reaching his destination or objective regardless of weather conditions en route. Since approximately 44,000 thunderstorms occur daily over the surface of the earth, you can expect to fly through a thunderstorm or thunderstorm area at some time or another.

Thunderstorms are a hot weather phenomenon. This is because only warm air can hold enough moisture. Since heat is a usual factor in the production of thunderstorms, they occur mostly in the afternoon when temperatures are at their highest.

CONDITIONS OF THUNDERSTORM FORMATION

A certain combination of atmospheric conditions is necessary for the formation of a thunderstorm. These factors are—conditionally unstable air of relatively high moisture content and some type of lifting action.

Conditional Instability

A column of air is said to be conditionally unstable when its lapse rate is intermediate between the dry and moist adiabatic lapse rates. Under

such conditions, dry air is stable since it would be cooler than the surrounding air when lifted adiabatically, while saturated air is unstable since it would be warmer than the surrounding air when lifted adiabatically. Thus, the stability of the air column depends on its moisture content.

Lifting Action

When an unsaturated parcel of air in a conditionally unstable layer (air column) is lifted, it becomes colder than the surrounding air since it cools during the lifting at the dry adiabatic lapse rate. When lifting continues beyond the level where the parcel becomes saturated (saturation level), it is then cooled at the moist adiabatic lapse rate, so that the air parcel eventually reaches a level where it becomes warmer than the surrounding air. This altitude is called the "level of free convection," because the air parcel continues to rise of its own accord once it reaches this level.

Some type of external lifting action is required to lift the parcel of air to the level of free convection. This lifting action may be mechanical (such as forced lifting over a front or mountain), thermal (such as convection heating), or convergence (which occurs in troughs, easterly waves, and the equatorial (ITCZ) front).

TYPES OF THUNDERSTORMS

Thunderstorms generally have the same physical features. They do differ, however, in intensity, degree of development, and associated weather phenomena such as hail, turbulence, and electrical discharges. Thunderstorms are generally classified according to the way the initial lifting action is accomplished. They are therefore divided into two general classes - frontal thunderstorms, and air mass thunderstorms. These, in turn, are subdivided as follows -

Frontal types:
- Warm front
- Cold front
- Pre-frontal (Squall line)

Air Mass types:
- Convective
- Orographic
- Nocturnal

Frontal Types

Warm Front Thunderstorms. A warm front thunderstorm is caused when warm, moist, unstable air is forced aloft to the level of free convection over a colder, denser shelf of retreating air (Fig. 30-1). Because of the extreme shallow-

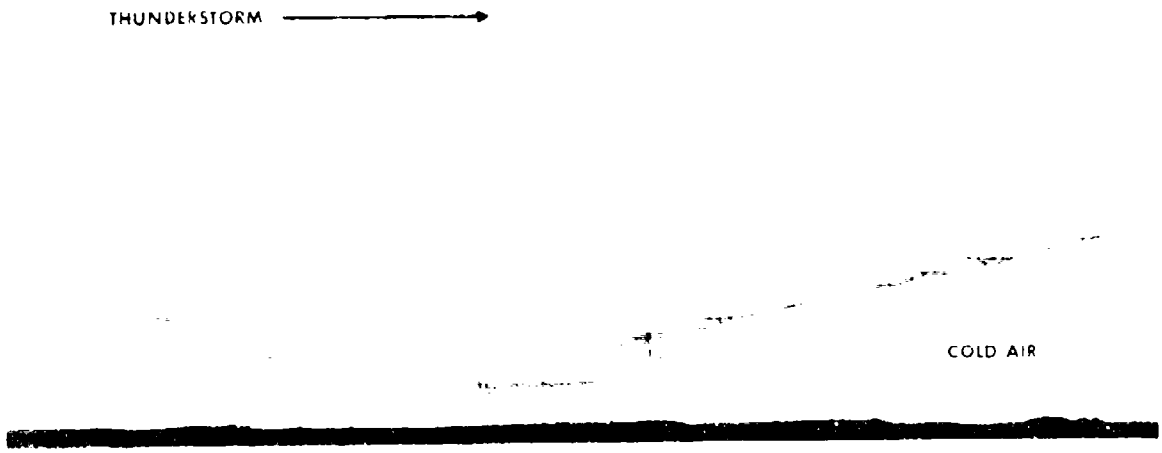

Figure 30-1. Warm-front thunderstorm

ness of the warm frontal slope, the air is lifted gradually. The lifting condensation level is reached long before the level of free convection, generally resulting in stratus conditions.

If the level of free convection is reached, however, warm front thunderstorms form. The level of free convection will normally be reached at isolated points along the lateral surface of the front aloft, and therefore warm front thunderstorms are generally scattered.

Warm front storms are extremely difficult to identify because they are obscured by other clouds. The warm front thunderstorm is dangerous because you may fly from an area of relatively smooth instrument flight into an area of great turbulence in a matter of seconds. Make a thorough preflight study of the appropriate upper-air soundings along the proposed route so that you may be forewarned of the existence of possible thunderstorm areas. Static in the earphones may also provide warning of approaching thunderstorms. Another indication of cumulus or thunderstorm activity is presence of showery precipitation in the warm front weather pattern.

Cold Front Thunderstorms. A cold front thunderstorm is caused by the forward motion of a wedge of cold air into a body of warm, moist, unstable air (Fig. 30-2). The slope of a cold front is relatively steep, and this causes the lifting condensation level and the level of free convection to be near the same level. Cold front storms are normally positioned in an apparently continuous line along the frontal surface aloft. The problem of recognition is negligible because most cold front storms are partly visible when approaching the front from any direction. The bases of these storms are usually closer to the surface than the bases of warm front thunderstorms.

Pre Frontal or Squall Line Thunderstorms. When the air above a cold front moves in the same direction but faster than the cold air at the surface position of the front, some of the cold air mass aloft is advanced miles ahead of the front at the ground. Thus, the warm air rises much farther ahead of the front than normally, creating a low pressure trough at the surface which parallels the advancing wedge of cold air. This phenomenon is commonly called a squall line (Fig. 30-3). The lifting action that takes place at a squall line is normally great enough to force the warm air up to the level of free convection, thereby producing a line of thunderstorms along the squall line. These thunderstorms are normally like cold front thunderstorms, but more violent. Tornadoes are

Figure 30–2. Cold-front thunderstorm

Figure 30–3. Squall-line thunderstorms

normally associated with the most violent of squall lines. A squall line usually dissipates within 12 hours. It is most dangerous during its first hours of life; therefore, check Severe Weather Advisories (Chapter 26).

Air Mass Thunderstorms

All air mass thunderstorms have two things in common: they form within an air mass, and they are generally isolated or scattered over a large region.

Convective Thunderstorms

Convective thunderstorms may occur almost anywhere in the world, over land or water. These storms are caused by solar heating of areas of the land or sea, which in turn provides heat to the lower layers of the air and results in rising currents of the warmed air (Fig. 30-1). Land type convective thunderstorms normally form during the afternoon hours at about the time the earth is receiving maximum heating from the sun. Dissipation normally occurs during the night or early morning hours after the land has lost its heat to the atmosphere.

Ocean type convective thunderstorms form in the same way but at different hours. They are generally formed during the night, and are strongest near sunrise. This nocturnal formation is due to the fact that large water bodies radiate the greatest amount of heat during the night.

Orographic Thunderstorms. Orographic thunderstorms form in mountainous regions where the air traverses a sufficiently long or steep slope to permit the level of free convection to be reached. (See Figure 30-5.) A good example of this type of storm is frequently found in the northern Rocky Mountain region.

Such thunderstorms frequently form in a long unbroken line like the cold front type, and persist as long as the upslope circulation continues. From the windward side of the mountains, identification of orographic storms may sometimes be difficult because they are obscured by other clouds, usually somewhat stratiform. From the lee side, identification is positive; the outlines of each storm are plainly visible. It is not advisable to fly through an orographic thunderstorm because this type of storm almost always enshrouds a mountain peak or a hill. For the same reason, don't try to fly under this storm unless the opposite side of the area is clearly visible.

Nocturnal Thunderstorms. Nocturnal thunderstorms occur late at night and in the early

morning hours in the Central Plains area of the United States from the Mississippi Valley Region westward. Their occurrence is explained as follows: The synoptic situation is one in which a weak warm frontal surface overlies the area affected in such a way that a relatively moist layer of air exists aloft. Night time radiation from the moist layer causes extreme cooling of the air at this level. Then the layer of air which has cooled settles in the early morning hours and forces conditionally unstable surface air aloft to initiate thunderstorm activity.

STRUCTURE OF THUNDERSTORMS

The fundamental structural element of the thunderstorm is the unit of convective circulation known as a convective cell. A mature thunderstorm contains several of these cells, each varying in diameter from one to five miles. The circulation in each cell is generally independent of that in surrounding cells in the same storm. Each cell progresses through a cycle which usually lasts several hours. In the initial stages of cumulus development, the cloud consists of a single cell, but as the development progresses, new cells may form and older cells dissipate in a continuous and unbroken process. The life cycle of a thunderstorm consists of three stages -first, the cumulus stage, then the mature stage, and finally the dissipating or anvil stage. The transition from one stage to the next is not an abrupt one; each stage blends gradually into the next.

Cumulus Stage

The common cumulus cloud is the initial stage of all thunderstorm formation. Actually, only a very small percentage of cumulus clouds ever become thunderstorms. The chief distinguishing feature of the cumulus or building stage is the updraft that prevails throughout the entire cell (Fig. 30-6). The speed of the updraft may vary from a few feet per second to as much as 100 feet per second in well developed cumulus clouds. As the updraft builds a cumulus cloud to higher altitudes, small water droplets are formed. The greatest number of droplets form near the freezing level and grow in size by collision with other droplets. Usually rain does not fall during the cumulus stage because the raindrops are carried upward or remain more or less suspended by the upward air currents which exist throughout the cloud.

The Mature Stage

The occurrence of rain at the ground generally indicates the transition from the cumulus stage to the mature stage. By this time, the cell has usually attained a height of 25,000 feet or more. After the number of raindrops has increased to such an extent that they can no longer be supported by the updrafts they begin to fall from the cloud and exert a drag on the air within the clouds (Fig. 30-7). Such drag is a major factor in the formation of a downdraft which characterizes each convective cell in the mature stage. The downdraft is evident at the surface as a strong and gusty horizontal outflow which results when the downward flow of air is forced to move horizontally because of the solid lower barrier presented by the earth.

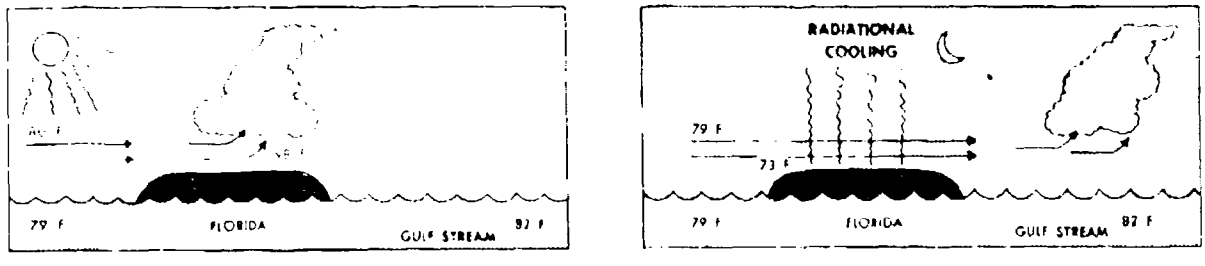

Figure 30-4. Convective thunderstorms

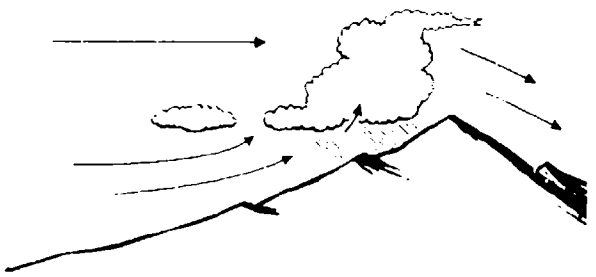

Figure 30-5. Orographic thunderstorms

Downdrafts begin to form in the middle region of the cloud and gradually increase in both horizontal and vertical directions. Downdrafts in thunderstorms tend to be less gusty and smaller in speed than updrafts, but frequently are as strong as 40 ft/sec. In contrast, updraft speeds of 100 ft/sec are not uncommon early in the mature stage. Since the downdraft is right next to the updraft in each cell and since several cells are continuously forming and dissipating, it is apparent that severe turbulence may be expected when flying through a thunderstorm.

Mature cells generally extend to altitudes of 30,000 to 50,000 feet. It is in this stage of the formation process that hail is frequently formed when a cell extends to great heights and has very strong updraft speeds. The "hard" rains which are often characteristic of thunderstorms also occur during the mature stage of each cell. In contrast to the life span of 10 to 15 minutes of the cumulus stage of an individual cell, the mature stage usually lasts for 15 to 30 minutes. Remember, though, that a thunderstorm is composed of several cells which continuously form and dissipate so that the life of an entire thunderstorm is usually much longer.

Dissipating or Anvil Stage

Throughout the life span of the mature cell, the downdraft continues to develop both horizontally and vertically as a result of momentum and the drag effect of the falling precipitation. At the same time, the updraft is in a state of dissipation. As this process progresses, the entire lower levels of the cell become an area of downdraft, and the upper levels become an area of little or no vertical motion (Fig. 30-8). A downward current throughout the cell is the chief characteristic of the dissipating stage of a cell.

The dissipation stage may be identified at the surface by reduced precipitation and finally an end to precipitation. At the same time, the lower levels of the cloud frequently tend to become stratiform in appearance. A further identifying feature of the beginning of the dissipation process is the formation of the characteristic anvil top which results from the strong horizontal winds aloft blowing the upper portions of the cloud forward of the main portion. The life span of the dissipating stage is considerably more variable than that of the other stages and depends on the strength of the original updrafts and the amount of moisture which the air contains.

Vertical Development

Measurements of the vertical extent of thunderstorm activity have been made by radar equipment. It has been found that the closest correspondence between the radar-measured top and the actual top occurs during the cumulus stage, because the ice crystal tops in the mature and anvil stage do not give good radar echoes.

Storms with radar-measured heights of 50,000 feet or more were measured in less than 10 percent of the cases observed. The greatest portion of storms measured had heights between 25,000 and 29,000 feet. The mean of all heights measured was 37,000 feet, and the maximum height observed was 56,000 feet. Others have been accurately measured as high as 67,000 feet.

DRAFTS AND GUSTS

A draft is defined as a large-scale vertical current of air continuous over many thousands of feet of altitude. This is an important consideration, but another distinguishing feature of drafts is their relatively constant speed as contrasted to gusts. Gusts are smaller-scale discontinuities or variations in speed associated with the draft proper. Individual gusts have only a very short horizontal and vertical extent, but it is these gusts which account, at least in part, for the severe bumpiness so common in a cumuliform cloud. A draft may be compared to a great river flowing at a fairly constant rate, whereas a gust is com-

parable to an eddy or any other random motion of water within the main current.

Drafts

Considerable data on drafts have been collected, and it has been found that the maximum updrafts are in the middle and upper levels flown. Mean updraft and downdraft velocities increase with height, and updraft are generally of greater velocities than downdrafts.

Certain data have also been made available regarding aircraft vertical displacement as a result of drafts. Greater aircraft displacement was observed at the higher levels. An aircraft flying at 150 mph suffered a displacement of as much as 6,000 feet in the upper levels of the storm cell, whereas similar aircraft flying at the same airspeed at the 6,000-foot level experienced maximum displacement of only 1,600 feet. In the middle and upper levels of the cell, mean displacement caused by updraft was greater in all cases than mean displacement caused by downdraft. Therefore, flight through storms in the middle and upper levels will result in a gain in altitude. In no case was an aircraft flying at the 5,000- or 6,000-foot level brought dangerously close to the ground by a downdraft (uneven terrain areas excepted).

Downdrafts below the cloud base. A very important part of a thunderstorm is the cold downdraft in the area of heavy rain. This downdraft continues below the base of the cloud and, under certain circumstances, may constitute a definite aeronautical hazard. As it approaches the ground it spreads out and forms a layer of relatively cold air over the surface. In the immediate area of rain, the downdraft possesses considerable downward momentum and may approach much closer to the ground than might be expected. Measurements have indicated that significant downdrafts may exist at altitudes less than 1,000 feet above the ground (Fig. 30-9).

The only place where the downdraft beneath the cloud base is likely to have a speed great enough to be hazardous to aircraft is in the rain core when the rainfall is heavy. The distance that an aircraft will be carried downward in flying through the downdraft area beneath a storm depends on the extent and speed of the draft and the forward speed of the aircraft.

A pilot flying in heavy rain areas under thunderstorms may expect downdrafts ranging up to 20 ft/sec or more, depending on the altitude above the terrain at which the flight is made. Considering the speed and width of the downdrafts and the speed of modern aircraft, it seems unlikely that an aircraft could be carried downward more than 1,500 to 2,000 feet by the action of a downdraft alone. Under certain conditions, in the lowest few hundred feet under the cloud gusts may be as strong as those at higher altitudes in the storm. If you elect to fly under a thunderstorm try to avoid the area of maximum rainfall.

Gusts and Turbulence

Turbulent motions (gusts) within thunderstorms have a considerable effect on an aircraft. In fact, the actual severity of a storm depends on the intensity and frequency of these gusts. Incidentally, when the term "heavy turbulence" is used, it generally refers to violent accelerations--

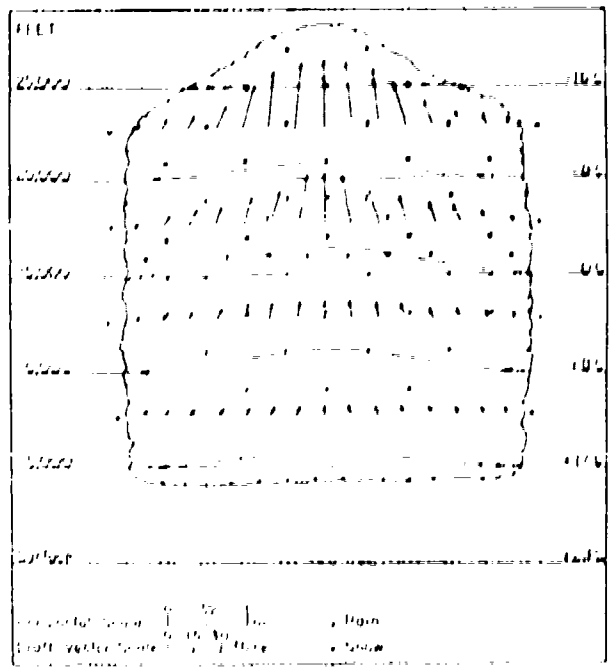

Figure 30-6 Idealized cross section through thunderstorm cell, cumulus stage

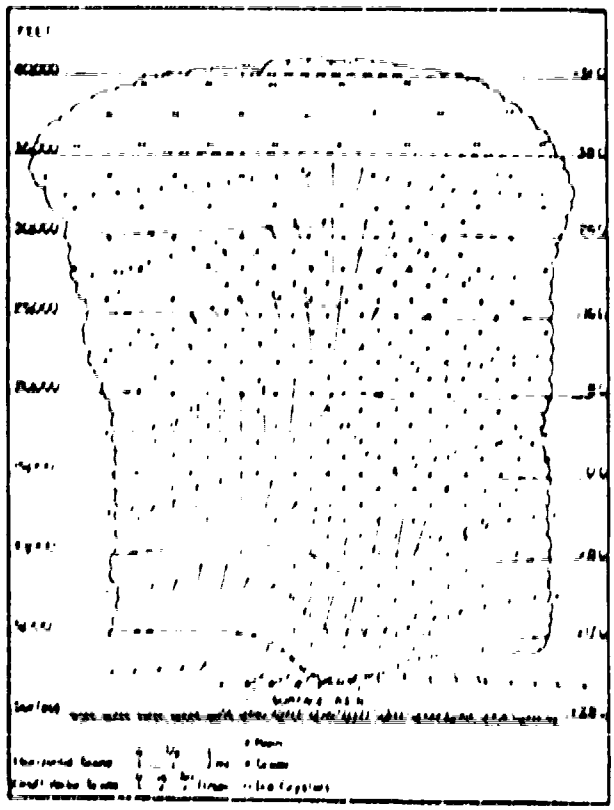

Figure 30-7. Idealized cross section through thunderstorm cell, middle of mature stage

that is, "bumps" or "jolts" rather than to the degree of roll or pitch induced. These accelerations vary with airspeed, virtually in direct proportion.

Lower gust speeds, 2 to 10 fps (feet per second), are far more frequent at all levels than those of higher velocity. Gusts in excess of 21 fps, however, have been found at all altitudes within thunderstorms.

WEATHER WITHIN THE THUNDERSTORM

Rain

On entering any thunderstorm, you may expect to encounter considerable quantities of liquid moisture which may not necessarily be falling rain. Liquid water in a storm may be ascending if it is encountered in a strong updraft; it may be suspended, seemingly without motion, in extremely heavy concentrations; or it may be falling to the ground. If it is falling, it is rain in the usual sense of the word. Rain, as normally measured by surface instruments, is associated with the downdraft. This does not preclude the possibility of your entering a cloud and being swamped, so to speak, even though rain has not been observed at the surface. Rain is found in almost every case of penetration of a fully developed thunderstorm below the freezing level. There have been instances in which no rain was reported, but in these the storm probably had not developed into the mature stage.

It has been found that the greatest turbulence in a thunderstorm is associated with the highest water concentrations. This relationship was found to hold at all levels within the storm. The association results from the fact that the gusts are largely induced by the drafts, and it is in the updraft that large quantities of water vapor are converted into liquid water. When the water falls to the ground as rain, it causes a vigorous downdraft to develop.

Hail

Information from all sources indicates that hail can be found in three different areas of a thunderstorm: in the precipitation area within the cloud; falling from the anvil or other overhanging cloud; or several miles from the cloud itself. No completely accurate method has been found for determining the presence of hail within a thunderstorm, nor has a completely satisfactory method of forecasting the occurrence of hail within a thunderstorm been developed. You should, therefore, be alert to the possibility of encountering hail in any thunderstorm.

Lightning

According to substantiated reports, lightning strokes occur in a very small percentage of thunderstorm penetrations. However, strokes may occur at any level, if conditions are favorable. Lightning is not dangerous to occupants of a metal aircraft except that it may damage the aircraft itself in rare cases. Magnetic compasses of aircraft which have been struck by lightning may be 20° to 30° in error.

Icing

Since ice requires temperatures at or below freezing, the icing level will lower with the freezing level. Inasmuch as the freezing level is also in the zone of greatest frequency of heavy turbulence and heavy rainfall, altitudes within a few thousand feet above or below the freezing level should be regarded as particularly hazardous. Winter, spring, and fall thunderstorms, though not so frequent, more often involve low-level icing.

First Gust

A significant surface hazard associated with thunderstorm activity is the rapid change in wind direction and speed immediately before thunderstorm passage. Strong winds at the surface accompanying thunderstorm passage are the result of the horizontal spreading-out (divergence) of the downdraft currents from within the storm as they approach the surface of the earth. The total wind speed is a result of the downdraft divergence plus the forward velocity of the storm cell. Thus, the speeds at the leading edge, as the storm approaches, are ordinarily far greater than those at the trailing edge, and the effect of the approach of a thunderstorm is to cause a sudden and marked increase in the surface winds at a station. This initial wind surge as observed at the surface is known as a "first gust." The speed of the first gust is normally the highest recorded during storm passage and may vary in direction as much as 180° from the surface wind direction which previously existed. First-grade speeds increase to an average of about 15 knots over prevailing speeds, although gusts with a total speed of more than 90 knots have been recorded.

Altimeter Errors

Rapid and marked surface pressure variations generally occur during the passage of a thunderstorm. The typical sequence of these variations is for an abrupt fall as the storm approaches, an abrupt rise accompanying the rain, and a gradual return to normal as the rain ceases. To you, the importance of such pressure fluctuations is that they may result in significant altitude errors if the altimeter setting you use is not current almost to the minute. Remember that any altimeter setting that you get during or immediately before a thunderstorm is highly unreliable.

Tornadoes and Waterspouts

As noted before, a tornado may occur in association with severe squall line conditions. A tornado is a violent whirlpool of air with an average diameter of about 250 yards. Within its funnel-shaped cloud, winds are estimated at 100 to more than 300 knots, making it the most violent of all storms. Not only is it small in area, but usually it wears itself out in an hour. Nobody has ever flown into a tornado and lived.

Waterspouts are much the same, but waterspouts occur over the ocean and contain much moisture whereas the tornado contains much dust and debris from the surface.

FLIGHT PROCEDURES

When you have been warned, either by the crash static in your earphones or by sight, that you are approaching a thunderstorm, you have an immediate decision to make. You must decide

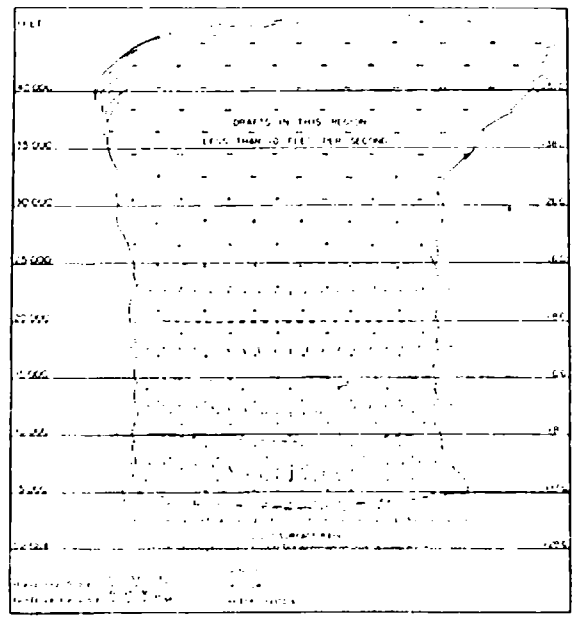

Figure 30-8. Idealized cross section through thunderstorm cell, dissipating stage

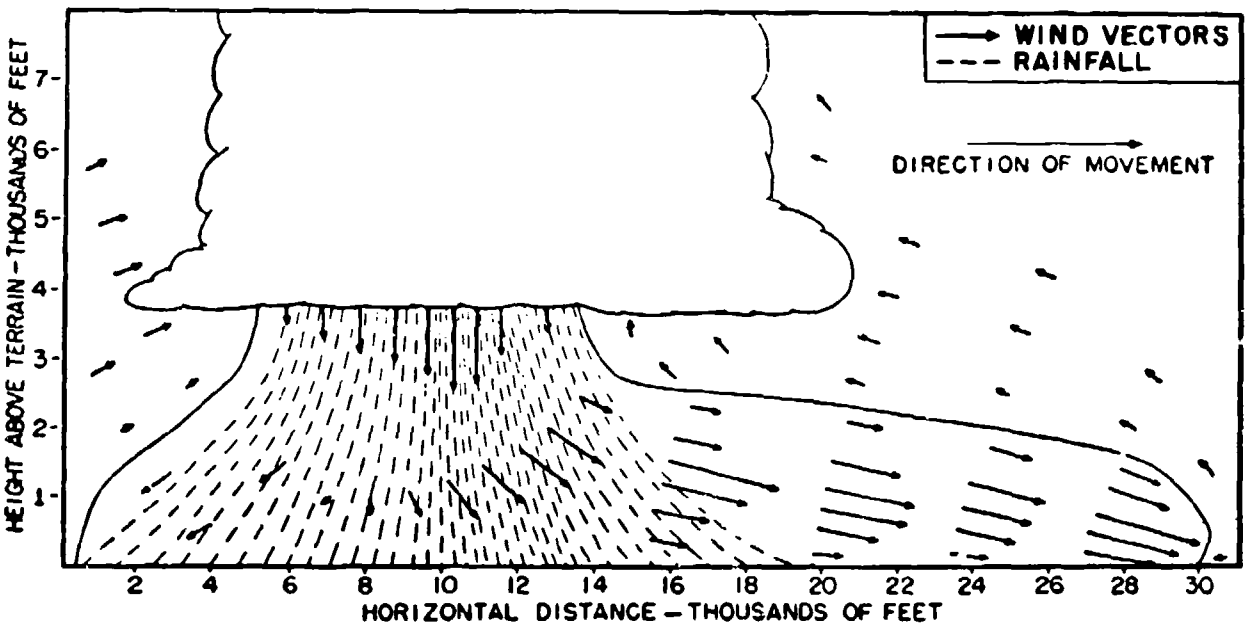

Figure 30–9. Cross-section through dome of cold air beneath thunderstorm cell, mature stage

whether it is possible to circumnavigate the storm or avoid it by going under or, if all routes are closed to you, whether your mission is important enough to warrant going through.

Avoiding the Storm

Circumnavigation. Circumnavigation presents no special flight problems. When you have decided that circumnavigation is possible (as is the case in isolated air-mass storms), you merely alter your course to go around. Since most thunderstorms are less than 50 miles across, a slight detour to one side or the other does not appreciably add to either the time or distance of the flight. In case of a line of thunderstorms, it is possible to circumnavigate by flying through "thin spots" between storm centers.

Over-the-top-flight. Over-the-top flight, which as few as 10 or 15 years ago was usually out of the question because of altitude and oxygen limitations, is performed more and more frequently as aircraft capabilities increase. It's a good way to avoid a storm if the airplane you're flying is capable of it.

Flying under the base. Whenever circumnavigation is impossible, flight can sometimes be made under the base of the storm, if it lies over the sea or flat open country. Never fly under the storm in mountainous areas unless there is a definite ceiling with good visibility underneath Quite frequently storms in mountains have their bases below and often around peaks.

Radar and thunderstorm flying. Radar is, without question, one of the best instrument aids to thunderstorm flying currently available. The regions of maximum turbulence and drafts coincide with the regions of high water content and, consequently, are within the area delineated by the radar echo. Radar is particularly useful for planning flights at higher altitudes, where there is considerably greater distance between convective centers than at low altitudes. In daylight these open areas might be visible, but they are not visible in darkness or in the presence of enshrouding cloud layers. In such cases, indications from the radar equipment should enable you to select a flight course which will completely avoid turbulent areas.

In the case of squall lines, it is possible to pick a route that will take the aircraft through the line in the least time and will result in encountering the least turbulence. Even in intense squall lines,

it is seldom that the cells are so close to one another that you could not find a flight path through it without having to detour excessively from your original flight plan. If your aircraft is equipped with a radar set having a reasonably long range and a PPI scope, you may observe the structure of the squall line while still many miles away and take action to plan your penetration or circumnavigation with a minimum loss of time.

Penetrating the Storm

When it is not possible to avoid the storm, you must decide whether your mission is urgent enough to require penetration. Once the decision is made, there should be no turning back. You must begin to prepare yourself and the aircraft for penetration of the storm.

Preparation for penetration. Since both the direction and altitude of the flight have to be maintained in the storm with reference to the gyro instruments, make sure before entering that they are set up and functioning properly.

To guard against the possibility of being temporarily blinded by the bright flash of lightning, turn on the cockpit lights full up. Turn the radio down or move the earphones forward to protect the ears against static. If the radio has become useless due to excessive amount of static, turn it off.

Speed of flight. Tests prove that the faster an aircraft is going when it strikes an updraft or downdraft, the greater will be the shock received from the draft. The pilot's handbook for each type of aircraft gives the correct range of speed for penetration. This gives a safe speed for penetration and still leaves a good margin above stall speed for maneuverability.

Icing. Since it is very likely that ice will be encountered in the pitot tube and in the carburetor, apply heat to both. When the mixture is placed in full rich, the aircraft is prepared for penetration.

Maintaining attitude. Once inside the storm, let the aircraft ride out the updrafts and downdrafts while you concentrate on maintaining a level attitude. Even if there is a possibility of being "blown out of the bottom of the cloud" attitude should be maintained in preference to altitude. As soon as the aircraft breaks clear of the clouds you should be able to control altitude with comparative ease.

Rules for safe penetration. Here are some procedures you should remember when entering a thunderstorm:

1. *The aircraft must be readied before penetration.* Slow down to the best penetration speed and constantly keep the aircraft prepared. Check instruments, lights, carburetor heat, de-icing and oxygen equipment, safety belts, mixture, rpm, manifold pressures, etc. Reel in the trailing antenna.

2. *Fly attitude.* Once in a storm, relatively level *attitude* must be maintained. Thunderstorms must be flown primarily with the gyro instruments and a constant power setting. Barometric instruments give false readings because of the rapid changes of pressure encountered in the storm. Concentrate principally on keeping a level attitude by the horizon indicator.

3. *Do not "chase" airspeed.* This will result in excessive attitudes, especially in high speed and heavy aircraft; and you can easily visualize the result of the nose being high and a sudden gust increasing the angle of attack to a stall! Use throttles only when the high or low airspeed limits are exceeded. Remember that heavy rain may slow down the indicated airspeed reading as much as 70 mph, because of partial blocking of the air entrance of the pitot tube. This may also cause erratic behavior of other pitot-static instruments such as altimeter and rate of climb.

4. If you are flying at night, turn the cockpit lights full bright to minimize the blinding effect of lightning. Maintain the original heading, which is the quickest way out. Do not make any turns unless absolutely necessary.

CHAPTER 31

PRESSURE PATTERN AND SINGLE HEADING FLIGHT

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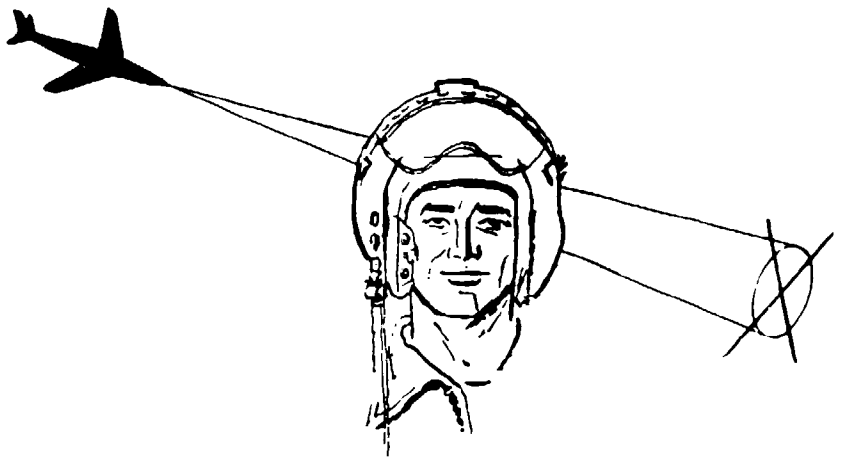


CHAPTER 31

PRESSURE-PATTERN AND SINGLE-HEADING FLIGHT

BOTH pressure-pattern flying and single-heading flying take advantage of formulas by which the amount of change of the height of a constant pressure level over a flight route determines the net amount of drift right or left of heading. This is based, in turn, on four principles:

1. The direction of the geostrophic wind (wind over about 3000 feet) is parallel to the isobars.

2. The force of the geostrophic wind is directly proportional to the pressure gradient (slope or change of height of the isobaric surface such as the 700 mb surface).

3. In northern latitudes, low pressure is always to the left and high pressure to the right of a person facing downwind (vice versa in south latitude).

4. The force of the geostrophic wind varies with latitude, being stronger at lower latitudes. Winds below latitude 20° are not geostrophic, and this procedure cannot be used. Winds above latitude 70° also do not follow the pattern of flow upon which this theory is based.

Pressure pattern flying involves planning of a flight to obtain the most favorable winds by flying around pressure systems as need be.

Single heading flight involves flight planning so that the net drift over a flight or a leg of a flight is computed to obtain a single true heading for the entire trip. This technique is also useful for aircraft with scanty navigation equipment and for

flight over areas of little aerological data except at departure and destination. It achieves time savings by tending to follow a pressure pattern route. It is sometimes called "Aerologation."

For best results, both of these methods of determination of flight route involve in-flight recomputation using the radar altimeter. For this reason, these methods used to be confined largely to transoceanic transport flights where specially trained navigators or navigator-pilots are carried. However, the range of modern jets and certain tactical aircraft plus the high wind factors at jet altitude now make it desirable to use these methods in flight planning in order to achieve maximum fuel economy and range. Of course, no tactical pilot normally has a radar altimeter or the time for in-flight observations. Thus, these procedures are limited to pre-flight planning except for patrol or transport aircraft. Insofar as in-flight observations using the radar altimeter are concerned, the procedures are limited to flights over oceans to obtain a sea level basis for measurements.

With aerological pressure level information, it is possible to make flight plans from forecast weather data which involve:

1. Selection of a route which offers maximum tailwinds so that there is a reduction in total flight time as compared to flight along the great circle route.

2. A net amount of drift over the whole trip (if desired) when a single true heading is used.

If a radar altimeter is provided, this same factual data permits:

1. Correcting the flight plan for changes in pressure levels.

2. Obtaining lines of position based on miles of right or left drift.

3. Estimating probable changes or movements of pressure systems to forecast future wind conditions and frontal location.

4. Providing valuable data concerning pressure levels by in-flight weather reports to forecasters.

These techniques have been proven by thousands of flights and have been shown to be accurate. Savings of time are particularly important since they provide more reserve fuel at destination, reduce costs of flight, and increase the amount of pay-load which a given number of aircraft can carry over a route.

PRESSURE-PATTERN FLIGHT

Pressure-pattern flight involves flight planning by selecting routes around pressure centers as much as possible, on a route which offers maximum tailwinds.

Flight-Planning—Conventional

The conventional method of flight planning for a long range flight differs little from planning a shorter flight. In the continental U. S. we use Lambert or polyconic projection (W. A. C. and Sectional) charts because radio beams and bearings and approximate great circle courses show as straight lines. Directional measurement and angular measurement on such charts, however, offer problems which become important when a

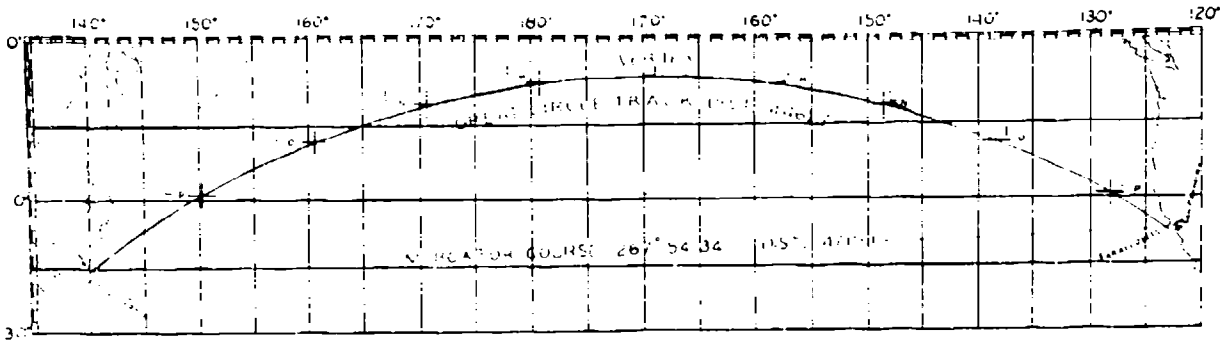


Figure 31-1. Great-circle track plotted on a Mercator chart

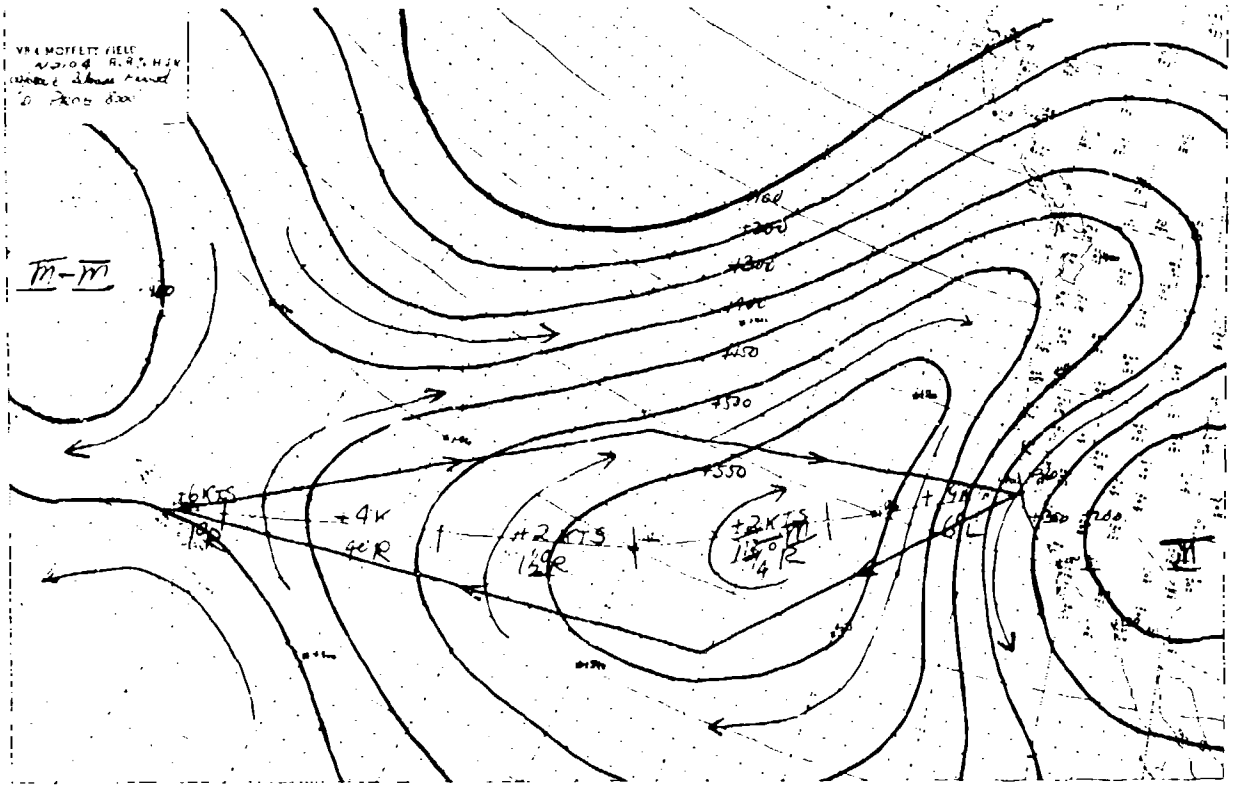


Figure 31–2. Pressure pattern flying

chart is used to plot celestial fixes and to measure drift and long distances. Therefore, the navigation chart for long range flights is usually a Mercator projection. If the flight is in tropical regions there is no problem, but at higher latitudes (above about 20° to 30°) you must consider rhumb line vs. great circle courses. A straight line on a Mercator chart between two points is useful for navigation because it intersects all latitude and longitude lines at the same angle. No heading changes are needed except to counteract drift. However, this route, called the rhumb line track, is not generally the shortest distance between the two points. On all courses in such latitudes except north-south, the great circle course, the straight line on a globe, is shorter. On a Mercator chart such a course appears as a curve (except where north-south) with the greatest curvature at the ends as shown in Figure 31-1. To fly this course, you would have to change heading gradually over the entire route.

In practice, therefore, the great circle course is plotted on a Gnomonic or great circle sailing chart and selected coordinates are taken and transposed to the Mercator navigation chart. The actual flight then becomes a series of rhumb line courses to approximate the great circle route. Since the great circle route takes time to determine and since most flights follow regular routes, air stations which are terminals for transoceanic flights have predetermined the great circle courses to all regular destinations to which the great circle route offers distance savings. The navigator plots this route on his chart, usually in terms of rhumb lines across every 5° longitude. With this route, he takes forecast winds and plans his flight between each 5° turning point as if it were a cross country flight at which those were reporting points on the airways. If the great circle route offers no appreciable savings, or if traffic control requires specified routes, the flight is nevertheless broken into legs of about 5° longitude or 300 miles, as con-

venient, and forecast winds established in each leg. Ground speed in each leg, distance over each leg, and fuel consumption are all calculated to determine en route time and required fuel. Often this is done for two or three altitudes to determine the best level.

Flight Planning—Pressure Pattern

Pressure pattern flight planning introduces one new element, the upper air maps. After the rhumb line and great circle route are known, the navigator knows that any course between the two will at least not be longer than the rhumb line. Any course near these is not excessively longer. He looks at the constant pressure charts to see if it is possible to fly around any pressure systems between A and B. Figure 31-2 shows a typical situation. An eastbound flight from Honolulu to San Francisco can pick up tailwinds going north of the High; a westbound trip by flying south of it. The track shown through the High passes over an ocean-station vessel.

In this case, the navigator calculates flight time to the turning point selected. Since he may try several alternate routes, this may take time. He should also look at the weather maps for various levels to select an altitude at which winds are best. Comparison of gross flight times will tell him whether the extra distance involved justifies deviation from the rhumb line or great circle route. In some cases, the helpful winds obtained will justify the longer route; in others they will not.

Even this calculation, however, is so time-consuming and so hard for the inexperienced, that most major international flight terminals have done this for the pilots in advance. They select a few of several "standard" courses at various levels which appear to offer help to outbound trans-oceanic flights, and precompute flight time based on an average airspeed to find out the best route. They then offer the pilot either the great circle, rhumb line, or best pressure pattern flight route. Thus, to select his route, the pilot or navigator needs only to check their calculations, using the airspeed of his own aircraft. Since that terminal may have twelve or more outbound flights during the six-hour weather forecast period, all going to one or two regular destinations, such procedure is routine and time-saving. Make it a rule, however, not to accept course and distance data on legs of a flight based on computation by operations personnel without cross-checking it for accuracy. Even more important, if they compute speeds and times, recheck them for errors.

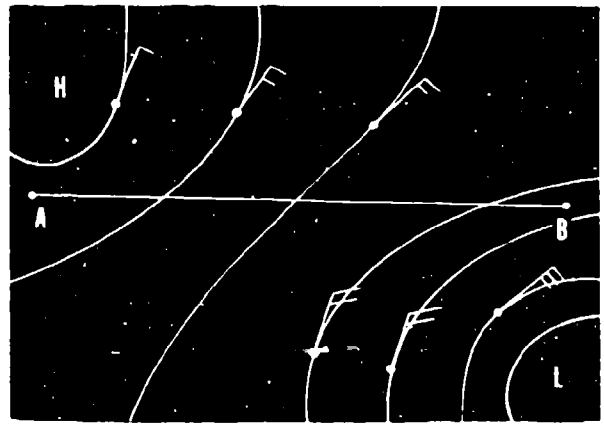


Figure 31-3. Flight from high to low pressure always introduces right drift in northern latitudes

Pressure-Pattern Flight

After selection of a favorable route, the actual flight begins. Since any pressure pattern route which does not follow the rhumb line or great circle means greater distance, it is important that the weather forecast hold up if that route is followed. Even in bad weather, if the radar altimeter is carried, drift and pressure lines of position can be obtained as positive checks on position and forecast wind. More important, however, the pressure height readings permit construction of the actual upper level chart for flight altitude. By comparison of these pressure readings, the forecast chart for that level may be corrected in flight for errors. Thus, you have a check on actual past conditions and a corrected map for future conditions to help keep track of the route to be sure headwinds will not destroy the anticipated time saving. If things go bad, you know how to alter course to obtain benefits of the revised pressure pattern.

The in-flight determination of pressure, drift, and position by use of the radar altimeter is dis-

cussed later in the chapter because these techniques are used in both pressure pattern and single heading flights.

SINGLE-HEADING FLIGHT

Ignoring variation changes for the moment, if you knew the total drift in miles or in degrees between points A and B, you could select a single heading for the entire route. You know that above 3,000 feet the wind blows parallel to isobars. Therefore, if you fly across three isobars, whether they are close together or far apart, that wind will blow you the same number of miles off heading. This is because the force of this wind is directly proportional to the pressure gradient (the amount of pressure change between A and B) at the same latitude. If you knew the latitude factor and the pressure change, you could calculate the total drift. The direction of the drift is determined by whether you are going from high to low pressure, or vice versa. Since low pressure is to the left in north latitudes when facing down wind, a flight from high pressure to low pressure involves wind from the left which would give right drift. (See Figure 31-3.)

This effect of wind has a ground speed component and a vertical, or track, component. The vertical component is determined by total pressure change and latitude. There is a formula for determining this vertical drift factor which can be

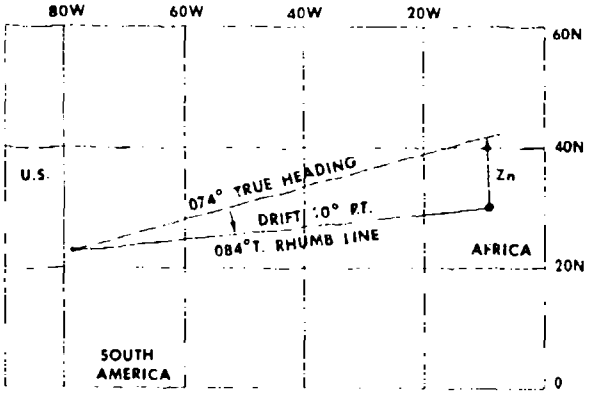
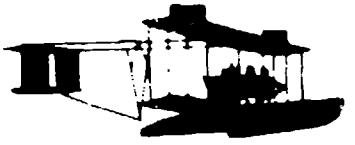


Figure 31-4. Plot Zn vector to find true heading line



used any time the pressure heights at two points are known accurately. Tests show that it gives a more accurate answer than calculating drift in various legs of a flight from forecast winds to establish a heading suitable for an entire trip. The formula is used both for flight planning and for en route calculations.

Flight Planning—Single Heading

Single heading flight planning does not require a radar altimeter. Instead, pressure height data is obtained from Aerology, and the isohypes on the constant pressure charts are used to obtain heights at origin and destination for the desired pressure level.

The formula used in single heading flight planning is the same as the one used for lines of position (discussed later); it is similar to the one used to establish drift in flight:

$$Zn = \frac{K(D2 - D1)}{TAS}$$

in which:

Zn: the net effect of the geostrophic wind at right angles to the true heading of the aircraft, expressed in nautical miles. On a long flight, no significant error occurs if it is measured at right angles to the rhumb line course.

K: a constant factor for latitude. This is the result of division of 21.47 by the sine of the mid-latitude of the flight (or flight leg). Since you do not carry tables of trigonometric functions in flight, use the table for "K" shown here. This "K" value is used in all formulas in this chapter. It allows for those variations in force of the geostrophic wind which occur as a result of latitude.

D1: the height in feet above sea level of the selected pressure level (flight altitude) over point of departure (forecast for time of take-off when possible).

D2: the height of the same pressure level at destination, forecast for estimated time of arrival. D2 −D1 gives the pressure gradient between point of take-off and destination.

TAS: mean True Air Speed expected for flight.

Table of "K" Values for Altimetry Formulas

Mid-Lat.	K	Mid-Lat.	K	Mid-Lat.	K	Mid-Lat.	K
15°	44	30°	43	42°	32	54°	26.5
20°	43	32°	43.5	44	30	56°	25
22°	42	34°	38	46°	29	58°	24
24°	41	36°	36.5	48°	28	60°	23
26°	40	38°	35	50°	27	62°	22.5
28°	40	40°	33	52°	27	64°	23

Determining True Heading. A simple and accurate way to find true heading is to plot the Zn value on the navigation chart as a vector at destination (Fig. 31-4). If the Zn value is negative, drift is right because you are flying from high to low pressure. Remember, you drift *from* heading *to* track. So plot the Zn vector left of the rhumb line course (if drift is right) to locate the heading line. If Zn is positive, drift is left. (These examples are for north latitude; in south latitude, minus Zn value is left drift). Whether Zn is negative or positive depends on whether D1 or D2 is the greater, and this, in turn, depends on whether pressure levels increase or decrease between points D1 and D2.

Another way to determine the heading involves determination of the drift angle by the off-course formula (Chapter 10) on the computer.

$$\text{Drift angle} = \frac{Zn \times 60}{\text{Distance (Rhumb line, naut. mi.)}}$$

This is based on the fact that 1° drift takes you off course 1 mile for every 60 miles traveled. Set Zn on the outer computer scale against total distance on the inner scale, and read off the angle opposite the speed index (60) of the inner scale.

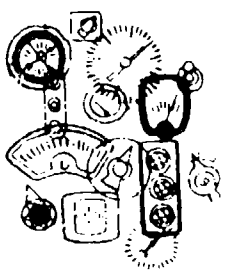
Drift-Correction Angle. The drift correction angle determined by this method will not be exact if the distance is greater than 600 miles. With distances over 600 miles, a small error is introduced because plane trigonometry is being used to solve a spherical triangle. This error is negligible, however, since the angles involved are very small.

You use forecast information for the determination of a constant drift correction angle; however, you use just two forecast values—height of the isobaric surface at each end of the flight—instead of the many forecast winds en route. This reduces the possibility of error. Besides, the heights of the pressure level can be determined with greater ease and forecast with more accuracy than is possible in forecasting winds.

Determining the (D2 D1) value by this method requires the use of constant pressure upper-air charts. If upper-air charts are not available, the navigator or aerologist will have to extrapolate surface pressures to the desired flight level and then convert these flight level pressures to heights. Even with upper-air charts, the desired flight level will seldom coincide with the upper-air charts, and the navigator must interpolate the heights given by the various charts to his selected level.

Ordinarily, the computed drift correction angle is applied to the rhumb line course, and the navigator has a constant true heading for the entire route. If desired, the computed drift correction angle can be applied to the separate rhumb line chords that make up the great circle course. In both cases, the drift corrections used are constant.

Bad Weather Procedure. It is possible that under certain circumstances the aircraft might be drifted into areas of bad flying weather. This is the case when a low pressure area is located on course between departure and destination and the aircraft is eastbound. The best flying weather is north of the low pressure center, but the mini-



new drift correction would allow the aircraft to drift south into the frontal zones. In this case, time saving would have to be sacrificed to avoid the poor flying weather, and the flight would be planned to keep the aircraft north of the pressure center. To do this the navigator would pick a turning point, north of the center, solve first for a constant correction to this point, then solve for another constant correction from this point to the destination. This requires careful analysis of the synoptic and forecast weather maps before planning the flight, and a continuous check of existing weather conditions during the flight in order to avoid serious weather. Good judgment cannot be replaced by any device or procedure.

Flight Procedure

During the flight, the navigator must keep a constant check on the sea-level pressure or flight-level pressure at the destination. If the forecast height of the isobaric surface appears to be in error, then an adjustment of the constant drift correction angle is indicated. This requires the solution of a new problem from a known position (fix) to the destination. The navigator must extrapolate the radioed sea level pressure of destination to his true altitude, and then convert this pressure to height. He then computes a new drift correction angle as explained later, and a new true heading flown. The navigator should obtain the sea level pressure and temperatures at surface and flight level from the destination every hour. These should be carefully compared to the forecast pressures to make certain that the forecast pressure will be accurate. If the navigator does his work carefully and seriously, the aircraft will be delivered to within a very small distance of the desired destination. The pilot must also work continually to hold the headings given by the navigator. Steering errors can put the aircraft many miles from the destination.

Tests made on more than one hundred flights using the constant drift correction show that ninety percent of the flights arrived within fifteen miles of destination, and fifty percent of these flights were within ten miles of destination. Considering that the average distance flown was 1,500 nautical miles and that most of these flights were made by use of a single true heading, the safety value of the system is apparent.

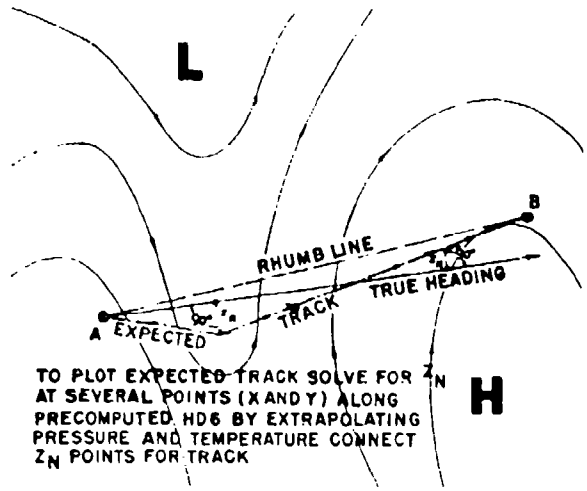


Figure 31–5. Determination of expected track

To see the expected track and to determine the distance to be traversed on this aerologation route, it is necessary to compute several Zn vectors before the flight. For practical purposes, these Zn values need be computed only for the wind shift points en route. These wind shift points are located at low pressure troughs and high pressure ridges on the upper-air charts. By plotting the Zn vectors in the proper direction from the precomputed heading line and connecting these points with a line from departure through the end of the Zn vectors and destination, the expected track is shown. Figure 31-5 shows the determination of the expected track. A comparison of this track with the upper-air charts will show whether or not the aircraft will drift into bad weather areas.

The theory of navigation by altimetry can be expanded still further to determine the expected ground speeds en route. This is the final step that makes the forecast winds unnecessary for flight planning. However, this technique should not be undertaken until considerable transocean navigation experience is gained. See *Aerologation*, NAVAER 50-IP-516.

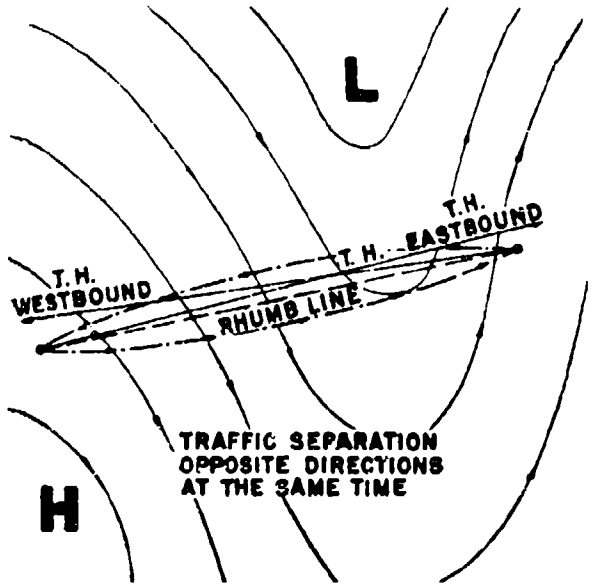


Figure 31–6. Traffic separation on single-heading flight

Traffic Separation

Another advantage of the aerologation route (single drift correction route) is apparent when the problem of traffic separation is considered. If all aircraft flying in opposite directions between two points are maintaining a great circle or rhumb line track, the only separation possible is a vertical clearance. Errors in adjusting the altimeter to the proper altimeter setting might jeopardize the safety of several aircraft. On the other hand, if they are following a single heading track, a horizontal as well as a vertical separation is usually provided. Figure 31-6 shows how this is possible while each aircraft has the most desirable route. In this illustration it is assumed that there is but one pressure system between departure and destination. If there were two pressure systems en route, the paths of the aircraft would usually coincide at just one point.

Flight Application

Application of the formula for single heading flight is very useful; as noted before, however, it is important to keep track of position throughout the trip and to keep checking pressure heights (or surface pressure) at destination with the forecast value. If the aircraft carries a radar altimeter, it is possible to recompute from any convenient point to destination, as explained later. The radar altimeter also permits drift checks, lines of position parallel to heading, and reconstruction of the weather map. Each of these procedures is explained later in this chapter.

Nevertheless, single heading flight can be used for planning long flights by jet aircraft and other aircraft not equipped with radar altimeters. In this case, the pilot must plot the probable track and alter heading if navigation shows he has left it by any great amount. He may also recompute the total drift between departure and destination as the pressure at the terminal changes from forecast. For example, if he finds that the formula which gave drift 7° L. (with the original terminal forecast pressure and actual departure pressure) now gives 9° L., he can compute what fraction of the trip remains and alter course. If he has gone half-way, a heading allowing for 11° L. during the second half should offset his having flown on the basis of only 7° L. during the first half. This method is not so good as following conventional navigational data, but may be all there is, especially for a jet.

One other thing should be noted. Flight planning for single heading flight may be done for any flight, whether over land or water, because the flight planning data comes from aerological pressure heights, and no radar altimeter is needed for the flight planning stage. This is particularly interesting for jets which often fly direct in the U. S. instead of by airways.

Since the jet aircraft often has little navigation equipment except a direction finder, the use of single heading flight planning is valuable, for it eliminates a number of heading changes and offers a reasonably accurate way of reaching destinations with minimum fuel consumption. In the case of larger aircraft which have a radar altimeter, however, the use of that equipment is most helpful.

In-Flight Use of Altimeter

Altimetry is a name sometimes given to navigation by use of a radar altimeter and a pressure altimeter. Since the pressure altimeter can be used to measure the pressure level by relation to

pressure altitude and since the radar altimeter provides absolute altitude, it is possible to obtain pressure gradient information when flying over the ocean by comparing the difference in the readings of these two altimeters at two different locations. Since pressure gradient determines drift at a given latitude, regardless of distance between the pressure readings, this provides an accurate navigation aid which is not affected by weather. Data is obtained regardless of visibility and without surface radio or other aids.

Three items of information are obtained by this method: (1) drift measured at right angles to heading (which does no., by itself, give wind or groundspeed), (2) pressure lines of position (PLOP) parallel to heading, and (3) data for reconstruction of the constant pressure level weather map at flight altitude. Whether the flight is planned by conventional methods, pressure pattern flying, or by single heading flight, this data is available in flight if a radar altimeter is aboard.

Variations in Pressure and Temperature

The standard atmosphere is 1013.2 mb surface pressure at a surface temperature of 15° C and a standard lapse rate. Pressure altimeters are calibrated to the standard atmosphere. Actually, though, surface pressures and temperatures vary considerably as a result of unequal heating and are constantly changing. Furthermore, a uniform lapse rate does not exist aloft. These departures from standard affect the height of a column of air in several ways.

Consider four columns of air. Figure 31-7 provides a representative picture of atmosphere under standard conditions. In this figure, you find the 700 mb pressure surface located at an altitude of exactly 9,880 feet above sea level. (The 850, 500, 300 mb or any other pressure surface could have been used; under standard conditions they are at 4,780, 18,280, and 30,060 feet respectively.) Such a pressure surface is commonly referred to as an isobaric surface.

Now consider actual conditions in the atmosphere. Variations in surface pressure and density of the air (due to temperature variations) will deform the shape of an isobaric surface so that it will appear as in Figure 31-8.

Slope of Isobaric Surfaces

When the height of an isobaric surface departs from standard as indicated in figure 31-8, horizontal wind flow begins. As a matter of fact, the flow of the wind is determined by the slope of the isobaric surface. As the slope increases, the wind flow increases proportionately.

The pressure altimeter records only standard atmospheric conditions. The altitude at any given instant (instrument being set at standard sea level pressure of 29.92 inches) is called the pressure altitude. This is the altitude at which the instrument would be if standard atmospheric conditions prevailed.

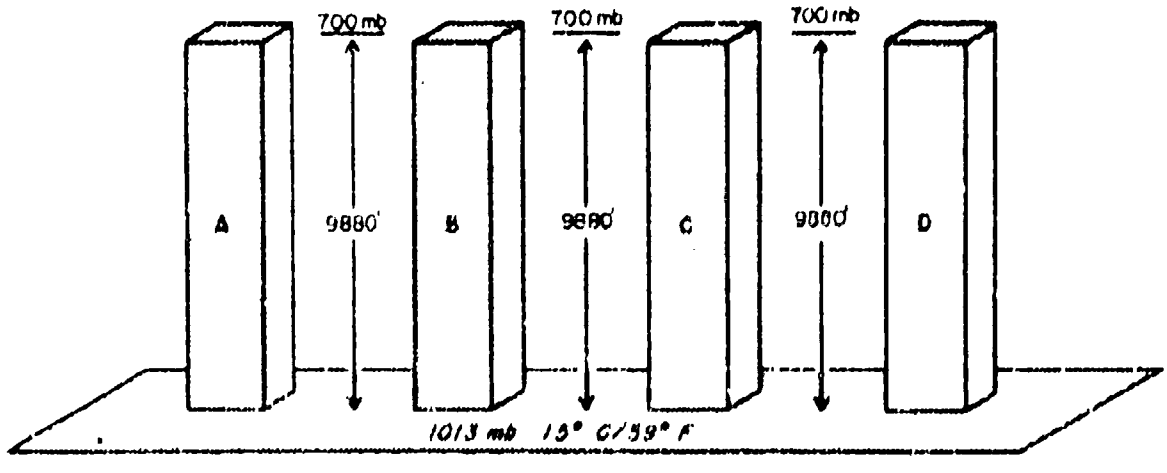


Figure 31-7. Standard atmosphere

The radar altimeter, however, gives actual altitude above the water. The difference between the reading of the radar altimeter and that of the pressure altimeter at a given instant (with corrections applied) represents the departure in feet from the standard height of the pressure surface at that particular time and location. Thus, the navigator, by taking simultaneous readings at given intervals, can determine the slope of the isobaric surface at flight level along his track.

Determination of Drift

Earlier in this chapter, you found how to compute drift by formula on the basis of the comparative heights of pressure levels at two airports. The answer (Zn) was in miles of drift perpendicular to the true heading line. You can do the same thing in flight except with the values of D2 and D1 being the difference between the corrected readings of the two types of altimeter (radar or absolute altitude minus pressure altitude) when observed at two points, D2 at the end of a run and D1 at the beginning. However, this would give miles of drift; to find the drift angle or other value you could use on the computer, you would have to make further correction for the time elapsed between the observations at D1 and D2. It is easier to modify the formula for time as follows. To get a one hour value for Zn, you would divide Zn by elapsed time in hours (or fractions). Thus, if

$$Vn = \frac{Zn}{\text{Time in hours}}$$

$$Vn = \frac{Zn}{\text{Time}} = \frac{K(D2 - D1)}{TAS \times \text{Time}}$$

Now assume that $X = TAS \times \text{Time in Hours}$. Then:

$$Vn = \frac{K(D2 - D1)}{X}$$

This is the final drift factor formula with the following values.

Vn is the average wind component in knots perpendicular to the true heading.

D is the difference between the readings of the radar and pressure altimeters with the latter set at 29.92 inches. (Temperature and other corrections must be applied to the indicated pressure altitude.)

D2 is the difference at the end of a run.

D1 is the difference at the beginning of a run.

X is the distance in nautical miles traveled on the TAS between first and second observation multiplied by the time in hours, or fraction of an hour. The recommended time between observations (D2 and D1) is not less than 30 minutes.

K is a factor which depends upon the latitude, the value being taken from the table on page 31-6 for the midlatitude between readings D1 and D2.

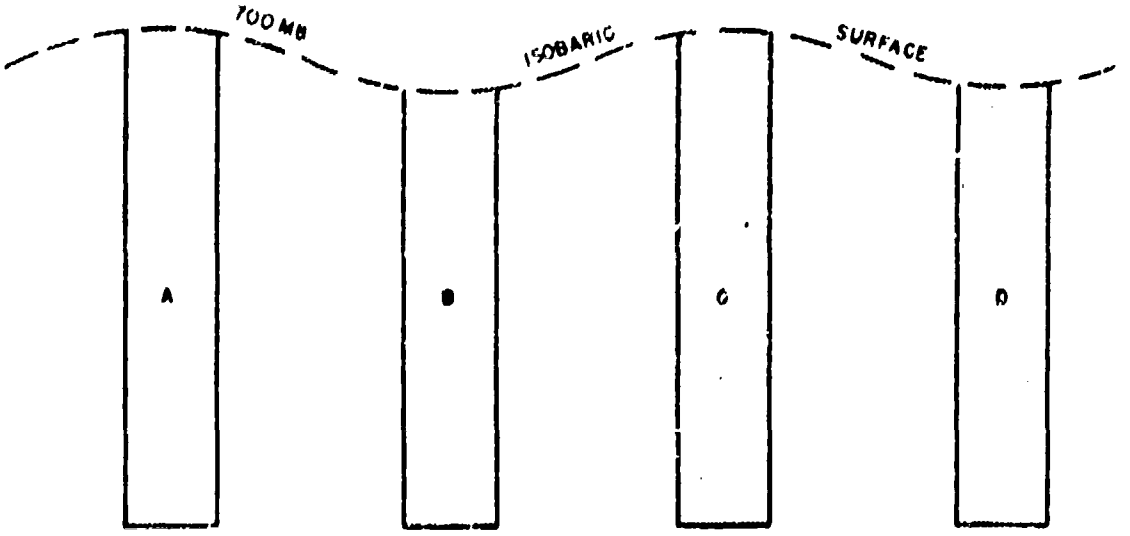


Figure 31-8. Isobaric surface

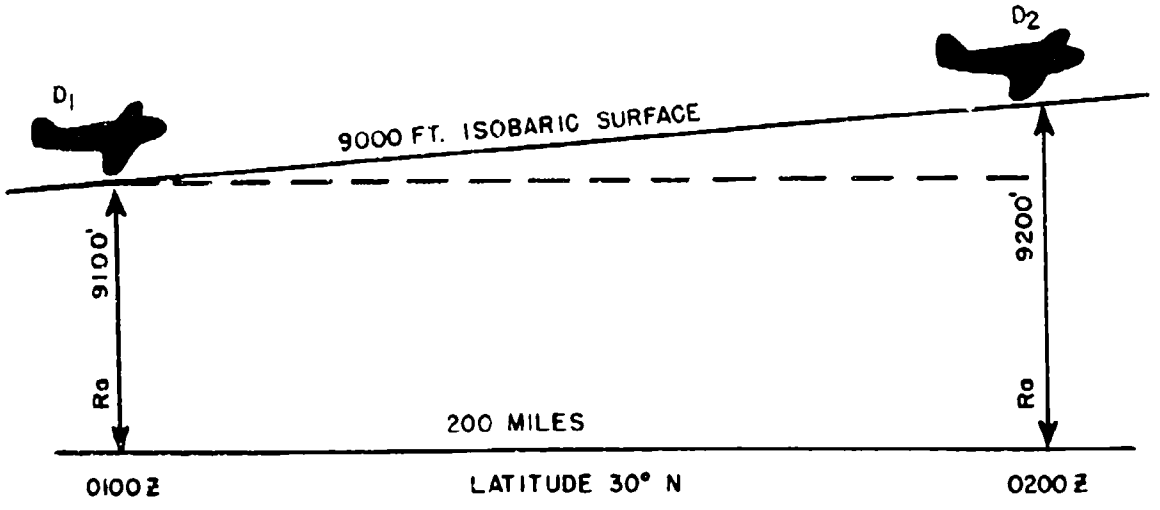


Figure 31-9. Example of isobaric slope for values of D_1 and D_2

Varying surface pressure or mean virtual temperature varies the height of a given isobaric surface as shown in Figure 31-8. These changes bulge the isobaric surface upward over high pressure cells and cause it to sag downward over low pressure areas. If a bird's-eye view of such a surface were possible, it would appear as a vast plain, gently to moderately rolling. A pilot flying a constant altitude by reference to his pressure altimeter (set at 29.92 inches) is in reality flying at a constant pressure altitude on an isobaric surface. Because of the constant pressure altitude, the aircraft rides up and down the undulations of the isobaric surface somewhat as a boat rides long, gentle swells. (As shown later, this is actually an exaggerated example, but for the present serves the purpose.) Since the navigator has a radar altimeter at his disposal, he may note increases and decreases in true altitude. Since he can measure absolute height above sea level (over the ocean), he can determine the slope of the isobaric surface.

As an example, assume that the aircraft shown in Figure 31-9 has been cleared to maintain 9,000 feet. Although the pilot maintains, 9,000 feet indicated from D1 to D2, his absolute altitude increases from 9,100 feet at D1 to 9,200 at D2. This means the slope of the isobaric surface is 100 feet in 200 miles. Substituting these figures into the basic formula, the wind component acting at right angles to the course heading can now be determined.

$$Vn = \frac{K(D2 - D1)}{X}$$

K = 43 (tabular value for lat. 30°)
D2 = 9,200 − 9,000 = 200
D1 = 9,100 − 9,000 = 100
X = 200 × 1 = 200

Substituting:

$$Vn = \frac{43(200 - 100)}{100}$$

$$= \frac{43 \times 1}{2}$$

$$= 21.5 \text{ kts}$$

By plotting this wind component corrected for lapsed time at right angles to the true heading as shown in Figure 31-10, you can measure the drift angle by means of a plotter. If a plotting board is used, the drift angle can be read directly from the plotting board.

The next step is determining the direction of drift. You know that the isobaric surface bulges upward over "highs" and sags downward over "lows." You know also that wind circulation in north latitudes is clockwise around the former and

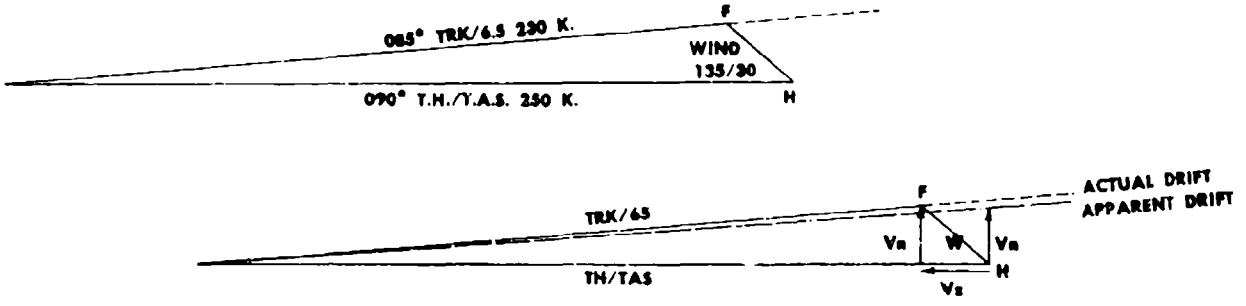


Figure 31-10. The drift angle shown by Vn drawn from the TH line when ground speed is unknown is the apparent drift

counterclockwise around the latter. Therefore, when true altitude is increasing, you are approaching an area of higher pressure; conversely, when true altitude is decreasing, you are approaching an area of lower pressure (pressure altitude remaining constant). Consequently, in the Northern Hemisphere, increasing true altitude results in left drift, decreasing altitude result in right drift, as you can see in Figure 31-11.

In this illustration, if the aircraft proceeds from W to X, true altitude decreases from 10,300 to 10,100 feet. By rule of thumb and by inspection of Figure 31-11, you see that drift must be to the right. From X to Y, true altitude increases from 10,100 feet to 10,400 feet; drift must be to the left. As the aircraft proceeds from Y to Z, altitude decreases from 10,400 to 10,200 feet and drift must again be to the right. In the problem shown in Figure 31-9, however, the true altitude was increasing and drift, therefore, was to the left.

By using the Navy's drift angle computer, drift angle may be computed without mathematical computation. Drift also may be determined by use of the Navigation Computer. Just set up the true heading, swing the rotatable inner grid 90° to left or right corresponding to direction of drift, and plot Vn as though it were the wind. After rotating the scale back to the true heading once again and placing TAS at the grommet, you can read degrees of drift at the outer end of the arrow. When you plot a wind on the computer to obtain drift, the wind is broken into two components, track and drift. The drift component is Vn. Solving for Vn graphically, by use of the computer, you obtain a drift of approximately $6\frac{1}{2}°$. Since the true altitude was increasing, the drift was to the left.

If you hold a constant pressure altitude, you can note any change in drift in an instant. If true altitude remains constant, no drift exists. If it is increasing, drift is to the left; if it is decreasing, drift is right. Change can be detected almost immediately. It also follows that where true altitude decreases, D2 − D1 gives a negative result and Vn becomes negative. Therefore, if Vn is negative, drift is right in the Northern Hemisphere (left in the Southern, of course).

Of course, drift determined by use of TAS is the *apparent drift*. If some accurate means of determining the distance on track covered between the D1 and D2 readings (in other words, ground speed) is available, use this total actual distance as X in the formula; then drawing Vn at right angles to heading will locate the actual wind point at the distance from D1 to D2. In this case, the drift is actual. In the usual case, however, the X value in the formula must be TAS × Time because ground speed is not known with accuracy. Therefore, the drift normally found by Vn is apparent drift.

Pressure Line of Position (PLOP)

In the formula just used, Vn is an amount measured in knots, that is to say, nautical miles per hour. It is, therefore, a one-hour vec-

tor. Zn from the first formula is the amount measured in nautical miles during the total time between the pressure level (altimeter) readings:

$$Zn = \frac{K(D2 - D1)}{TAS}$$

The navigator plots this on his chart as follows (Fig. 31-12):

1. Locate position at time of D1 reading (preferably the reading should be taken near to time of a good fix).

2. Draw in a line for true heading projected to the time of the D2 observation (and airport).

3. Measure Zn right or left of the heading line. (Remember, if Zn is negative, drift is right in northern hemispheres, and vice versa.)

4. Draw a line of position (PLOP) parallel to true heading passing through the end of the Zn vector measurement.

5. If a speed line, such as a sun line or other LOP lying across track, can be obtained near the time of D2 and advanced or retarded to the time of D2, then a fix may be obtained.

The accuracy of a PLOP depends on the accuracy of the airplot. If started from a good fix, the airplot and the resultant PLOP will be as accurate as a celestial line of position (LOP). If computed from a poor fix or a D. R. position, it is no more accurate than the location of the point of origin, though the amount of drift is nevertheless correct.

It is possible to run the airplot (TH extended for TAS times Time) forward through a change of heading. For example, figure 31-13 shows a flight which altered course 10° at 1620Z. Altimeter readings were taken at the last fix, 1500Z, and again at 1700Z. The 1700Z PLOP is determined from the net TAS and TH—that is, from the dashed line connecting the 1500 position and the 1700 air position. So long as the 1700 air position from the airplot is accurately determined, it would not matter if the aircraft zig-zagged all the way between the 1500 and 1700 readings. Thus, if an aircraft is equipped with an air position indicator (API) which keeps

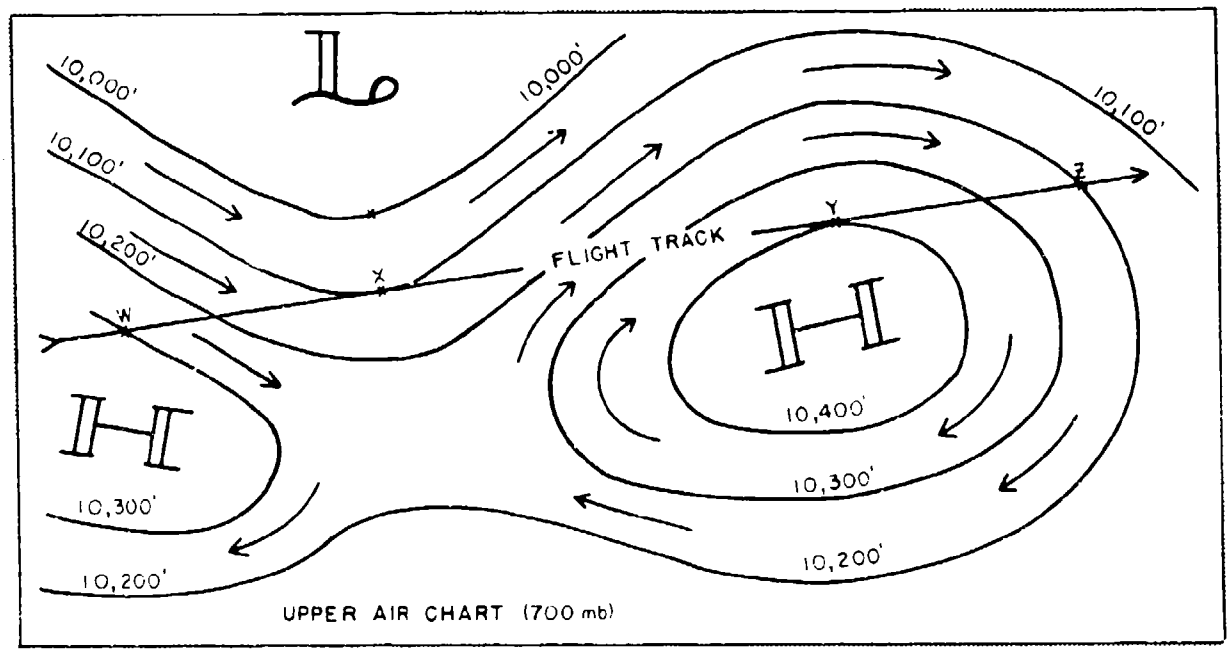


Figure 31-11. True altitude and drift

track of air position from a starting point, the readings from that indicator can be used.

Since the accuracy of the PLOP depends on the accuracy of the airplot, errors in heading and airspeed which cause the airplot to be inaccurate are cumulative. Therefore, it is not recommended that a PLOP be obtained from an airplot more than 3 hours in duration. This rule also applies to determination of drift from TH and TAS data.

Flight Procedures

The pilot and navigator both contribute to the accuracy of all navigation by altimeter. Heading and airspeed must be accurately maintained. An averge error of 1° in heading will cause a 1-mile error in every 60 miles of flight. A 10K error in airspeed will cause an error in Zn or Vn of about 1 mile in every hour of flight in a typical instance with a 200-knot TAS. Some such errors may be beyond control during flight, depending on errors in the heading indicator or airspeed indicator.

The aircraft should be flown at all times within 200 feet of the proper pressure altitude. The navigator must read the altimeter and airspeed frequently, as in any navigation work, to obtain a good average. Correction of indicated pressure altitude for temperature is important. The radar altimeter must be properly calibrated and readings made within 10 feet. The readings of the pressure altimeter must be simultaneous with those of the radar altimeter if possible and both be accurate within 10 feet. The pilot tries to fly a good average altitude, but the navigator reads the precise instant altitude for his calculations though the altitude at the instant selected should be about average. Minor errors in headings and readings become less important if the time between altimeter readings for D1 and D2 is not less than 30 minutes, but 20 minutes may be accepted as an absolute minimum time interval.

Since readings are easy to obtain and the formula is simple to use, it is recommended that several readings of the D values be taken to obtain drift or PLOP's. Frequent readings of the D value also are useful for reconstruction of the constant pressure chart in flight.

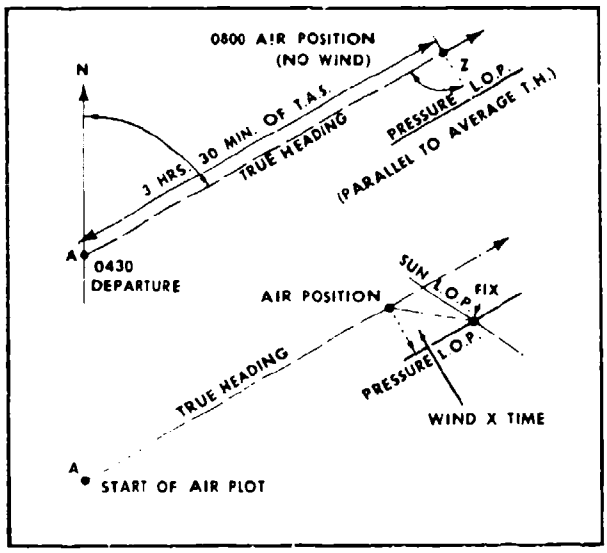


Figure 31-12. Plotting a pressure line of position

RECONSTRUCTION OF UPPER AIR CHART

The radar altimeter is probably most useful in determination of drift and reconstruction of upper air charts when unanticipated winds or weather are encountered. As an example, look at the Fleet Logistics Air Wing "D" Chart (Fig. 31-14). En route time for all flights between Alameda, California, and Honolulu, Hawaii, is computed from such "D" charts. ("D", you remember, is the difference between the heights as determined from the pressure and radio altimeters.) By forecasting "D" for the area between the West Coast and Honolulu, Fleet Logistic Air Wing aerologists determine the slope of the isobaric surface at flight level; this slope defines the wind at flight level.

One of the three authorized tracks appears superimposed on the chart. Wind flow is parallel to lines of equal "D" (isohypes, in effect). "D" lines from the forecast are solid lines in Figure 31-14. By inspection, you can find zones of left and right drift. If "D" values decrease, drift is right; if they increase, drift is left. If drift encountered is considerably different than expected, the navigator can reconstruct the "D" chart (west-bound) or the 700 mb chart (east-bound).

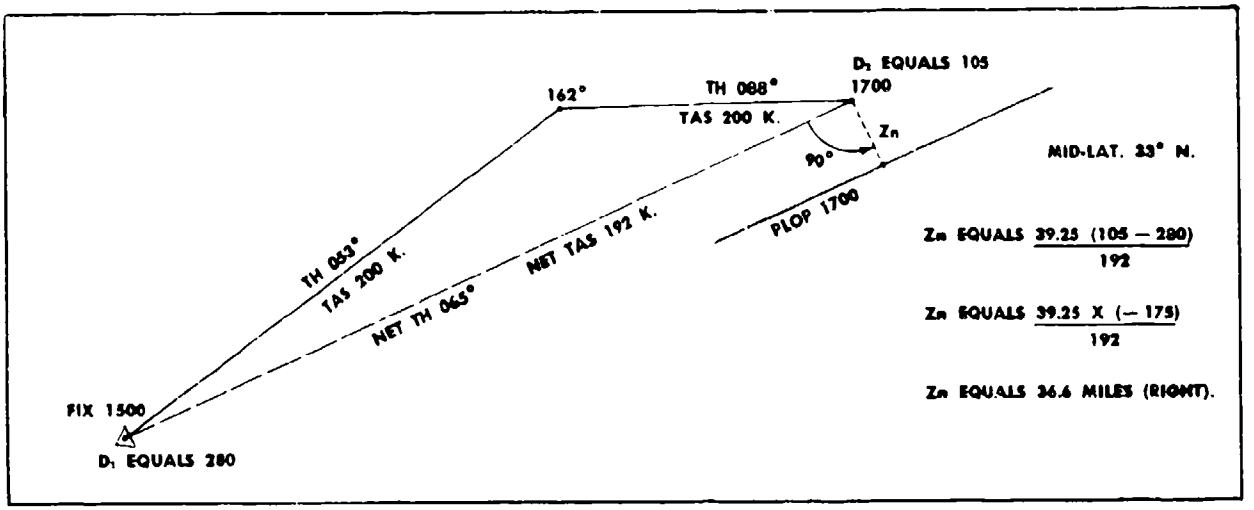


Figure 31–13. PLOP when heading was changed between D1 and D2

Reconstruction of the "D" chart has been done here, as shown by the dashed lines. Reconstruction of the "D" chart merely requires plotting the "D" values observed along the track. After the values are plotted, little imagination is required to draw new lines of equal "D," even in advance of the flight—and thus obtain the actual wind condition at flight level. The numbers appearing on the track represent the observed absolute altitude above sea level less the pressure altitude at each such point (the "D" values). Alameda, the point of departure, is off the right side of the chart. In other words, the (D2–D1) part of the formula is readily available to the navigator for recomputing drift between any points en route. X, the distance travelled, can be computed for the time in question. K may be obtained from the table using the average or mid-latitude between the points selected.

Bringing the Prognostic Chart Up-to-Date

Prognostic charts are usually prepared to cover a number of flights over a period of time. Unless the chart is specially made up for a specific flight, it is necessary, for interpretation of weather in flight, to adjust the chart for the proper take-off time. By noting actual pressures on the chart furnished by the weather office and readjusting pressure systems, you can get a more comprehensive picture of the weather

CHANGE IN FLIGHT PLAN

A successful flight follows the track which will prove most valuable from the standpoint of time and weather. This does not necessarily mean that the most desirable track is the one contained in the original flight plan. Even the most careful pre-flight analysis can go wrong, and the science of pressure pattern flying calls for course change in flight to take advantage of changing conditions.

Altering course in flight, when actual weather varies from forecast weather, is the most difficult problem of ocean flying. Therefore, it is imperative that the crew on a transocean flight be able

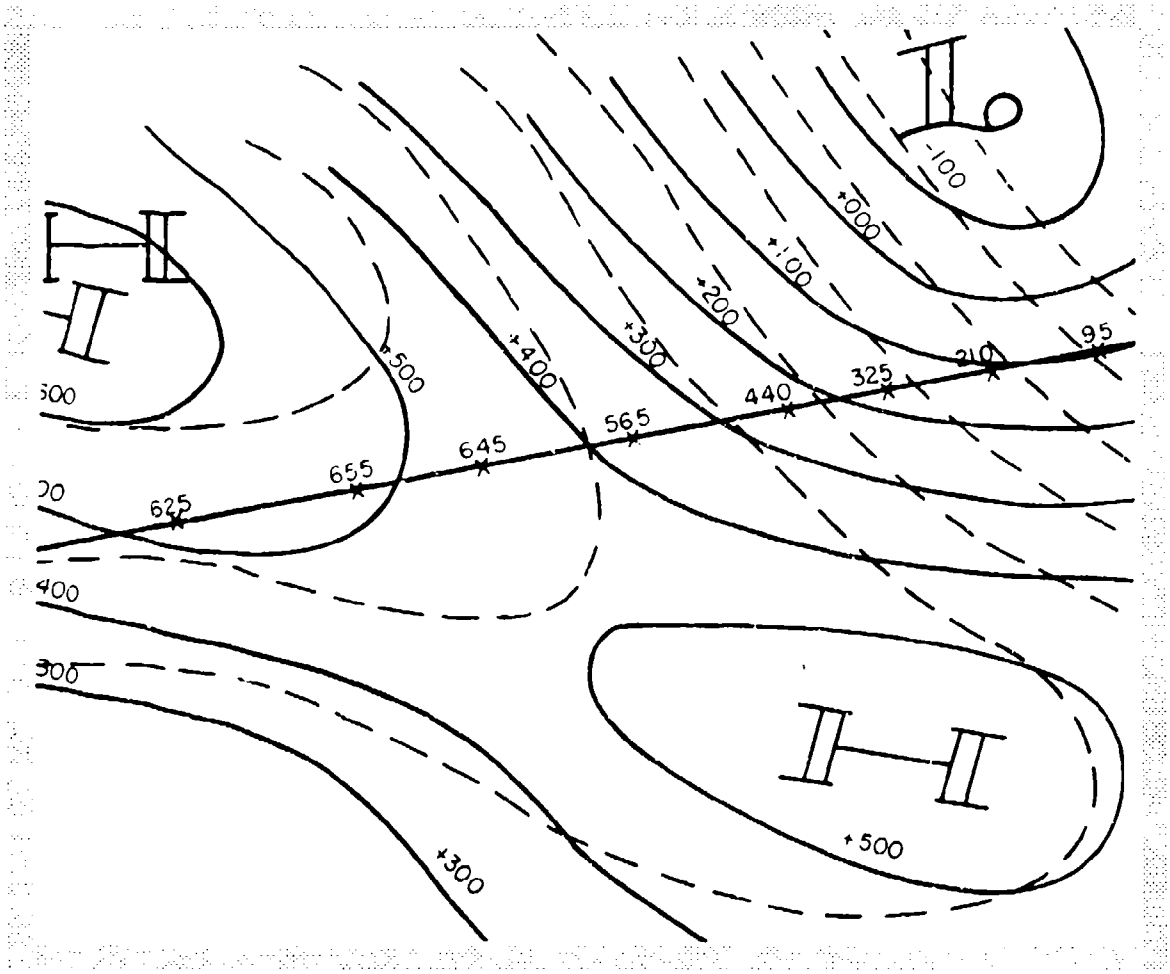


Figure 31–14. Fleet Logistics Airwing "D" chart

to analyze conditions while in flight and make any necessary readjustments. A change in course is always advisable when time can be saved, provided it will not lead into bad weather. For example, an eastbound flight in north latitude might prefer not to pass south of a low to get tailwinds if to do so it has to traverse both the warm and cold fronts which usually lie southeast and southwest from the low pressure center.

Finding Locations of Pressure Systems

To find out whether time will be saved by a departure from the original flight plan, it is necessary to know the location of pressure systems. When sea and constant level pressures are computed, the pressure trend along the flight path is established, and it can readily be seen whether a low or high pressure area is being approached. This information, used in conjunction with drift angles, or with wind directions and velocities when these are available, makes it possible to locate pressure centers. The plotting of winds directly on the navigation chart is very helpful in picturing weather conditions. The wind arrows show a definite trend in circulation and provide the navigator with a check on the reliability of his computations. In addition, if perpendiculars are drawn from each arrow, as shown in Figure 31-15, they will converge in a small area; this area will be the approximate center of the pressure systems.

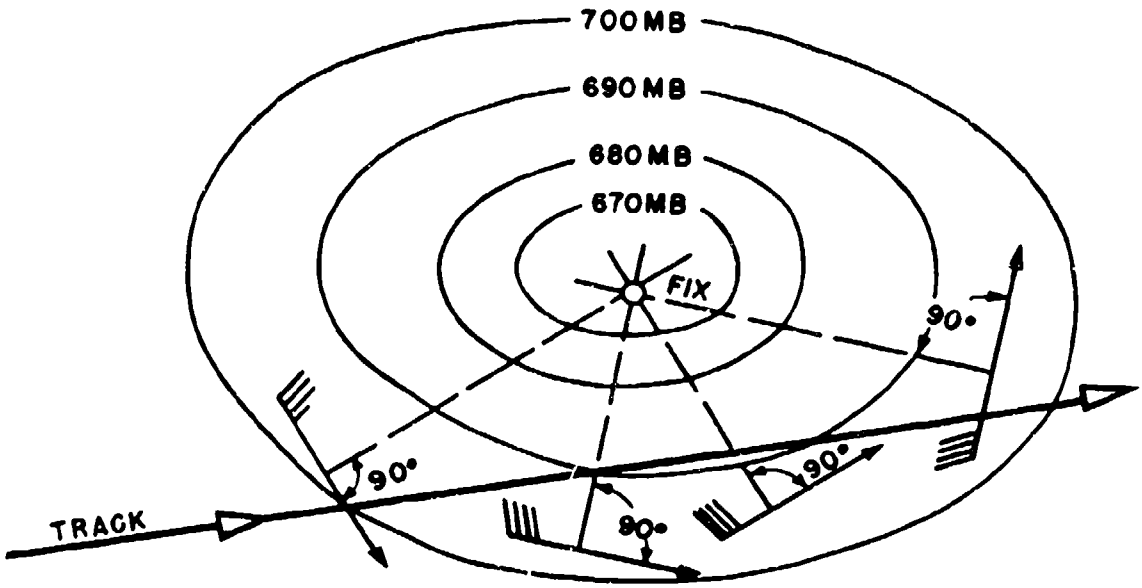


Figure 31-15. Fixing location of pressure center

If the movement of the pressure system can be estimated, the perpendiculars can actually be advanced (as a line of position can be advanced) to locate the pressure center more exactly. Besides being extremely useful to the crew in flight, this information is invaluable to the weather station.

Taking Advantage of Winds

Beam winds with either falling or rising pressures will indicate passage directly through a pressure center. Under these circumstances, it is always advisable to alter course to circumnavigate the pressure center and take advantage of winds. In the Northern Hemisphere, if the pressure is falling, the course should be altered to the right. This is true regardless of the direction of flight, provided, when eastbound, no bad frontal weather will thus be encountered. Conversely, if the pressure is rising, the course should always be altered to the left.

CHAPTER 32

WORLD WEATHER AND CLIMATE

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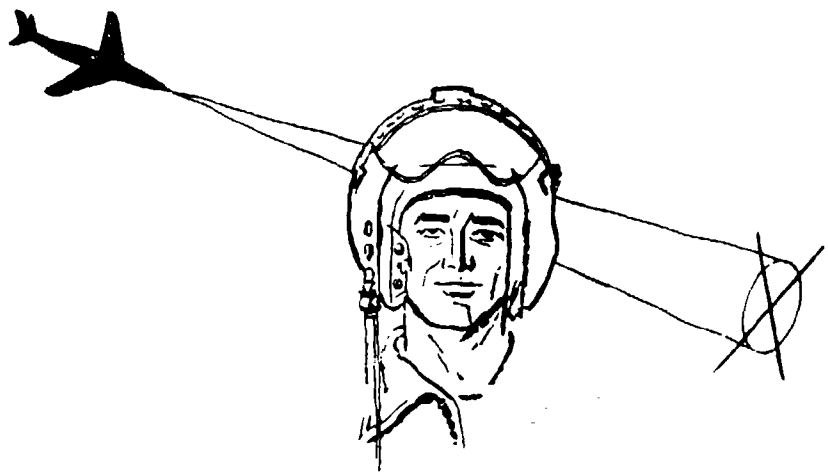


CHAPTER 32

WORLD WEATHER AND CLIMATE

THE similarities and differences in the weather of operationally important regions constitute world weather. As a naval aviator, you should have a knowledge of world weather principles, for your operating area is the globe. The most important principle of world weather study is that two areas with similar average weather are similarly located with respect to one or more of the major climatic controls.

GLOBAL CLIMATIC CONTROLS

Air masses bring all weather, both air mass and frontal. However, climatic controls determine the sources, directions of movement, and characteristics of air masses. The climatic controls, operating together, give the earth a general climatic pattern. The four factors which largely determine the climate of every ocean and coastal region are:

Latitude.
Land and water distribution.
Ocean currents.
Topography.

An understanding of these controls will help you understand and remember the climate and weather of naval operation zones.

Latitude

The angle at which rays of sunlight reach the earth, and the number of "sun" hours each day depend on the distance from the Equator. There-

fore, the extent to which an air mass is heated is influenced by the latitude. This uneven distribution of heat is responsible for the general pattern of planetary air circulation; it influences the sources and direction of air masses and the weather they bring with them.

In particular, because of the low angle of incidence of solar radiation in polar regions, a given horizontal area in high latitudes receives less solar radiation than an equal area closer to the Equator. Thus, proceeding from the pole toward the Equator, the temperatures of the surface of the earth and the air near it increase far more than the temperature of the atmosphere as a whole. The air in low latitudes, therefore, expands vertically, while the cooling in high latitudes results in a vertical shrinking.

Land and Water Distribution

Because land and water heat and cool at different rates, the location of continents and oceans greatly alters the earth's pattern of air temperature and influences the sources and direction of movement of air masses.

Influence on air temperature. Coastal areas take on the temperature characteristics of the land or water to their windward. In the latitudes of the prevailing westerly winds, for example, west coasts of continents have oceanic temperatures and east coasts have continental temperatures. Since the upper layers of the ocean are nearly always in a state of violent stirring, heat losses or heat gains occurring at the sea surface are distributed throughout a large volume of water. This mixing process sharply reduces the temperature con-

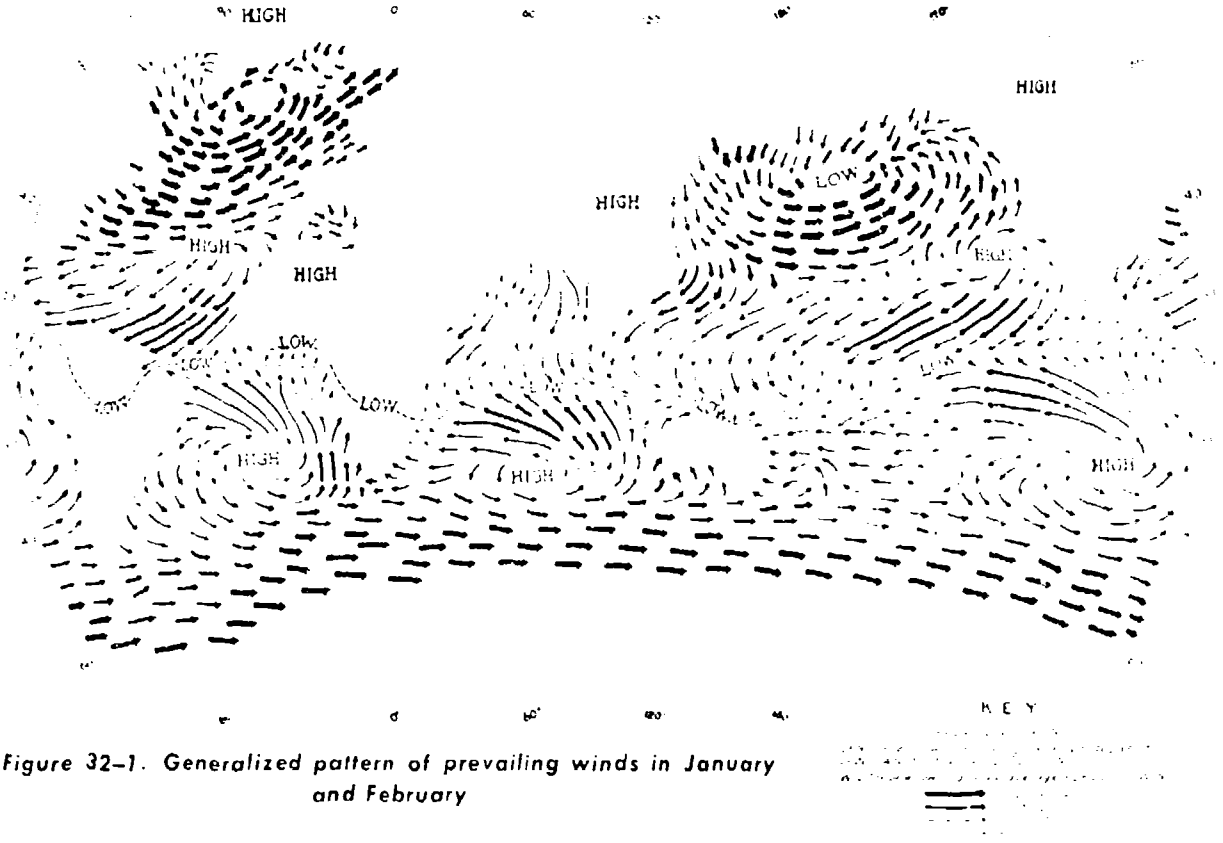


Figure 32-1. Generalized pattern of prevailing winds in January and February

trasts between day and night and between winter and summer in oceanic areas.

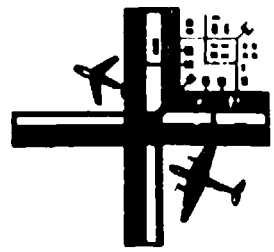
In land, there is no redistribution of heat by turbulence, and the effect of conduction is negligible. Thus, violent contrasts between seasons and between day and night are created in the interior of continents. During the winter, a large part of the sparsely incident solar radiation is reflected back toward space by the snow cover that extends over large portions of the northern continents. For these reasons, the northern continents serve as efficient manufacturing plants for dry polar air. The polar air cap is no longer symmetrical, but is displaced far to the south, particularly over the interior of Asia.

Influence on air circulation. The higher mean temperature of the Northern Hemisphere is not only an effect of its greater land cover. The oceans are also warmer in the Northern Hemisphere than in the Southern Hemisphere. This is partly due to the movement of warm equatorial waters from the Southern Hemisphere into the Northern Hemisphere as a result of the southeast trades, which cross the Equator. Another factor conducive to higher mean temperatures in the Northern Hemisphere is the partial protection of its oceans from cold polar waters and arctic ice by land barriers. There is no such barrier between the Antarctic Ocean and the southern oceans.

The Southern Hemisphere, with its practically uniform water cover, is characterized to a large extent, by a zonal arrangement of the different wind belts. In the Northern Hemisphere, however, uneven distribution of land and water areas causes the belts of high and low pressure associated with the wind system to break down into separate closed centers of high and low pressure. (See Figures 32-1 and 32-2.) During the winter season, at least six such centers may be observed in our hemisphere; the Icelandic Low, the Aleutian Low, the Pacific High, the Atlantic High, the Asiatic High, and the North American High.

Ocean Currents

Moving water obeys the same law of deflection as moving air. It is deflected toward the right in the Northern Hemisphere and toward the



left in the Southern Hemisphere, basically because of the earth's rotation. However, the prevailing winds, exerting pressure along the ocean surface, determine some of the circulation characteristics. As a consequence of the deflection, great clockwise ocean eddies occur in the North Atlantic and the North Pacific, while waters of the Southern Hemisphere swirl in a counter-clockwise fashion. Knowing this rule makes it possible to determine the general direction of ocean currents off most coasts of middle latitudes.

A similar pattern of currents is found in each of the great oceans. In the North Atlantic, however, the broad opening into the Arctic Ocean and the comparative narrowness of the Atlantic give the Gulf Stream system a northward sweep along the Norwegian coast. The sweep has no counterpart along the Alaskan coast of the Pacific. This results in a milder climate in Norway than in Alaska for similar latitudes.

For flying, the principal significance of ocean currents is their influence on climate and weather. The climate of an ocean area is related to currents found in it. Water in a warm current is relatively warm with respect to the temperature of the area over which it is moving. Warm currents move from equatorial regions. Cold currents move from high, cold latitudes.

In middle latitudes, ocean currents carry warm water away from the Equator along the eastern coasts of continents and carry cold water toward the Equator along the western coasts. Prevailing winds of the middle latitudes are from the west. During winter, the prevailing westerly winds are cold continental air outbreaks of continental polar air) over the warm waters of the Gulf Stream and the Japan Current. The most

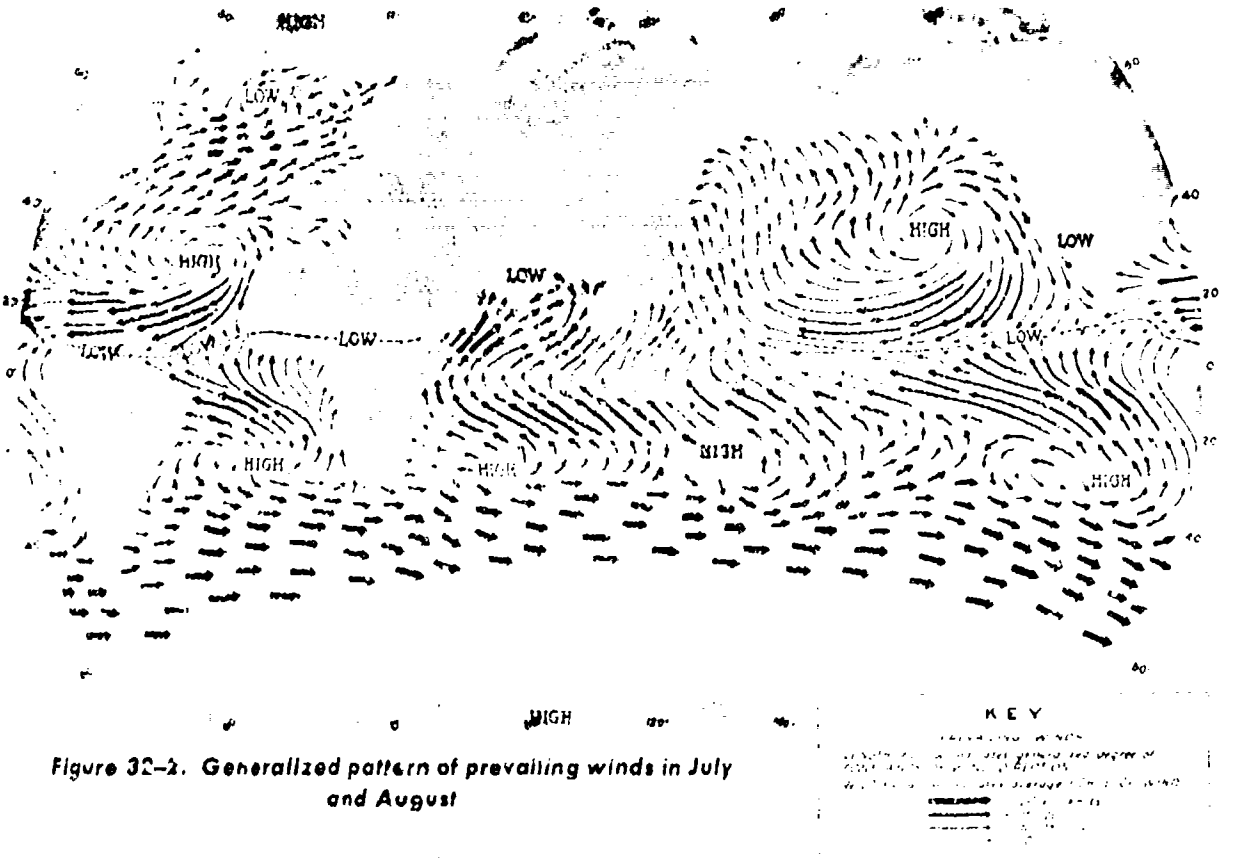


Figure 32-2. Generalized pattern of prevailing winds in July and August

active frontal zones of the winter season are found where this cold continental air moves over warm water off eastern coasts.

Ocean currents also affect the weather within a moving air mass. An air mass moving over an ocean surface warmer than the air tends to form cumulus clouds and produce thunderstorms. An air mass moving over an ocean colder than the air tends to form stratus clouds or extensive fog over the ocean. The latter accounts for much of the Newfoundland and Aleutian fogs and the coastal fog of California.

Topography

Physical features of the land influence the climates of coastal areas and islands. When air is forced to ascend over mountains, excessive precipitation may result on the windward side. This occurs over mountainous islands, such as the Hawaiians, and also over the west coast ranges in the United States when westerly winds reach them. Windward slopes often have clouds and precipitation, while clear flying weather prevails on the leeward side. Mountains also retard the movement of fronts. Storm conditions may be held for several days on windward sides of long coastal ranges, accentuating the bad flying weather of windward regions.

WORLD AIR MASSES AND FRONTS

As you recall, the characteristics of an air mass result from stagnation of air over large areas of land or water in certain regions of the general circulation system. Once the air mass begins to move, however, the original characteristics are modified. Climatic controls influence the movement of air masses and the creation of fronts.

When a front occurs, it is the characteristics of the air mass that determine the nature of the frontal weather.

The regions of high pressure from which principal air flows originate are the primary source regions for the air masses that move over the world. The relative intensity of the continental and maritime highs determines the location of the zones of convergence between them. In these zones of convergence, where air masses with different properties meet, lie the Polar Fronts. Figures 32-1 and 32-2 show that persistent cells of high pressure exist in the zone between latitudes 25° and 40° in both hemispheres.

Zones of lower pressure appear at or near the Equator and between latitudes 45° and 60°. These zones do not remain stationary throughout the year, but shift northward and southward within the latitude ranges just mentioned. This is indirectly associated with the seasonal differences in the solar heating of the earth's surface, and the zones follow the seasonal migration of the sun. In each hemisphere, all zones reach their most poleward extension during the summer months and are nearest the Equator during the winter. In addition to these semi-permanent regions of high pressure over the oceans, there are high-pressure cells over the continents in both hemispheres during the winter season. These cells are produced by the cooling of all extensive land surfaces.

REGIONAL CIRCULATIONS

The basic circulation pattern of the atmosphere was discussed in Chapter 26. As pointed out there, frequent deviations from this pattern occur in many regions because of terrain features. Many regions have unusual local weather phenomena caused directly by the temperature difference between land and water or by local topographical features. You should know the regional circulations which have significant effects on flight conditions.

Land and Sea Breezes

Ocean breezes generally occur on a summer afternoon near a coast line. When an air mass is stationary over a coast line and the land surface is warmer than the sea surface as a result of radiation heating, an onshore breeze is produced at the surface, with an outward drift aloft. At night, the radiation cooling of the land is greater than that of the sea, and the horizontal temperature gradient is normally reversed. This produces the offshore breeze, which reaches its maximum about at dawn. The land and sea breeze phenomenon is purely local. Its influence does not extend far from land and seldom extends to a height of 3,000 feet.

Monsoon Winds

Monsoon winds are characterized by a tendency toward a reversal in prevailing wind direction between winter and summer. The name Monsoon comes from the Arabic word *mausim* meaning season, and was first applied to the winds over the Arabian Sea which blow for approximately six months from the northeast and for six months from the southwest. Monsoons occur because the surface of the earth consists of great land and water areas which have unequal heating and cooling capacities.

The variation in specific heat between land and water causes relatively more heating over land in the summer and over water surfaces in the winter. For this reason there is a strong tendency in the average world pressure pattern for highs to form over land in the winter and over water in the summer; likewise, lows form mostly over land in the summer and over water in the winter. This, in effect, is the basis for the phenomenon of monsoon circulation. In the India, Burma, China re-

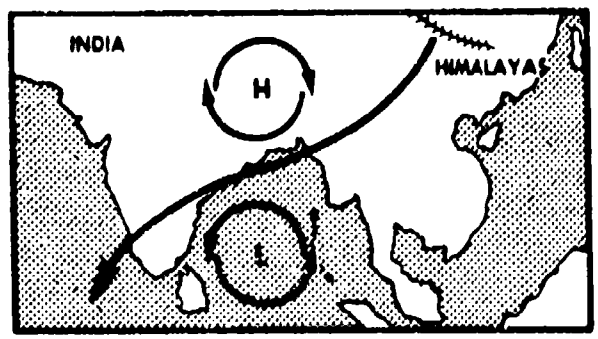


Figure 32-3. Winter monsoon

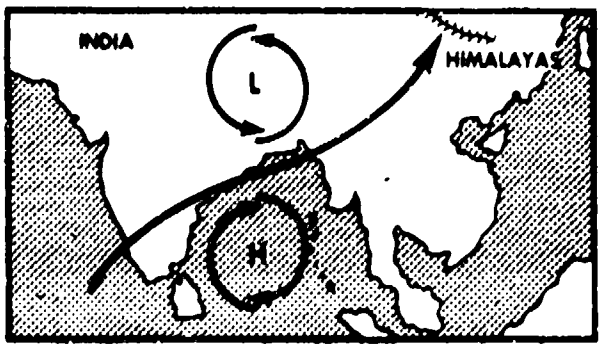


Figure 32–4. Summer monsoon

gion, the land and water areas are so located in relation to the seasonal circulation that during the summer season the southerly circulation is intensified, and, in the winter season the northerly circulation becomes predominant. The southerly circulation in summer brings in the warm moist air to the continent. When this air is lifted over the land, stratus clouds, precipitation, and poor visibilities result. The winter situation brings in the very dry air downslope from the north. (See Figures 32-3 and 32-4.)

Because of the great size of the continent of Asia, the monsoon is most developed over eastern and southern parts of it. However, monsoons in modified form, or monsoon tendencies, are characteristic of other regions as well. Southeastern United States, Northern Australia, Spain, and South Africa are regions with monsoon tendencies. These land areas are not extensive enough to cause a complete seasonal reversal of winds, as does Asia, but they produce partial monsoons which have a significant effect on the amount of seasonal rainfall.

Regions with strong monsoon tendencies usually are on the eastern sides of continents. This is especially true in the middle latitudes, since the western or windward coasts are distinctly marine in character, with only small changes in temperature from winter to summer.

EQUATORIAL AND TROPICAL WEATHER

In the temperate zone, where westerly winds predominate, pressure patterns move in an easterly direction. In the tropics, however, weather moves in the opposite direction. The normal moist layer is 5,000 to 8,000 feet deep and rises above 12,000 feet during periods of unfavorable weather. Convergence occurs in opposing tradewind streams, northward flowing air, and cyclonic curvature. The deep, moist layer and the convergence account for the weather in equatorial and tropical regions.

Intertropical Convergence Zone (ITCZ)

The most persistent zone of convergence over the oceans is that of the Intertropical Convergence Zone (ITCZ), where the air streams of both hemispheres meet in the equatorial region of low pressure. This region is also called the doldrum belt. Weather conditions along the ITCZ change from day to day according to the nature of the air streams which converge into the zone and the

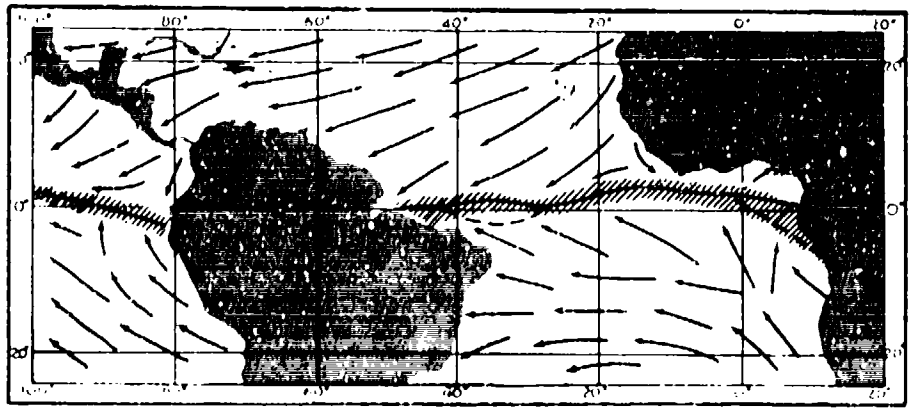


Figure 32–5. Average position of intertropical front in February

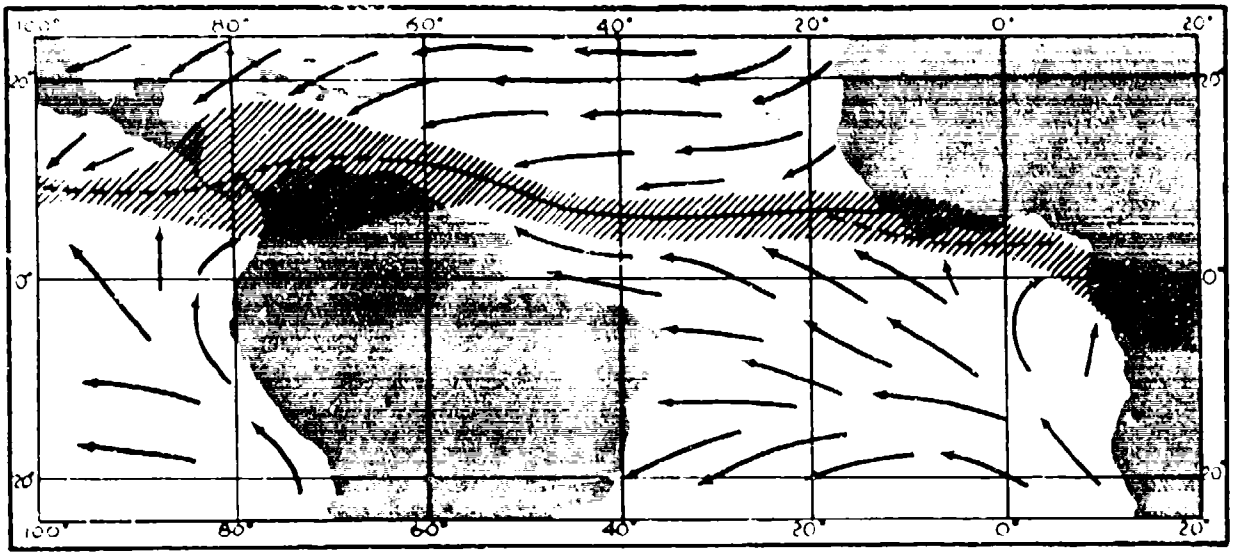


Figure 32–6. Average position of intertropical front in November

angle at which they meet. (See Figures 32-5 and 32-6.)

In most cases, the ITCZ has no sharp frontal discontinuity, but is a zone varying in width from 50 to 400 miles. At its worst, it is an area of solid cumulonimbus clouds rising to 40,000 feet or more, with thick layers of altostratus extending outward at several levels. Ceilings and visibilities are often lowered to near zero in heavy rain. Under such conditions, turbulence is severe, with heavy icing in clouds above the freezing level. At its best, the ITCZ may be merely an area of broken to overcast altostratus clouds, with swelling cumulus clouds below.

Other Bad Weather Zones

In addition to the ITCZ, there are several minor discontinuities in the tropical air streams. These are often drawn on synoptic charts as weak cold fronts, since the weather associated with them is of the type characteristic of weak cold fronts at higher latitudes. The region between two cells of the semi-permanent anticyclones which characterize the pressure field in the trade air stream is known as a shear line. It is a localized region of convergence. In such a region, there is no subsidence inversion, and the cumulus clouds can build to greater heights than elsewhere in the trade wind belt. The area of convergence consists of a broad zone of heavy cumulus and an occasional cumulonimbus, with patches of medium clouds in sheets at levels between 3,000 and 12,000 feet.

The shear line is found in the tropics when the leading edge of a continental Polar (cP) high advances southward and displaces the semi-permanent oceanic high (Fig. 32-7). Mixing in these lower latitudes causes the density discontinuity across the front to disappear, leaving only a wind shift. Convergence and cumuliform activity may be found along this wind shift line. As the new anticyclone advances, the old one tends to weaken so that with continued advancement into the tropics, the passage of a shear line is characterized by a narrow band of bad weather and then a distinct freshening or surge of the trade winds.

Polar troughs are regions of cyclonic circulation which frequently form near the west coasts of continents and toward the southern part of the zone of westerlies. They appear as a line of cyclonic circulation rather than a circular cyclone when the cold air from a Polar (cP) outbreak moves far southward and the accompanying low pressure line aloft moves rather far out ahead of the surface frontal position (Fig. 32-8). When

this line of low pressure aloft extends southward into the tropical regions, an area of bad weather results. There is clear weather to the west of the trough line and an area of bad weather to the east, but since this phenomenon occurs within the belt of westerly winds, the entire system moves from west to east, frequently becoming more or less a broad line of convective clouds which tends to dissipate gradually as it moves further eastward.

Easterly Waves

Easterly waves or troughs are usually attended by northeast wind (southeast in the Southern Hemisphere), falling pressure, and if the wave is moving more slowly than the air stream in which it lies, excellent weather prevailing ahead of the wave crest. In the rear portion of the waves, southeasterly winds (northeasterly in the Southern Hemisphere), rising pressure, convergence, and showery weather occur. The depth of the moist layer increases rapidly near the trough line and often attains a height of 30,000 feet near the zone of most intense convergence. In the latter area, well-developed squall-lines and rows of cumulonimbi are found. The weaker waves are often difficult to locate on the surface weather chart, since the convergence accompanying them may not be sufficient to produce bad weather zones over the open ocean.

The direction of movement is about normal to the trough line and parallel to the steering current in which it lies. Waves of this kind occur, on the average, about twice a week during the season of their most frequent occurrence. Their effects, in any given locality, may extend over a period of three or four days. Waves which are originally weak and hardly discernible on the weather chart may deepen rapidly over a period of 24 hours, particularly when they meet the ITCZ.

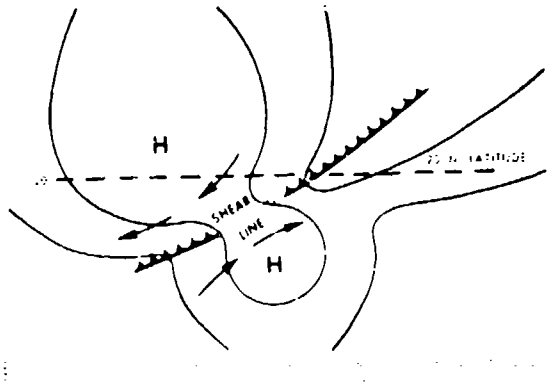


Figure 32–7. Shear line in the tropics

Flight in the ITCZ

The technique of flying through the ITCZ depends, to some extent, on the type of aircraft. Aircraft with service ceilings of 16,000 feet or higher rarely have difficulty in topping clouds. Other aircraft must weave among tops of cumulonimbus clouds at 12,000 feet or lower. If they fail to find intervals where they can traverse the area in clear air or in clouds with tops below 14,000 feet, they must descend to near the surface and fly through rain squalls.

The density and vertical extent of the cumulus clouds in the zone may vary considerably. Most of the time, a scattered row of cumulonimbus accompanied by considerable middle and high clouds typifies the ITCZ, but there are times when cumulonimbus clouds are so close together that it is not possible to make a transit of the front without penetrating clouds. It is safe to fly in clouds whose tops can positively be judged to be lower than 14,000 to 16,000 feet. Light-to-moderate turbulence and hail may be encountered, but strong, deep drafts are not likely. The principal danger lies in entering a cloud whose top is lower than 14,000 feet and then unintentionally getting into the convective column of a cumulonimbus; cumulonimbus tops may reach 20,000 feet or higher. When approaching the ITCZ, it is dangerous to fly blind in thick clouds when tops cannot be ascertained.

At night, it is difficult to see isolated deep clouds in the path of flight. There is a marked increase in cloud amount and turbulence over the ocean during nocturnal hours. This effect is most noticeable in the vicinity of islands. You should determine the orientation of the ITCZ at the point where you plan to cross and direct your flight at right angles so as to spend as little time as possible within the bad weather zone.

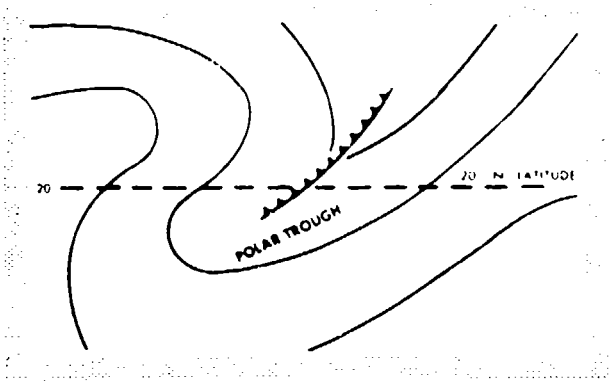


Figure 32–8. Polar trough in the tropics

Tropical Cyclones

One of the greatest weather hazards to naval ships, air bases, and aircraft, both in tropical and middle latitudes, is the tropical cyclone. Every naval officer should be familiar with the nature of these storms, the season of their occurrence, the areas in which they form, and their common tracks. (See Figure 32-9.)

The tropical cyclone is a phenomenon closely associated with the ITCZ. It is termed typhoon, hurricane, or willy-willy, depending on the area within which it occurs. The characteristic differences between the tropical and extratropical cyclones are in the steepness of the pressure gradient associated with the former and the area of formation. The well-developed tropical cyclone has a diameter of 50 to 400 miles, which is accompanied by winds as high as 150 knots toward the central, calm area.

South of the Equator, the wind spirals inward and upward in a clockwise direction around the center of lowest pressure. North of the Equator the rotation is the reverse, and the winds spiral in a counter-clockwise direction. A peculiarity of tropical storms is the calm center or "eye" of the storm. When the center of the cyclone passes over a given locality, the wind, which has been extremely violent, dies down suddenly, either to absolute calm or to a much lower velocity, and the precipitation stops. The diameter of the "eye," or calm center, varies from 10 to 30 miles. After it passes over, the violent winds begin again.

A tropical cyclone is roughly circular, but by no means symmetrical. The worst zone is the right front (Fig. 32–10). Obviously, to establish which is the right front, you must know the direction of movement. Some clue to the direction of motion, if not forecast, is found from the latitude. See Figure 32-9, but remember that the paths shown are only average. Some storms have been known to stop a while, go around in a small circle, or zigzag.

As the storm develops, particularly after it begins to turn northward, the rain area becomes immense. The great amounts of moist air lifted to high altitude spread out for 100 to 300 miles producing extensive rains. In addition to the flight hazards, there are high tides, great waves, winds, and flooding from rainfall which plague coastal regions and islands even where hurricane winds may not occur.

The region of strongest winds is usually small. At distances of about 100 miles from the center, hurricane velocities (64 knots) are seldom observed. The velocity of movement of the center is variable; it ranges from a few miles per day in its early stages in the subequatorial regions to approximately 100 miles per day after it has become well developed, and it increases to 300 to 400 miles per day after recurving. This recurving of the tropical cyclone is characteristic and is the normal result of the passing of the storm into the zone of prevailing westerlies.

Tropical storms never form within 5° of the Equator. They form only over the open sea, where large amounts of energy are available in the moist air and where surface frictional forces are slight. Although the tracks of individual tropical cyclones may be irregular, they tend to describe a parabolic course after forming in the subequatorial regions.

In the Northern Hemisphere, the cyclones tend to move first in a general westerly direction nearly parallel to the Equator, then northwesterly, and finally, to north or northeasterly at latitudes 20° to 25°. In the Southern Hemisphere, the storms tend to move westerly, then southwesterly away from the Equator, and, finally, in a curve to the south or southeast. When they reach higher latitudes, or move over land surfaces,

their diameter increases while the intensity decreases. At higher latitudes, they often change into extratropical cyclones.

In none of the regions of tropical cyclone formation is the average annual number greater than twenty-five; in some regions, the yearly average is as small as two. In each hemisphere, tropical cyclones occur principally during the summer season, when the ITCZ is farthest from the Equator.

Flight Techniques in Tropical Cyclones

Often, when tropical cyclones are large enough to appear on the weather map, a flight can be made which will avoid the heaviest weather and take advantage of the best winds. In the subequatorial regions, however, the presence of tropical cyclones may not be revealed because of their small size when they are in the incipient stage. In the regions of their formation, small incipient storms are sometimes encountered before the synoptic chart has given any warning. Here are signs of such development:

1. Heavy clouds too high to climb over.
2. Rapidly shifting winds with increasing wind velocities.
3. Lightning.
4. Heavy swells running counter to smaller waves.
5. Westerly winds greater than 20 knots between 5° N. Lat and 5° S. Lat, a condition which indicates cyclonic activity to the north or south.
6. Cirrus and cirrostratus thickening to altostratus.
7. Rain falling from altostratus.
8. Turbulence in clear air.

Unless it is your duty to do so, don't try to penetrate a tropical storm except in emergency. If you meet such a storm, either turn back or go around it. In going around, go with the wind. Fly at about 500 feet or above 40,000. If you place the wind on your port quarter you will approach the center at a fairly fast rate. Do this until wind velocities at the surface reach about 50 to 60 knots, then turn to place the wind at the aft starboard quarter, more or less astern. If the wind velocity increases, turn right to place it more nearly abeam; if velocity decreases too much, place the wind more nearly astern. Since you fly around by relation to winds and not on compass courses, watch the true direction of surface winds to determine when you have gone to the opposite side and alter course for destination. (All the preceding is for north latitude.) In south latitude change left (or port) to right (or starboard), etc.

Several other rules to remember in connection with tropical cyclones are these:

To keep the circumference of the circumnavigation course within reason, do not turn downwind until the winds reach about 50 knots.

Beware of altimeter error. If a radar altimeter is available, use it. Extreme pressure drops might make a pressure altimeter read 2,000 feet higher than actual altitude near the eye.

In north latitudes, if you head *downwind* in a cyclonic circulation, the low center is on your left (from about 60° at 500 feet to 90° above 3,000 feet). In south latitudes, the low is on your right.

Any time you fly with the wind from the starboard quarter, you are going away from the storm center and getting a tail wind in the bargain. *The maximum rate of departure is obtained with the wind from the starboard beam.*

POLAR AND SUBPOLAR REGIONS

The polar regions include the northern coast of Alaska and Canada, the Canadian Arctic Archipelago, much of Labrador, most of Greenland, the Svalbard Archipelago, northern Siberia, and the Arctic Ocean. *The southern boundary of the Polar region roughly corresponds with the northern limit of the tree lines.* The subpolar regions comprise two regions differing in topography and climate—the coastal region and the interior. Interior Alaska includes the Alaska Range, which is an extension of the mountains of the southern coast. The Aleutian Island chain is subpolar in climate. Subpolar Canada includes a large section of the mainland and parts of the north coast.

Weather

Weather is comparatively shallow in the polar regions because of the relatively small amount of

moisture in the atmosphere and the lack of convective activity to carry moisture in the atmosphere and the lack of convective activity to carry moisture to high levels. This makes high-level flight more desirable.

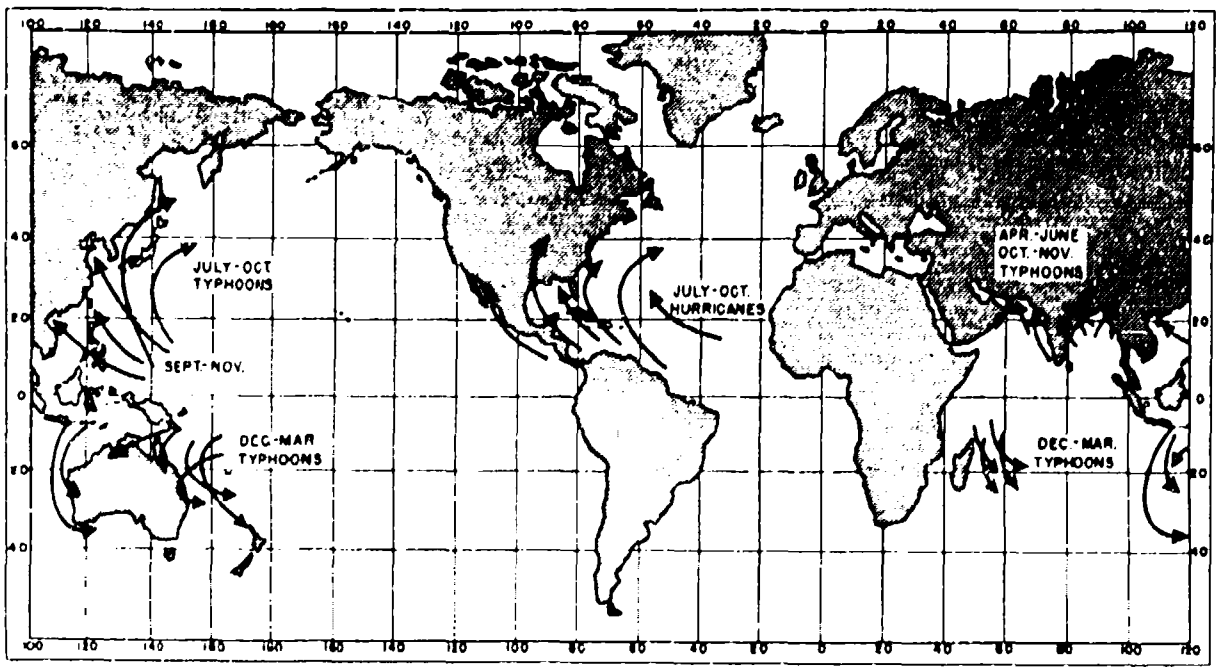
In general, the proportion of clear days at Alaskan bases is seldom over one-half and often less than one-third. Nearly all bases, except those in the interior, average many more cloudy days than clear days in the course of a year. The Aleutians, the southeast coast, and the Seward Peninsula present their best flying conditions during the winter. The gulf coast and the interior present their best flying conditions in summer. The best flying weather for all Alaska occurs in the interior and the parts of the gulf coast, such as the Anchorage area, which are well protected from the maritime influence.

The poorest flying conditions exist in the Aleutians and the southwest regions. The ceilings and visibilities are below 2,000 feet and 6 miles more than 10% of the time (annually) in the interior and Anchorage area, and over 50% of the time in the Aleutians and along the southeast coast.

Terminal conditions cause the greatest flight hazards in polar operations. The effect of polar lighting and weather on depth perception is a particularly serious hazard. On newly formed snow, or on a dull day, shadows are not visible. This has an effect somewhat similar to that of glassy water and makes it extremely difficult to judge height after leaving the ground. In addition, serious obstructions to vision are frequently produced by fog, rain, snow, and blowing snow. In certain areas, high winds also cause a terminal hazard.

There are many names given to fog in the polar regions—coastal fog, polar pack fog, spicule fog, and town fog. In addition, layers of thin mist start as low as 100 feet. These layers of mist are often present even during the day, for they are not dissipated by the midday sun. The windward side of an island in the subpolar regions is foggy more often than the leeward side. Three possible island fog situations are:

Figure 32-9. Typical hurricane and typhoon tracks



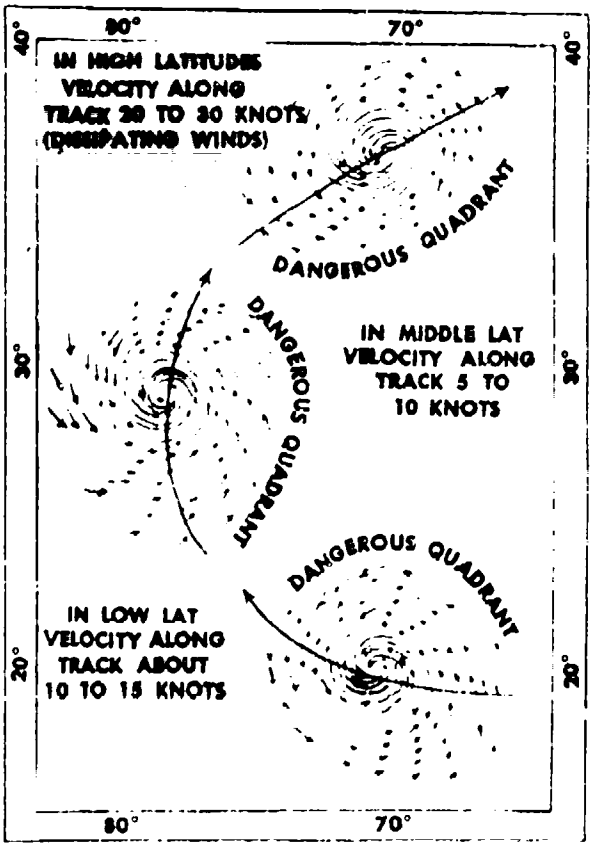


Figure 32–10. Tropical cyclone

1. A shallow advection fog may flow around an island, leaving a clear space on the leeward side.

2. A thick fog may flow over (as well as around) an island, but the adiabatic heating produced by the downdraft on the lee side of the island causes the fog to lift to low stratus and causes breaks in the low stratus to leeward.

3. The fog flowing over an island may be so thick that the adiabatic heating produced by the downdraft on the lee side of the island merely lifts the fog to low stratus and cannot break the low stratus.

Even on the foggiest days of summer, though, there is a good possibility that clear areas or breaks in the overcast occur on the leeward sides of mountainous islands.

Drifting snow also reduces visibility. Winds of 12 mph raise the snow a few feet off the ground, and the blowing snow obscures surface objects such as rocks and runway markers. Winds of 15 mph raise snow high enough to obscure buildings. With high winds and low temperature, blowing snow may reach a height of 300 feet. Under these circumstances, vertical visibility is generally good—small objects on the ground can be seen, if you are directly above them—but horizontal visibility is poor.

MOUNTAINOUS TERRAIN

Flight in mountainous terrain in all climate areas must take account of altimeter errors, turbulence, thunderstorm development, and frontal modifications over large continental ridges.

Frontal Modification

Mountain ranges greatly influence the speed slopes and activity of fronts. The orientation of the front relative to the mountain range, the size of the mountain, and the stability of the air masses involved determine the amount of modification that develops. The retardation of fronts in crossing mountain ranges frequently results in the development of new cyclonic waves on the front. This effect is observed on the south coast of Greenland, along the south coast of Norway, and also along the southern section of the Alleghenies in the United States.

Warm fronts. As a rule, the slope of warm fronts is much less than the slope of mountain ranges. Therefore, when a warm front approaches a mountain range, the warm front surface reaches the mountain ridge first and traps a wedge of cold air along the mountainside.

Since the cold air mass cannot escape, the warm front surface will become stationary along the leading slopes of the mountains. The precipitation area common to the lower portion of the warm front will persist over the same region for a long time. The upper portion of the warm front will pass over the mountains and descend on the leeward side of the mountain range. Precipitation (and sometimes cloudiness) is absent on this side because of adiabatic heating. When the

warm front arrives over flat country, it regains its characteristic cloud and precipitation pattern.

The effect of mountain ranges is, primarily, to widen the precipitation—to increase the duration and intensity of the precipitation on the windward side of the mountains, and to decrease the precipitation area and intensity on the leeward side.

Cold fronts. The cold front wedge is retarded on the windward side and accelerated on the leeward side of the mountains.

If the air on the leeward side of the mountains is colder than the advancing wedge of cold air, the cold front will merely travel across the top of the cold dome on the leeward side of the mountains as an upper air front. This happens frequently east of the Rocky Mountains during the winter and east of the Alleghenies during the early morning hours. At these times, the stagnant air east of the mountains will be colder because of radiation processes, while the well-stirred air associated with the cold front will maintain higher temperatures and therefore overrun the stagnant mass on the leeward side of the mountains. Frontal activity will be at a minimum until surface heating has become active in reversing the temperature conditions. Thunderstorm conditions and squalls may develop when the upper air front finally surfaces.

If the air on the leeward side of the mountains is warmer than the advancing wedge of cold air, the cold front will sweep the warm air away and frontal activity will continue unhindered.

The angle at which a cold front approaches and crosses a mountain range will determine the increase in frontal activity on the windward side and the relative decrease on the leeward side of the mountains. The maximum change in frontal activity occurs when the front lies parallel to the mountain range.

Occluded fronts. Occluded fronts crossing mountain ranges are influenced in the same way as cold and warm fronts. Cold front occlusions cross mountains like cold fronts, and warm front occlusions behave like warm fronts.

Mountain ranges frequently tend to accelerate the occlusion process when a warm-sector cyclone approaches. Under such circumstances, the warm front is retarded by the mountain range, while the cold front moves unhindered until it reaches the mountain range and the stalled warm front. This condition is often observed during winter on the west coast of continents.

NORTH ATLANTIC AND NORTH PACIFIC OCEANS

The naval aviator's usual flight environment—over the oceans—exhibits almost every type of weather known to the pilot. From the southern boundary of the polar regions, with its intense cyclones and fog, to the northern boundary of the tropics, with its good flying conditions, lies an area of changeable weather—the area over the oceans.

Ocean weather depends on the relative strength of the oceanic and transient high-pressure cells. An important factor in frontal formation and intensification is the location of warm ocean currents.

Ocean Currents

The Polar Fronts of the Atlantic and Pacific have their greatest intensity where the outbreaks from the polar highs meet the flow from the maritime highs over the warm ocean currents passing along the eastern coasts of North America and Asia. Seasonal variations in ocean weather occur with the migration of the Polar Front, placing a given area under the influence of frontal weather or air-mass weather. The heating or cooling of air over ocean currents accounts for a change in weather and cloud types as the air flow changes because of the shifting Polar Front. In summer, flights over the oceans deal mainly with air mass

weather. In winter, you must plan on encountering the Polar Fronts over the oceans.

The pattern of ocean currents causes the weather to follow similar patterns. The summer fogs of the Newfoundland-Grand Banks area of the Atlantic and of the Kurile-Kamchatka area of the Pacific are formed when warm mT air flows over the cold ocean currents found in these regions.

Ocean currents influence the temperature patterns of the Atlantic and Pacific. The sea-surface isotherms spread in an almost fan-like pattern from the east coasts of North America to Eurasia, bringing milder climates to the west coasts of these continents. In the North Atlantic, however, the difference in temperatures between the east and west sides is greater than in the North Pacific.

Polar Frontal Activity

In winter, the most favorable conditions for vigorous frontal activity are concentrated along the east coasts of North America and Asia. Cold air masses from continental sources meet warm moist air from over the oceans. The warm ocean currents along these coasts greatly accentuate the frontal activity. The great difference in the temperatures of the air masses, caused by the contrasting characteristics and proximity of their sources and the great amount of moisture that feeds into the air from the warm ocean currents, accounts for the intensity and persistence of these frontal zones off east coasts in winter.

Polar Fronts in the North Atlantic. In the Atlantic, the Polar Front of winter swings back and forth between the Wes. Indies and the New England Coastal States, with a maximum of intensity when the front coincides with the coast line. Waves with cold and warm fronts form along this Polar Front and move northeastward along the front. Like all cyclonic waves, they develop low-pressure centers along the frontal trough. They may grow into severe disturbances and go through the usual stages of development—formation, growth, occlusion, and dissipation.

These cyclonic waves occur in "families". Each "family" of waves is associated with a southward surge, or outbreak, of cold polar air. The Polar Front commonly extends approximately through the Great Lakes Area. As the polar air advances, it pushes the front southward. The outbreak occurs, and polar air, joining the trade winds, spills equatorward. These "families" of polar-front cyclones appear most regularly over the North Atlantic and North Pacific in winter.

During the summer months, the Polar Front of the Atlantic recedes to a location near the Great Lakes region, with the average summer storm track extending from the St. Lawrence Valley, across Newfoundland, and on toward Iceland. Polar outbreaks, with their accompanying "family" groupings of cyclones, are very irregular in summer and often do not exist at all. Over the United States, frontal activity is more vigorous in winter than in summer.

Polar Fronts in the North Pacific. The Polar Front activity of the Pacific is similar to that of the Atlantic, except that in winter there are usually two fronts. When one high dominates the subtropical Pacific in the winter season, the Pacific Polar Front forms near the Asiatic coast. In moving along the Polar Front of the Asiatic North Pacific in winter, storms occlude before reaching the Aleutian Islands or the Gulf of Alaska. Because of its steady cyclonic (counter-clockwise) circulation, the Aleutian low becomes a focal center, or a gathering point, for cyclones. When cold season cyclones reach the Aleutians and the Gulf of Alaska, cold continental winds from the Arctic feed them from the north, and cool maritime (mP) winds from the ocean feed them from the south. Here, where Arctic air meets maritime air over relatively warm water, is the Pacific Arctic front of winter. Though many occluded storms dissipate in the Gulf of Alaska, others become strongly regenerate.

From the Gulf of Alaska, cyclones (generally occluded) attempt to cross the mountains into Canada and northwestern United States. They cross the coastal ranges slowly and produce bad flying weather for long periods. Most of them stagnate along the Rockies, their mild and moist mP air being unable to displace the colder cP air commonly found over North America in winter.

When the Pacific subtropical high divides into two cells or segments, a front forms in th

vicinity of the Hawaiian Islands. Along this front, the Kona storms develop and move northeastward. Those that succeed in moving beyond the realm of the Northeast trades, which stunt them, may develop quite vigorously and advance to the American coast, generally occluding against the mountains. When this second Polar Front exists, two systems of cyclonic disturbances move across the Pacific. Because of their greater sources of energy, however, storms that originate over the Japan Current and move toward the Aleutians are always more severe.

During the summer months, the Pacific Polar Front lies to the north of Kamchatka and the Aleutians and shows no rhythmic polar outbreaks. In the Atlantic, a second Polar Front, similar to the second Polar Front of the Pacific, sometimes – though rarely—develops.

Air Mass Weather Over the Oceans

Flying weather is near its best in tropical maritime air at its source, within the subtropical highs. Scattered cumulus and then patches of stratocumulus clouds may develop, but the sky is almost never overcast and the scant precipitation falls in scattered showers. Variable, mild winds prevail.

The excellent flying weather of these mT source regions commonly extends through the moving air masses some distance from the sources. Cloudiness in the mT air increases with increase in distance from the source. On flights from Hawaii, or from the Azores northward through northward-moving mT air, stratiform clouds increase to the north. On flights from Hawaii or the Azores southward through southward-moving mT air (or the northeast trades), cumuliform clouds increase. (This for the Northern Hemisphere, but a comparable pattern exists in the Southern Hemisphere.)

Flight Planning in the North Atlantic and North Pacific

It has been shown that flights over the North Atlantic and North Pacific will encounter frontal weather for the most part during the winter months.

In winter, because of heavier icing, higher cloud tops, and more frequent gales, flying weather over the northern oceans is much more severe than continental weather.

In summer, flight weather is much milder over oceans than over the continent. Stable conditions predominate over cool northern waters, for the ocean is cooler than the continent in summer and northern waters are cooler than subtropical waters, from over which much of the air comes. Even the frontal zones have slight turbulence, and stratus and stratocumulus clouds prevail. The semipermanent lows are weakest at this season. Frontal activity is weak and infrequent, and winds seldom hinder operations. Icing is no great problem in summer. Instead, sea fogs become a hazard and a persistent nuisance.

THE "MEDITERRANEAN" CLIMATE

The Mediterranean Sea and adjacent coastal lands have a characteristic climate so distinct and well-known that the name "Mediterranean" climate is applied to this type of climate in all parts of the world. Mediterranean climate is found in

southern California, central Chile, the Cape area of South Africa, and parts of southern Australia. These sections of the world have small climatic differences, but great similarities.

Regions with Mediterranean climate are all exposed to maritime air from the west, and in latitudes 30° to 35°. Areas in these latitudes feel the season shifts of the pressure and wind belts. They are under the influence of the trade winds and subtropical highs during the summer, and under the influence of the westerlies and Polar Fronts (or Mediterranean Fronts) during the winter. The climate is characterized by dry summers and moderately moist winters; warm to hot summers and mild winters; and a high percentage of sunshine, especially in summer.

Air Masses

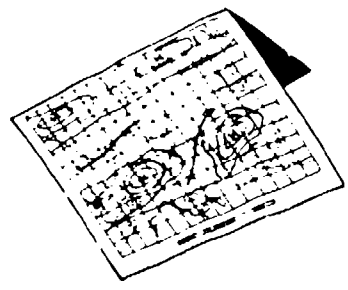
Maritime arctic and maritime polar air sometimes moves southward across France in the rear of strong cyclones over western France and penetrates to the Mediterranean. These air masses become unstable as they move south, and their instability increases over the warm Mediterranean. In winter, this causes heavy showers and thunderstorms, which are more intense in mA and in mP air. In summer, mA air is absent. The mP air, becoming warm and relatively dry during its passage over the heated lands to the northwest, provides good flying weather over the Mediterranean.

In winter, continental air from northern Europe often moves southwestward around the west side of the great Asiatic high, reaching the Mediterranean as a very cold and dry air stream. Sometimes it is an originally maritime air mass which has become dry by traveling across Europe. On reaching the warm Mediterranean, the air mass acquires moisture and becomes unstable by being heated in the lower layers. This causes cumulus and cumulonimbus clouds and showers.

Especially strong outbursts of arctic air sometimes develop behind a cold front or when a strong high exists over Europe with a low in the Mediterranean. These outbursts produce cold winds that often blow as gales through the valleys that break the mountain chain of southern Europe. Mistral is the name given to these strong winds in the Rhone Valley. The mistral may reach a velocity of 80 or 85 knots over the Rhone mouth, and it sometimes extends to Malta and North Africa. In the Adriatic Sea and in the Black Sea, similar winds are known as bora. Violent gusts and squalls sometimes reach speeds of 100 knots on the eastern side of the Adriatic (Dalmatian Coast).

From its source region in the North Atlantic high, maritime tropical mT air enters the Mediterranean from the west. In winter, this mT air sometimes overrides mP air, forming depressions that move eastward along the Mediterranean and yielding rain from the stratiform clouds. In summer, the Mediterranean is warmer than the neighboring parts of the Atlantic, so mT air arrives colder than the sea surface. Fair weather cumulus clouds form, but no rain results.

Clear and excellent flying weather, except for dust haze, characterizes continental tropical (cT) air. In winter, the chief source is North Africa.



It often moves as a southerly wind in advance of a depression over the western part of the Mediterranean. Warm and dry in its source region, it picks up moisture over the sea and arrives at Malta and the southern shores as a humid and oppressive wind, called the sirocco. In summer, cT air surrounds the Mediterranean. It is very warm and dry and becomes stable when it moves over the comparatively cool sea. If the winds are strong, the water vapor acquired over the sea is diffused rapidly upward; therefore, the air retains its dry, dusty characteristics far out to sea. If winds are light, little mixing takes place, and the lower layers become humid and oppressive.

RELATED REFERENCES

The current issue of OpNav Instruction 3710.7, General Flight and Operating Instructions for Naval Aviators, contains a list of references related to all-weather flight. These references should be assembled, kept current, and made a part of each unit's "All Pilots Read Folder."