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# MARITIME PATROL AIRSHIP CONCEPT STUDY
Contract N62269-78-M-6956

J. C. Bell,
J. D. Marketos, and
A. D. Topping
Bell Aerospace Textron
Division of Textron, Inc.
Post Office Box 29307
New Orleans, La. 70189

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Results of a preliminary conceptual parametric design study for a maritime patrol airship to be used by the U.S. Coast Guard or Navy are presented. Eight different Coast Guard mission profiles specified by the Naval Air Development Center are considered, and an optimum airship point design is developed for each. The report discusses ~~the~~ mission requirements, ~~the~~ airship operational requirements, the conceptual design approach, and the parametric design study which uses a computer program to assist in optimizing the critical parameters for each airship mission design. Simplified manual designs were

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also conducted for comparison and general verification of the computer airship designs.

The study includes airship sizes from 220,000 ~~ft$^3$~~ cu ft (18,000 lb vertical takeoff weight) to 3,000,000 ft$^3$ (230,000 lb vertical takeoff weight). ~~The~~ results show the unique features of the Bell unballasted, reversible-thrust airship design and the critical need for design optimization, owing to the sensitivity of the airship design parameters.

The computer design program shows airship conceptual differences and design trends rather than absolute design configurations, since it uses the preliminary subsystem weight relationships developed for recent airship parametric studies. Although the study design trends should remain valid, additional studies are recommended to establish better subsystem weight estimates and to incorporate life-cycle costing.

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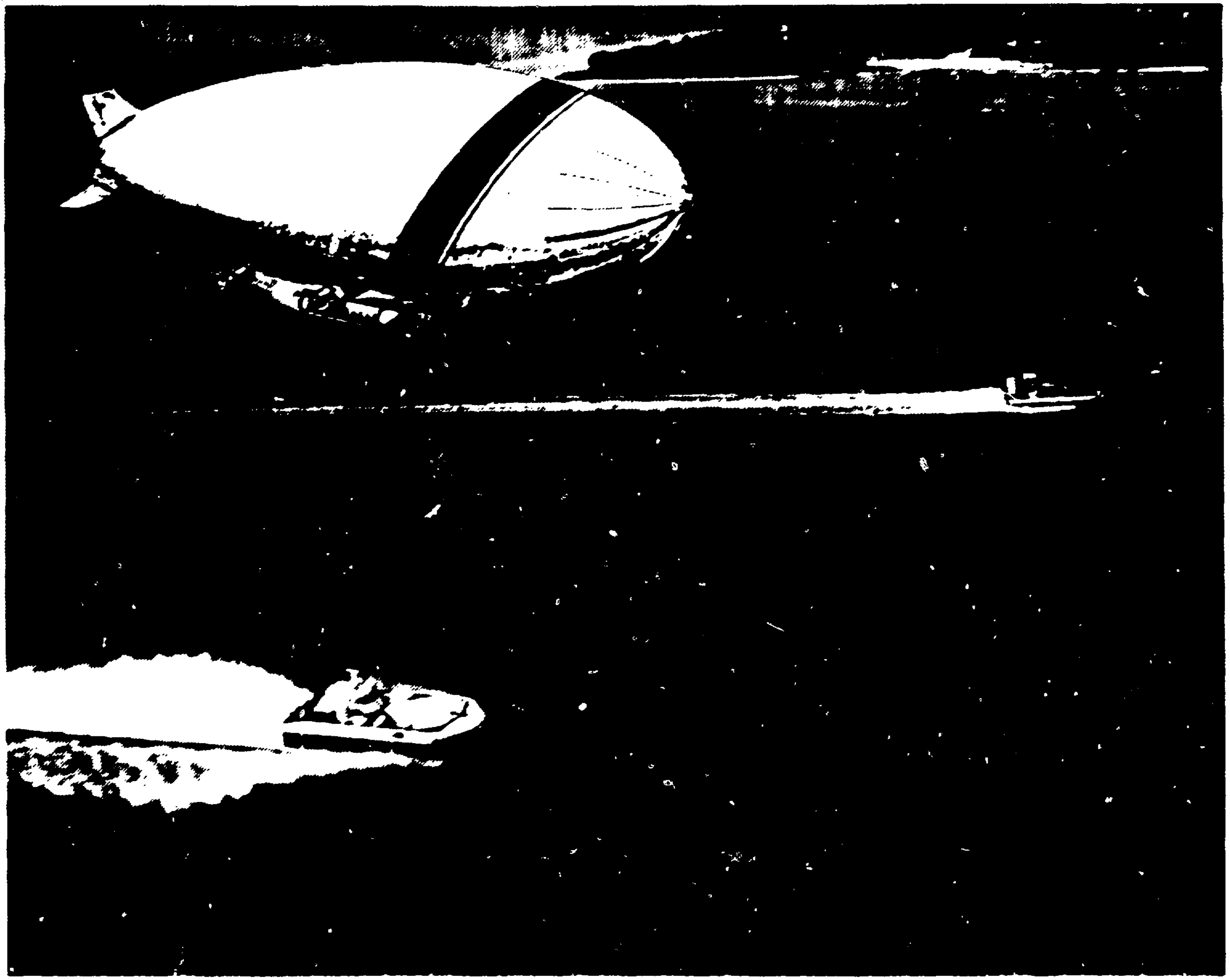

MARITIME PATROL AIRSHIP

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# INTRODUCTION

This Bell Aerospace Textron report presents the results of a preliminary conceptual design study for a maritime patrol airship (MPA). The resulting design not only has the traditional airship features of short takeoff and landing (STOL), long flight endurance, fuel economy, low noise, low speed, and safety, but it also has the added features of hover and ground taxi control, vertical takeoff and landing (VTOL), dash speed, and the elimination of the need for ballast and ballast transfer. Combined with the use of modern state-of-the-art materials, structures, and propulsion technologies, these new features are most important since they preclude the most significant traditional problems of previous airships, including ground handling and the resultant need for a large ground crew, lack of low-speed control, an inability to hover with precision in windy conditions, and the inconvenience of requiring ballast and ballast transfer to alleviate the effect of fuel and payload variations.

Bell's interest in the MPA and airships in general is a result of its pioneering aerospace tradition, its unique technological capabilities, and some specific airship innovations that have recently evolved at Bell. Founded in 1935 as Bell Aircraft Corporation, Bell Aerospace Textron is an aircraft and aerospace vehicle development company with a long and unique history of successful development of advanced and unconventional vehicles. Appendixes A, B, C, and D show the kind of Bell technological background that is being applied to the airship development. Moreover, Bell has the necessary technology in all disciplines, including systems management, which is both current and applicable to airship development. As an example, in addition to the background already mentioned, the marine systems experience and technology developed as part of the air cushion vehicle (ACV) and surface effect ship (SES) development is particularly applicable to airship technology. This current capability includes: the rugged inflatable seal structures that must withstand a severe weather and water impact environment; the turbine engine salt spray filtration systems; a strong engineering staff in vehicle design, aerodynamics, propulsion, stress and weights analysis, component and vehicle testing, and some personnel with airship development experience; the tilt-rotor development and hardware experience; the ducted and free propeller hardware experience; the design of control systems for aircraft which transition from vertical or horizontal flight; and the vehicle systems development and management team. Interest in airship development was further augmented by the technical innovations that substantially mitigated, and in some cases eliminated, the historical limitations previously encountered in airship operations.

The Bell MPA design, designated the Unballasted Reversible-Thrust Airship (URTA), has achieved its unique features by optimizing the vehicle buoyancy ratio and by providing a quad-rotor/tilt-propeller, reversible-thrust rotor propulsion system that can deliver extremely good control ability with any payload at any point in the mission by providing both positive and negative vectorable thrust.

The objectives for Bell in the U.S. Navy/U.S. Coast Guard MPA study were to develop conceptual vehicle designs to satisfy representative mission profiles provided by the contracting agency.

This report includes a brief discussion of mission definition and mission profiles provided by the Naval Air Development Center (NADC); a description of the vehicle concept and its operational characteristics; a discussion of computer and manual parametric tradeoff studies of airship size, weight, and performance; and a description of the preliminary point design configuration.

## 1. MISSION REQUIREMENTS

The various maritime roles considered for the MPA are listed below:

a. ENFORCEMENT OF LAWS AND TREATIES (ELT)

b. MARINE ENVIRONMENTAL PROTECTION (MEP)

c. MILITARY OPERATIONS/PREPAREDNESS (MO/MP)

d. PORT SAFETY AND SECURITY (PSS)

e. SEARCH AND RESCUE (SAR)

f. SHORT-RANGE AIDS TO NAVIGATION (A/N)

g. MARINE SCIENCE ACTIVITIES (MSA)

h. ICE OPERATIONS (IO).

These programs establish the performance requirements for the airship. They determine the needs for surveillance, trail, search and rescue, board and entry, marine pollution control, and other activities. Each program is characterized by a representative mission profile which specifies a sequence of operations or maneuvers to be executed from takeoff to landing.

The missions and mission profiles for each of the eight missions have been provided by NADC, and are presented in appendixes E and F for easy reference. Table 1 presents a summary of performance and payload requirements for each mission profile. Table 2 presents a breakdown of the MPA mission payloads.

## TABLE 1. MPA MISSIONS SUMMARY

| MISSION TASK | DURATION (HR) | TOTAL PAYLOAD (LB) | CRUISE SPEED (KT) | DASH SPEED (KT) | CREW* | MAXIMUM OPERATING ALTITUDE (FT) | TOW | PRIORITY |
|---|---|---|---|---|---|---|---|---|
| ELT<br>Enforce Laws and Treaties; Search and Board | 27.5 | 7,669 | 50 | 90 | 11 | 5,000 | - | 1 |
| MEP<br>Marine Environmental Protection; Cleanup | 12.5 | 22,372 | 50 | - | 6 | 5,000 | - | 2 |
| MO/MP<br>Military Operations; Military Preparedness; Tow ASW Arrays; Attack | 26.5 | 10,929 | 40 | 90 | 11 | 5,000 | Sonar | 4 |
| PSS<br>Port Safety and Security; Hazardous Vessel Escort | 8.35 | 6,237 | 40 | - | 6 | 5,000 | - | 5 |
| SAR<br>Search and Rescue; Search, Board, and Tow | 13.6 | 7,910 | 60 | 90 | 8 | 5,000 | Ship | 3 |
| A/N<br>Aids to Navigation; Buoy Maintenance | 17.0 | 7,396 | 50 | - | 8 | 1,000 | - | 6 |
| MSA<br>Marine Science Activities; Ice Patrol (St. Johns) | 35.5 | 7,761 | 60 | - | 11 | 5,000 | - | 7 |
| IO<br>Ice Mapping (Great Lakes | 20.5 | 7,482 | 60 | - | 6 | 5,000 | - | 8 |

*200 Lb Each

475-71

## TABLE 2. MPA MISSION PAYLOAD SUMMARY

| | WEIGHT (LB) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ELT | MEP | MD/MP | PSS | SAR | A/N | MSA | IO |
| **Permanent Equipment** | | | | | | | | |
| • Boat | 411 | 411 | - | - | 411 | 411 | 411 | 411 |
| • Rescue Equipment | 81 | 81 | 81 | 81 | 81 | 81 | 81 | 81 |
| • Dewatering Pumps | 110 | 110 | - | 220 | 110 | 110 | 110 | 110 |
| • Firefighting Equipment | 90 | 90 | - | 180 | 90 | 90 | 90 | 90 |
| • Towed Array System | - | - | 1,500 | - | - | - | - | 1,000 |
| • MAD Gear | - | - | 400 | - | - | - | - | - |
| • Buoy Maintenance Kit | - | - | - | - | - | 500 | - | - |
| **Expendable Equipment** | | | | | | | | |
| • Smoke and Light Floats | 42 | 42 | - | 84 | 84 | 42 | 42 | 42 |
| • Harbor Oil Boom | - | 440 | - | - | - | - | - | - |
| • Oil Recovery Devices | - | 15,000 | - | - | - | - | - | - |
| • MK-46NT (3) | - | - | 1,524 | - | - | - | - | - |
| • VLA/DIFAR (Dwarf) (20) | - | - | 200 | - | - | - | - | - |
| • Marker, BT, AN | - | - | 300 | - | - | - | - | - |
| **Permanent Provisions** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Expendable Provisions** | | | | | | | | |
| • Provisions, Water, Etc. | 315 | 78 | 304 | 52 | 114 | 142 | 407 | 128 |
| • Chemicals for Spill | - | 500 | - | - | - | - | - | - |
| **Crew** | 2,200 | 1,200 | 2,200 | 1,200 | 1,600 | 1,600 | 2,200 | 1,200 |
| **Fixed Payload** | | | | | | | | |
| • Sensor Suite | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 |
| • Avionics Suite | | | | | | | | |
| • Machine Gun and Ammo | | | | | | | | |
| • Winch and Controls | | | | | | | | |
| • Handling Lines | | | | | | | | |
| **Total** | 7,663 | 22,372 | 10,929 | 6,237 | 7,910 | 7,306 | 7,761 | 7,482 |

## 2. OPERATIONAL REQUIREMENTS

The airship design requirements are obviously a function of the intended mission. Therefore, a primary requirement for sizing an airship point design is a well defined mission. Although separate airship designs were evolved for each specific airship mission profile in the parametric study, the recommended initial prototype design must be able to perform more than one mission. Several general requirements have become evident, and designs under consideration must have:

a. VTOL. Essential for board and search operations, permits use of smaller landing fields, permits at-sea replenishment from vessels underway, and allows sea landings.

b. Precision-Hover and Low-Speed Control Capabilities. Required in the ELT, MEP, SAR, and A/N mission profiles for hovering; for towing operations in the MO/MP and SAR missions; and especially for all ground-handling operations.

c. Cruise Speed of About 60 Knots. Required for SAR, MSA, and IO mission profiles; and 50 knots needed for ELT, MEP, and A/N missions.

d. Dash Speed of 90 Knots. Needed for ELT, MO/MP, and SAR mission profiles.

e. Ability to Hover Over or Land On the Sea Near a Surface Craft. Important for board and search operations, rescue (rescue equipment is carried on all missions), and buoy maintenance activity.

f. Ability to Tow a Sonar Array. Essential for the MO/MP mission profile.

g. Ability to Tow a Small Disabled Surface Craft. Required for the SAR mission profile.

h. Payload Capability Up to About 22,000 Pounds. Required for the MEP mission profile.

i. Endurance Up to About 40 Hours. The MSA mission profile requires 35.5 hours, with a 10-percent fuel reserve.

j. Normal Altitude Capability of 5000 Feet with Full Payload (with ballonet capacity to permit a 10,000-foot altitude for emergencies).

The added ballonet capacity was included for emergencies and for transcontinental transport. The maximum altitude capability of 10,000 feet is possible to achieve with greater flight angles of attack or with reduced load, and has been standard in the past. It can easily be provided with oversize ballonets and without a significant weight penalty. Although it would be necessary to vent helium if the higher altitude had not been planned before the flight, the added ballonet capacity would provide safety in the event of an inadvertent altitude increase due to thermals, and would also provide greater speeds or reduced fuel consumption at altitude emergency conditions, since less thrust is required in the lower-density air. Also, the altitude flexibility could allow the use of more favorable winds and provide better visual conditions.

## 3. DESIGN CONCEPT

The preceding airship requirements, even VTOL and hover in favorable winds, could be met to some degree by previous existing airships. However, Bell advocates certain significant design improvements to show that modern technology and innovation can eliminate some of the limitations that have inhibited the use of the earlier airship designs.

Most important of these proposed design improvements is a swiveling, reversible-thrust propulsion system. Its advantages over and above proposed positive-thrust systems are listed below, and these features are discussed throughout this report:

a. The ability to precision hover, whether the airship is heavy, light, or neutrally buoyant, particularly since gusts can come in any direction and vertical equilibrium must be maintained in all three conditions (see section on Design Approach).

b. Reversible thrust, eliminating the need for ballast and ballast transfer for normal operations. (However, ballast pickup capability will be maintained to minimize fuel consumption for extended hover/loiter missions and in case of engine failure in the light condition.)

c. Downward thrust during ground taxi, which holds the airship to the ground and provides controllability in crosswinds, greatly reduces and in some cases eliminates traditional ground-handling problems and ground crews.

d. Using four vectorable rotors (quad-rotor configuration) with reversible thrust, thus positive control in low-speed and hover modes of operation can be provided.

e. The use of four reversible-thrust rotors permits the airship design to be a smaller, low-cost vehicle with lower fuel and maintenance costs.

The basic, key features of the Bell MPA are superior low-speed control, ground taxi capability, elimination of traditional ground-handling problems, elimination of the need for ballast or ballast transfer, larger payloads and better performance for same airship volume, smaller size with smaller propulsion system for lower initial and operating costs, and a unique sea anchor and float combination. These features are primarily a result of the vehicle design concept using the tilt-quad-rotor reversible-thrust propulsion system. However, much added advantage in weight and vehicle size is shown by basic good engineering design tradeoff optimization of the primary design parameters. This effort, which can be expanded even further, permits the selection of improved airship designs by providing improved and smaller aerodynamic envelope shapes and sizes for lower drag and more efficient envelope structures that best fit the various existing propulsion systems. The airship design curves for MEP missions shown in section 4 indicate a particularly sharply defined optimum suggesting a smaller, higher-speed envelope design may be the best, lowest cost configuration.

However, for the subsystem component weights, weight relationships used in previous NASA studies were used in the computer parametric study because of the limited scope of the program and to give a more direct comparison to previous airship studies. For this study, it is assumed that all possible known weight savings and design improvements that modern technology could provide were used in the formulation of these subsystem weights. As an example, it would include use of lighter, stronger materials (such as Kevlar fabrics) and suspensions systems and composite materials for a stronger, lightweight car and structural components. It would also assume the use of some subsystem design innovations such as the flotation/sea anchor subsystem described later in this report.

The following sections describe the airship, its operation, and the conceptual, operational, and design approaches.

## CONFIGURATION DESCRIPTION

For purposes of this study and the general parametric analysis, a basic configuration (figure 1) was assumed having the general features detailed in the following paragraphs.

The airship was assumed to be a nonrigid pressure airship with conventional ballonets fore and aft, internal suspension system, nose stiffening, and an empennage (and X-tail is shown in figure 1). A prime envelope fabric candidate is the standard Dacron-neoprene aluminized on the outside with a tensile strength-to-weight ratio of about 500,000 inches. Other envelope candidates would include laminated mylar fabric/aluminum foil composites, as well as Kevlar-reinforced materials.

The four turboprop propulsion units are less conventional. They incorporate reversible thrust, and both the turbine engines and propellers are tilted from vertical (up and down) to horizontal for forward flight, and back vertical for hovering, taxiing, or VTOL. Lateral thrust components for precision hover in crosswinds is obtained by vectoring the propeller thrust from the hub, or by cyclic pitch. To permit the tilting of the engines and propellers, they are mounted outboard on outriggers. These propulsion units would be similar to those used on the XV-15 (Bell Model 301) aircraft shown in figure 2 (see appendix D for additional details).

The vertical location of the propellers or rotors is difficult to optimize at this stage. Generally, the lower the rotors, the less the structural weight. However, a report by Neilsen Engineering and Research, Inc.,[1] shows some

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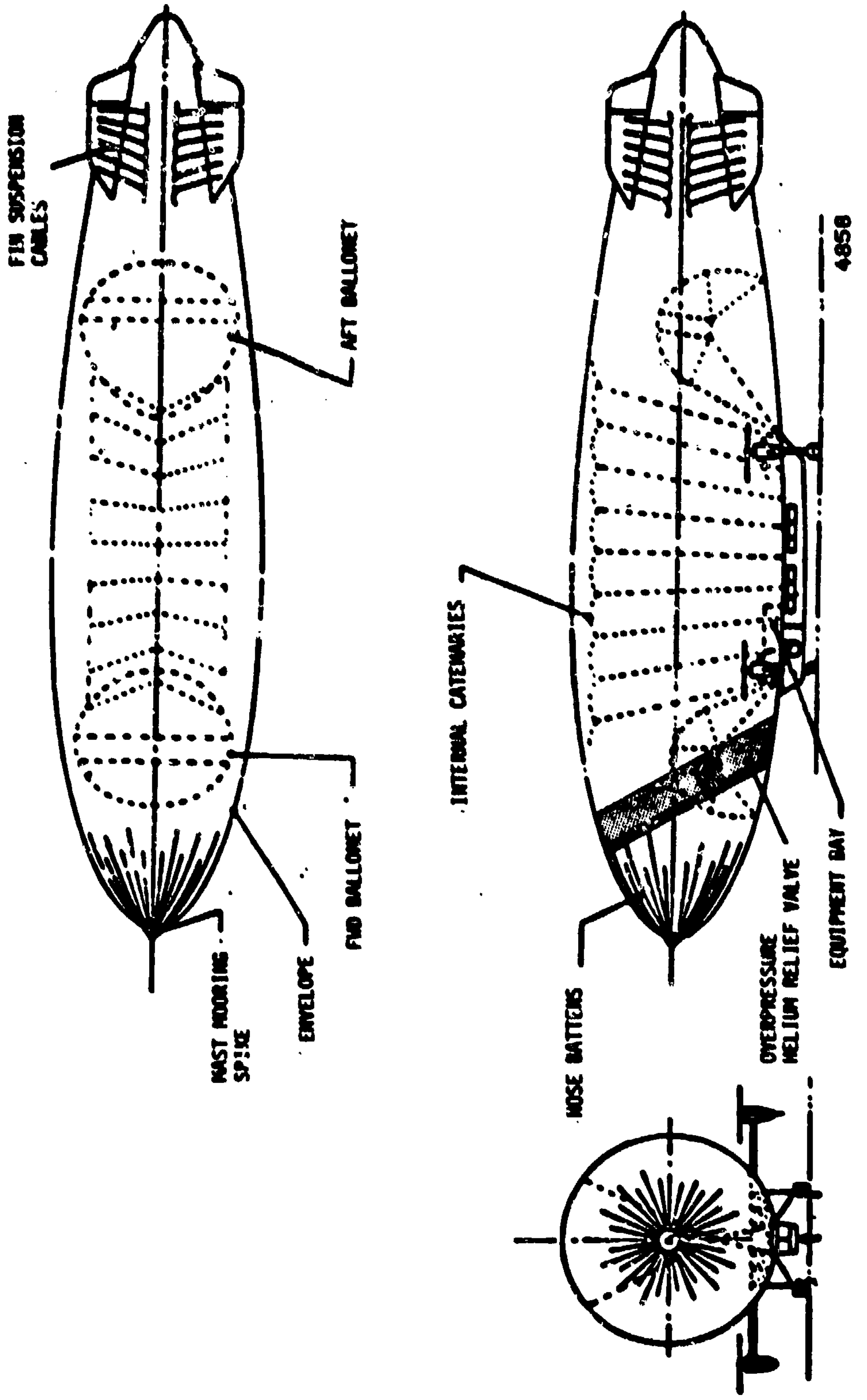
[1] S. B. Spangler and C. A. Smith, *Theoretical Study of Hull-Rotor Aerodynamic Interference on Semibuoyant Vehicles* (NASA Report CR-152127, April 1978).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EQUIPMENT BAY
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Figure 1 MARITIME PATROL AIRSHIP

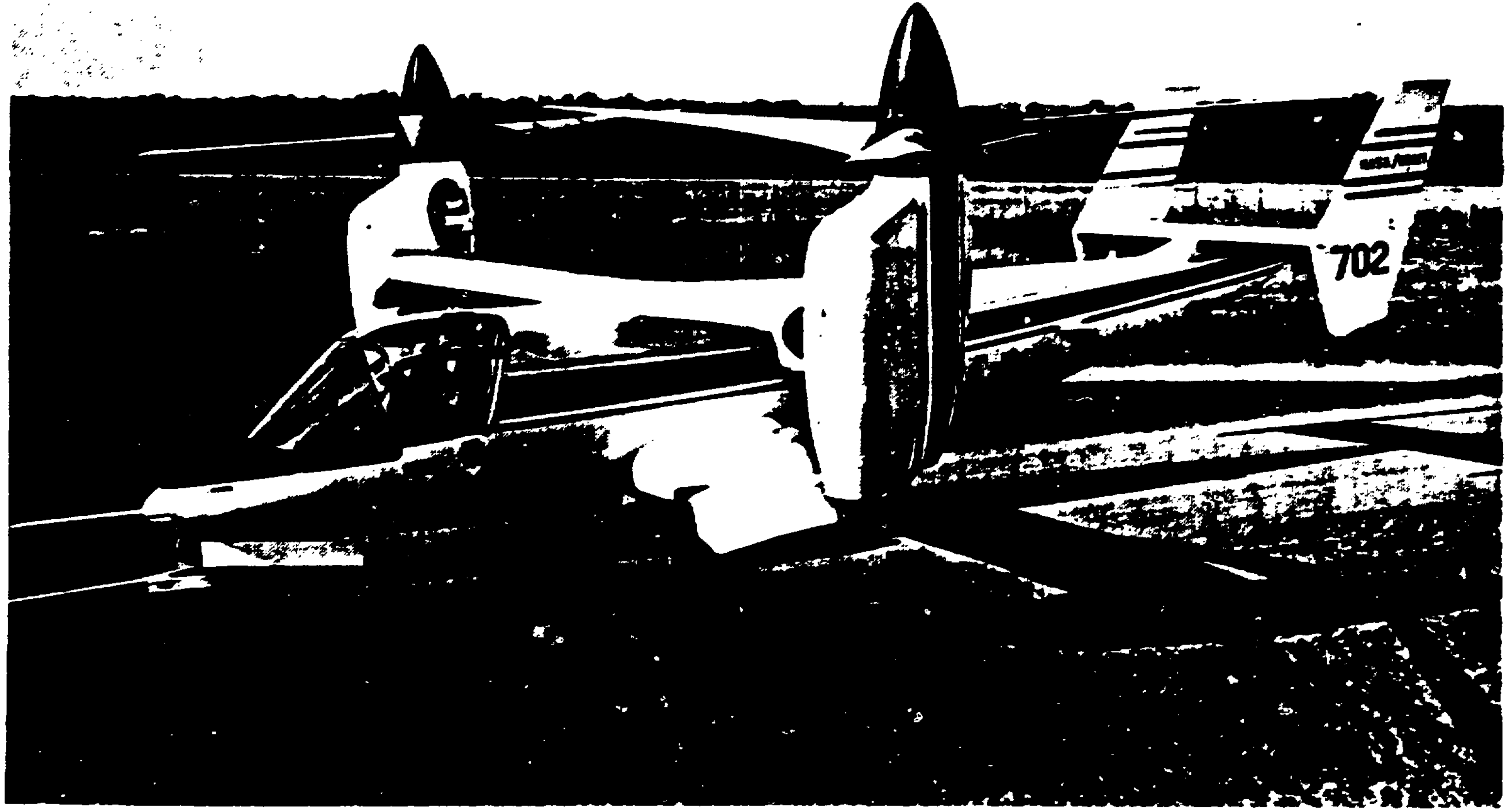


Figure 2 NASA/ARMY/BELL XV-15 TILT-ROTOR RESEARCH CRAFT (MODEL 301)

preliminary aerodynamic results from wind tunnel model testing of a heavy lift airship (HLA) which suggests that although some thrust augmentation is obtained by raising the level of the rotors up to a line 20 degrees below the horizontal drawn through the center of the envelope, very little is gained above 30 or even 45 degrees. However, below that, the effective lift of the rotors drops off rapidly. Historically, a data point is available from the airships *Akron* and *Macon*, which had swiveling propellers used for vertical thrust. Their propellers were located at about 37 degrees below the horizontal. For the proposed design, the location of the propellers for the vertical-thrust position was selected as 30 degrees down from the horizontal. Reference 1 also gives data showing that the rotors should be located as close to the hull as feasible. Clearance equal to 0.4 of the rotor radius has been used.

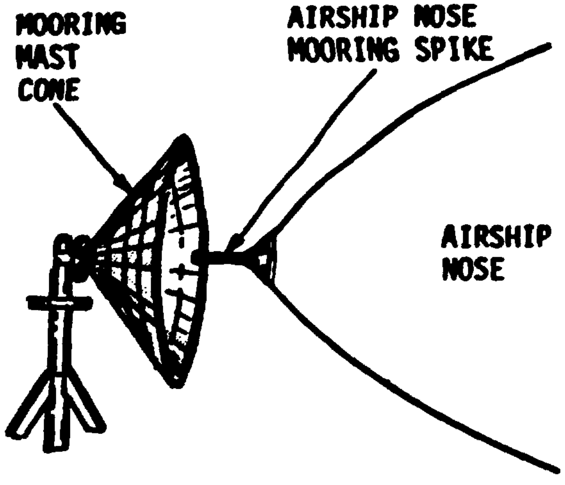
To provide the desired pitch and yaw control, the rotors must be located an appreciable distance apart. A relatively rigid structure is provided between the propulsion units, since the inflated envelope may be expected to be relatively soft in resisting local loads. To a degree then, depending on the separation of the forward and aft propulsion units, the airship tends to become a semirigid construction type.

In the MPA, where there is a large crew and where long mission durations may require accommodations and living space as well as space for fixed and movable equipment, a relatively large car is needed. It makes sense structurally to combine the car structure with the interconnecting structure between the forward and aft propulsion units. Since significant speed is a requirement of the full-scale patrol airship, the car will be streamlined. It will also have windows for observation, particularly in the forward end where the pilot's compartment will be located.

A tricycle landing gear is planned for the airship, consisting of a single wheel under the forward end of the car and two others at the aft end of the car and outboard for roll stability. Because of the elevation of the propulsion units, the legs of the gear would be impractically long if attached there, so they are mounted on the propulsion support structure near the sides of the car. The landing gear is retractable. Each wheel is castered.

Using downward and horizontal thrust components, the airship can be held stable on the ground and taxied to a mooring mast or even into a hangar in moderate crosswinds.

An automatic mooring system is planned for the airship. Although batten stiffening will be used on the airship nose, the conical mooring mast that will be used appears to be similar to the soft-nose mooring mast which has been developed for tethered balloons. As shown in figure 3, the patrol airship, with its high degree of hover and taxi precision, is nosed into the cone of the mooring mast, which guides the nose to the center so that the nose cone spike of the airship mates and locks into a female fitting at the apex of the cone.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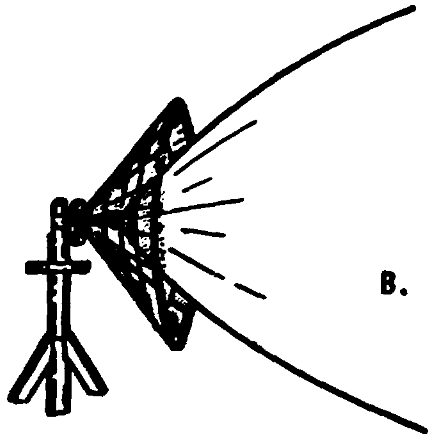
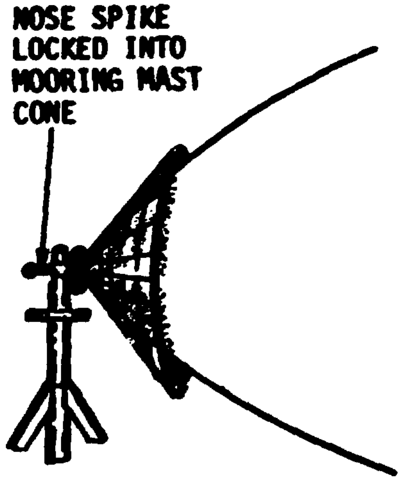
A. AIRSHIP NOSE APPROACHES CONE ON MOORING MAST



B. MAST CONE FUNNELS AIRSHIP NOSE INTO MOORING MAST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C. AIRSHIP NOSE SPIKE ENGAGES INTO MOORING MAST CONE

Figure 3 AIRSHIP AUTOMATIC MOORING MAST ENGAGEMENT TECHNIQUE

The cone with the airship is then free to turn through 360 degrees of azimuth. An aft tie-down line for the airship would use a hook running on a circular track. This tie-down hook would attach to the aft landing gear to prevent kiting (see figure 4).

The MPA will have a flotation system to permit water landing at sea. This system is under preliminary study and may result in a combined system of flotation bags and sea anchors (figure 5). However, inflatable, retractable, vertical floats are also being considered. These vertical floats are also depicted in figure 5.

Vertical floats are being considered because of their inherent stability as flotation devices. Previous tests conducted with vertical floats, such as the test with the flying boat shown in figure 6, indicate that human tolerance to sea state conditions improves very significantly with use of the vertical floats.

For added flotation stability sea anchors may be deployed and retracted automatically as part of the vertical float deployment and retraction. The floats are attached to both the main and nose gears. Sea anchors are extended from nose and tail locations to develop pitching stability in rough-water conditions.

## OPERATIONAL DESCRIPTION

The operational mode of the airship is depicted in figure 7. To start a mission, the airship propulsion system is started while still on the mooring mast. (Normally, but not necessarily, loading and refueling are done with the airship on the mast.) Whether light or heavy, the airship uses negative lift to hold itself down and provide ground-taxi capability. The mooring and tie-down attachments are then automatically released, and the airship achieves lateral, forward, and aft ground controllability by using the horizontal component of the negative thrust vector to steer and propel the craft in the desired direction.

At takeoff, the MPA may either take off vertically with the rotors thrusting directly upward, or it may make a conventional running takeoff down a runway with the rotors in a horizontal-thrust position. By inclining the rotors at some forward angle, a running takeoff with an extra-heavy load could be made, using dynamic lift from the envelope to augment the buoyant lift and the vertical-propulsive-thrust component. The length of takeoff would be a function of the amount of overload; however, most overload takeoff lengths would be relatively short (on the order of hundreds of feet rather than thousands).

In flight, the airship is initially heavy, and is flown at a positive angle of attack to provide dynamic lift to offset the heaviness in the conventional manner, with engines providing horizontal thrust. If needed, some upward tilt of the engines may be employed. As fuel and supplies are consumed, the airship becomes lighter, reaching neutral buoyancy when about 60 percent of the fuel

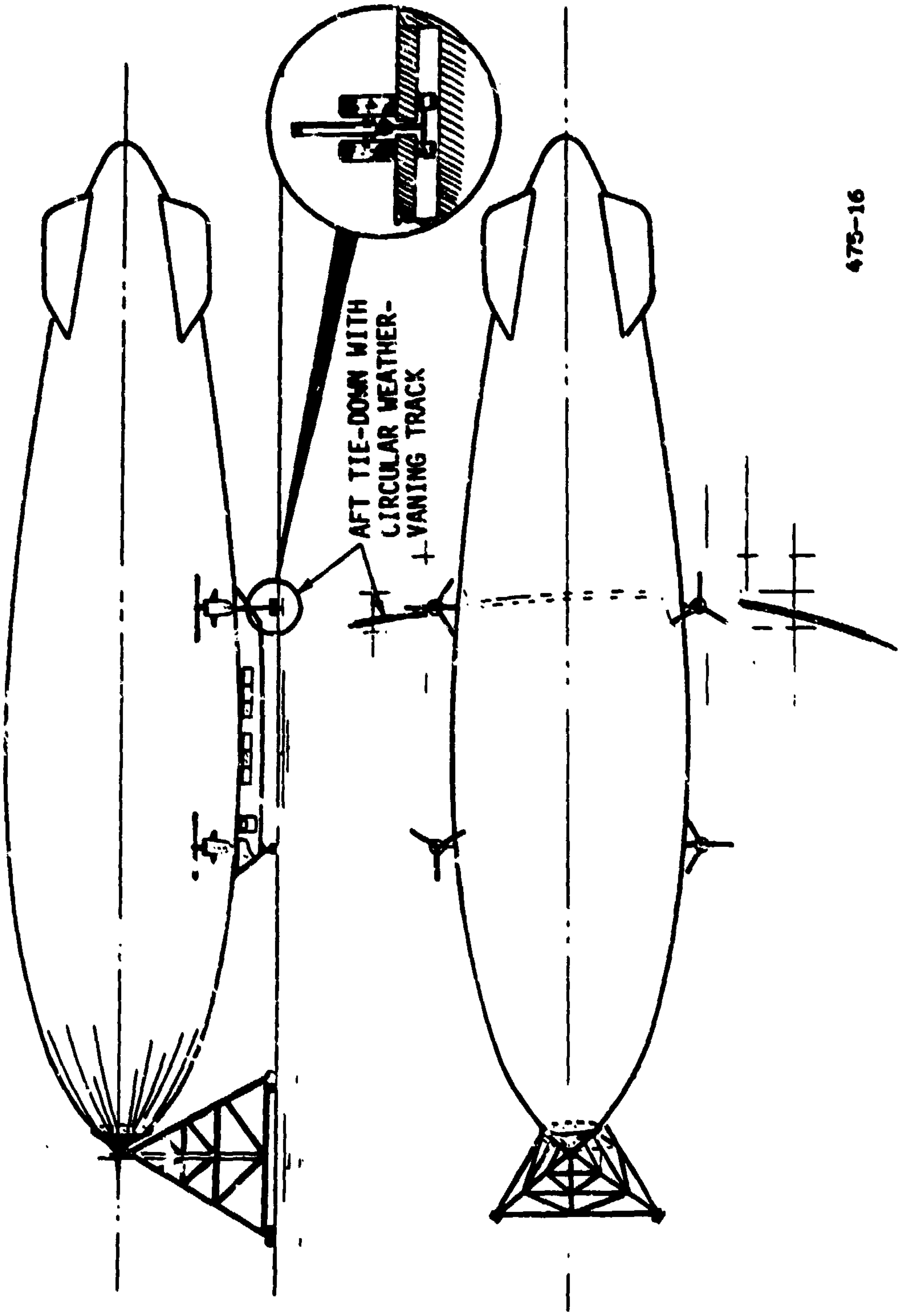

AFT TIE-DOWN WITH CIRCULAR WEATHER-VANING TRACK
475-16

Figure 4 AIRSHIP MOORING AND TIE-DOWN SYSTEM

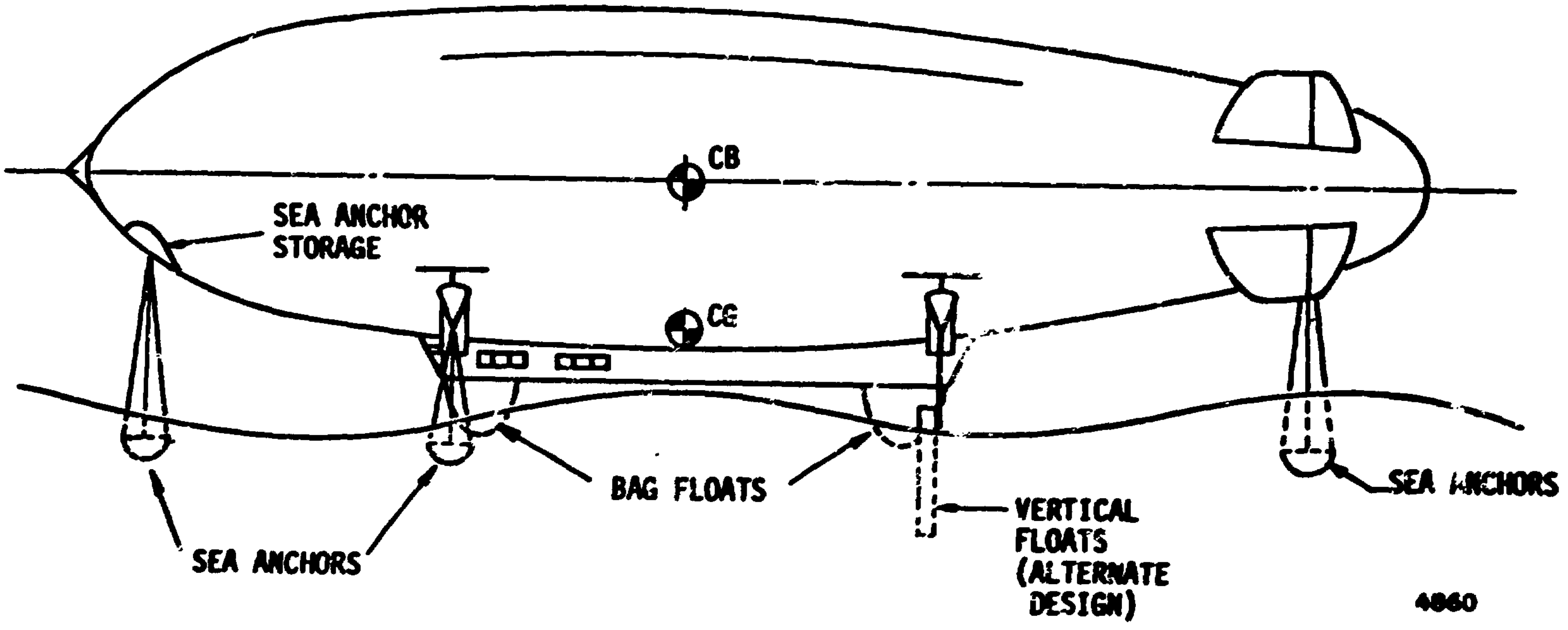

CB
CG
SEA ANCHOR STORAGE
SEA ANCHORS
BAG FLOATS
VERTICAL FLOATS (ALTERNATE DESIGN)
SEA ANCHORS
4860

Figure 5 FLOTATION AND SEA ANCHOR SYSTEM

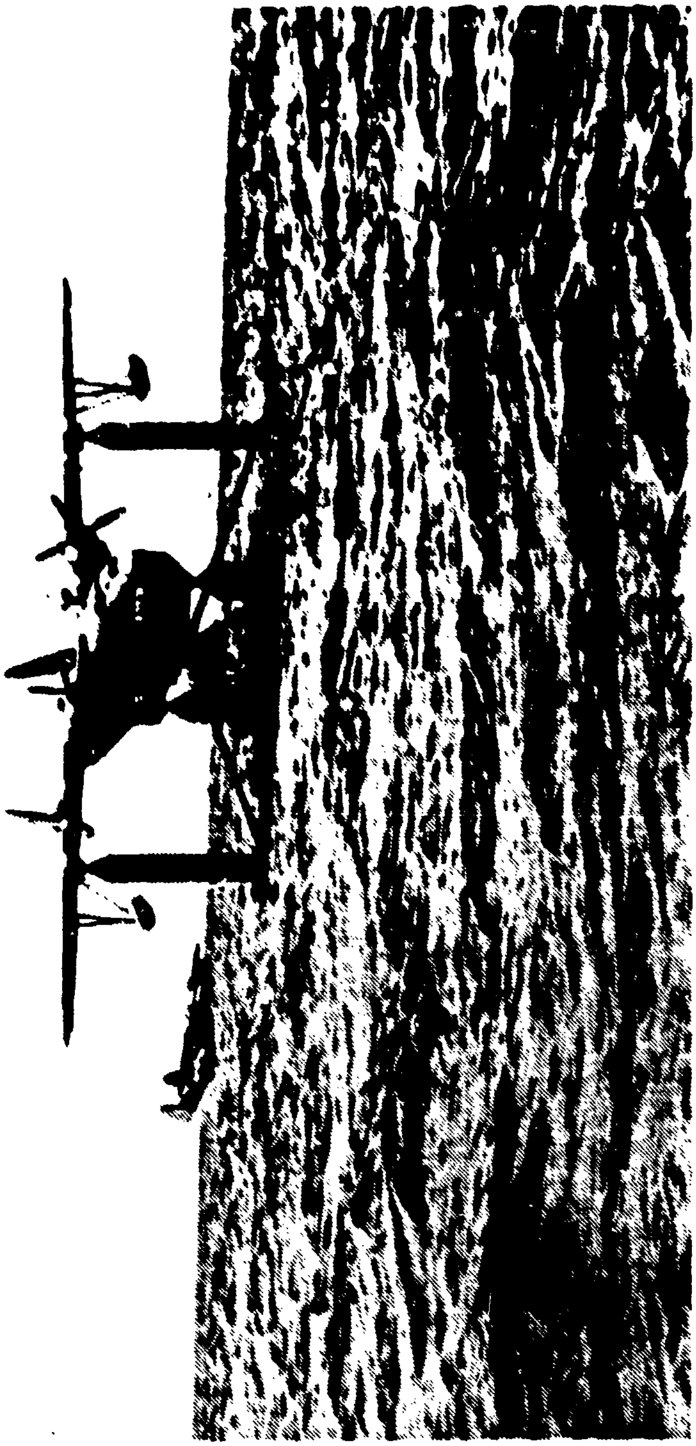
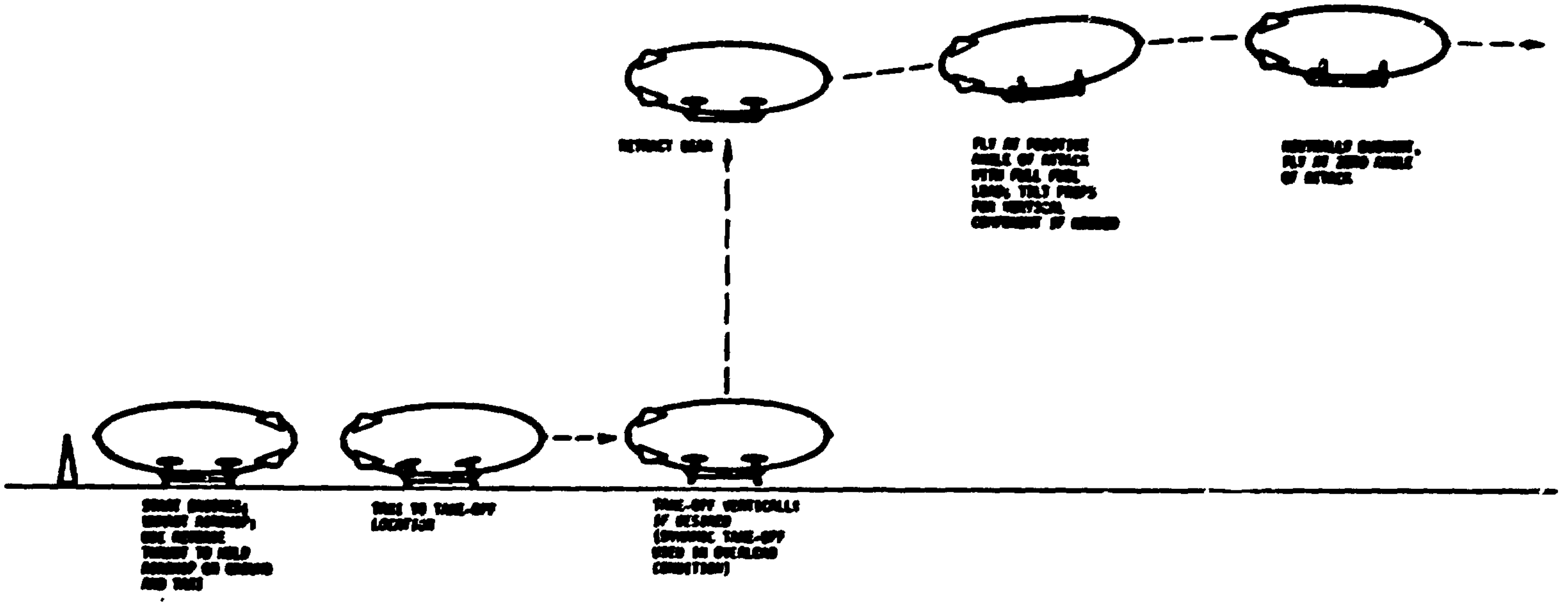
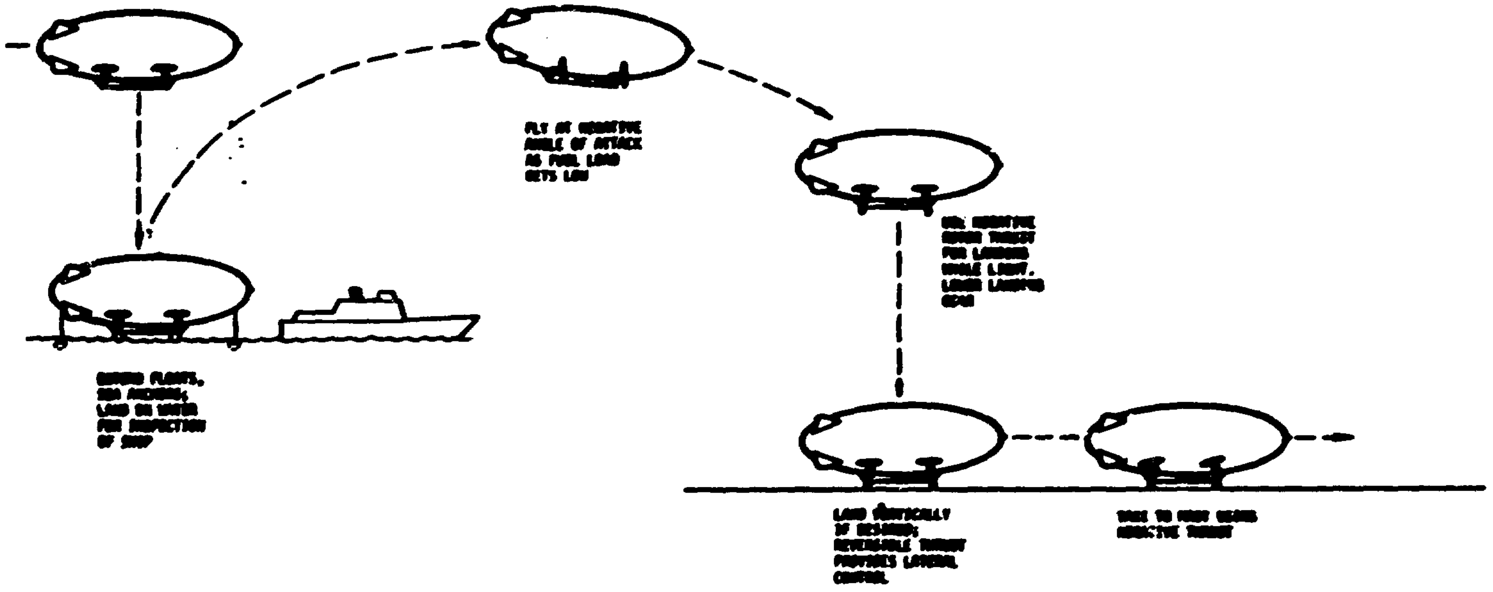


Figure 6 DEMONSTRATION OF FLOTATION STABILITY OF VERTICAL FLOATS


START ENGINES; [illegible] AIRSHIP; USE REVERSE THRUST TO HOLD AIRSHIP ON GROUND AND TAXI
TAXI TO TAKE-OFF LOCATION
TAKE-OFF VERTICALLY IF DESIRED (DYNAMIC TAKE-OFF USED IN OVERLOAD CONDITION)
RETRACT GEAR
FLY AT POSITIVE ANGLE OF ATTACK WITH FULL FUEL LOAD; TILT PROPS FOR VERTICAL COMPONENT OF THRUST
NEUTRALLY BUOYANT, FLY AT ZERO ANGLE OF ATTACK

4877 1/2

Figure 7 REVERSIBLE-THRUST MPA FLIGHT OPERATION (EI: MISSION)
(Sheet 1 of 2)


[illegible] FLOATS, SEA ANCHORS, LAND ON WATER FOR INSPECTION OF SHIP
FLY AT NEGATIVE ANGLE OF ATTACK AS FUEL LOAD GETS LOW
USE NEGATIVE [illegible] THRUST FOR LANDING WHILE LIGHT. LOWER LANDING GEAR
LAND VERTICALLY IF DESIRED; REVERSIBLE THRUST PROVIDES LATERAL CONTROL
TAXI TO [illegible] USING POSITIVE THRUST

4877 2/2

Figure 7 REVERSIBLE-THRUST MPA FLIGHT OPERATION (ELT MISSION)
(Sheet 2 of 2)

has been used. The angle of attack is reduced to maintain equilibrium, becoming approximately zero at neutral buoyancy, and is made negative to provide negative dynamic lift as the MPA becomes lighter than air. If necessary (eg, at low speed), the rotors can be given a tilt to provide a downward component of thrust. Maximum forward speed is obtained when the airship is neutrally buoyant and the rotor thrust is parallel to the axis of the airship. A typical Coast Guard mission is simulated in figure 8 monitoring an offshore oil rig.

With its long endurance, range, field of view, and relatively high-speed capability, the airship can maintain station, detect, overtake, and board even the fastest of surface craft such as the Bell-Halter 110-foot SES shown in the figure.

Landing is the reverse of takeoff. Negative thrust is used when the airship is light, and a lateral component of this thrust counteracts wind during hover and landing. It is also used for ground-taxi control. After taxiing to the mooring mast area, the airship, using its automatic mooring capability, drives its nose extension into the mooring cone, simultaneously engaging the ground-tether hookup fitting on the landing gear to a circular track tether attachment. Water or other ballast would be used for mooring in lieu of this automatic mooring system.

In some cases, a landing may not be desirable or even possible. Figure 9 shows an airship approaching its hover target. A hovering maneuver may be the only way to provide the emergency assistance to ships in rough seas as can be seen in the figure. In hover, as shown from a cockpit view in figure 10, the airship aligns itself into the wind and the Bell quad-rotor propulsion system provides the significant improvements in power and control that will permit airships to have many practical Coast Guard applications in even the most adverse weather conditions. When hovering over its target, the airship can lower and retrieve a service module to and from the deck of a ship.

## DESIGN APPROACH

As previously mentioned, when considering the previous list of operational requirements, it is clear that most of them can be generally satisfied by conventional, previously existing, nonrigid airships without the benefit of vectorable and reversible thrust. This provides a high level of confidence in the development capability of such a vehicle. However, because it lacks both power and power vector control, the conventional airship cannot fully achieve the controllability required for hover and VTOL operation. The conventional airship is able to hover only by heading into a steady wind of no less than about 20 knots, and it is difficult to control laterally in variable winds or if the winds subside.

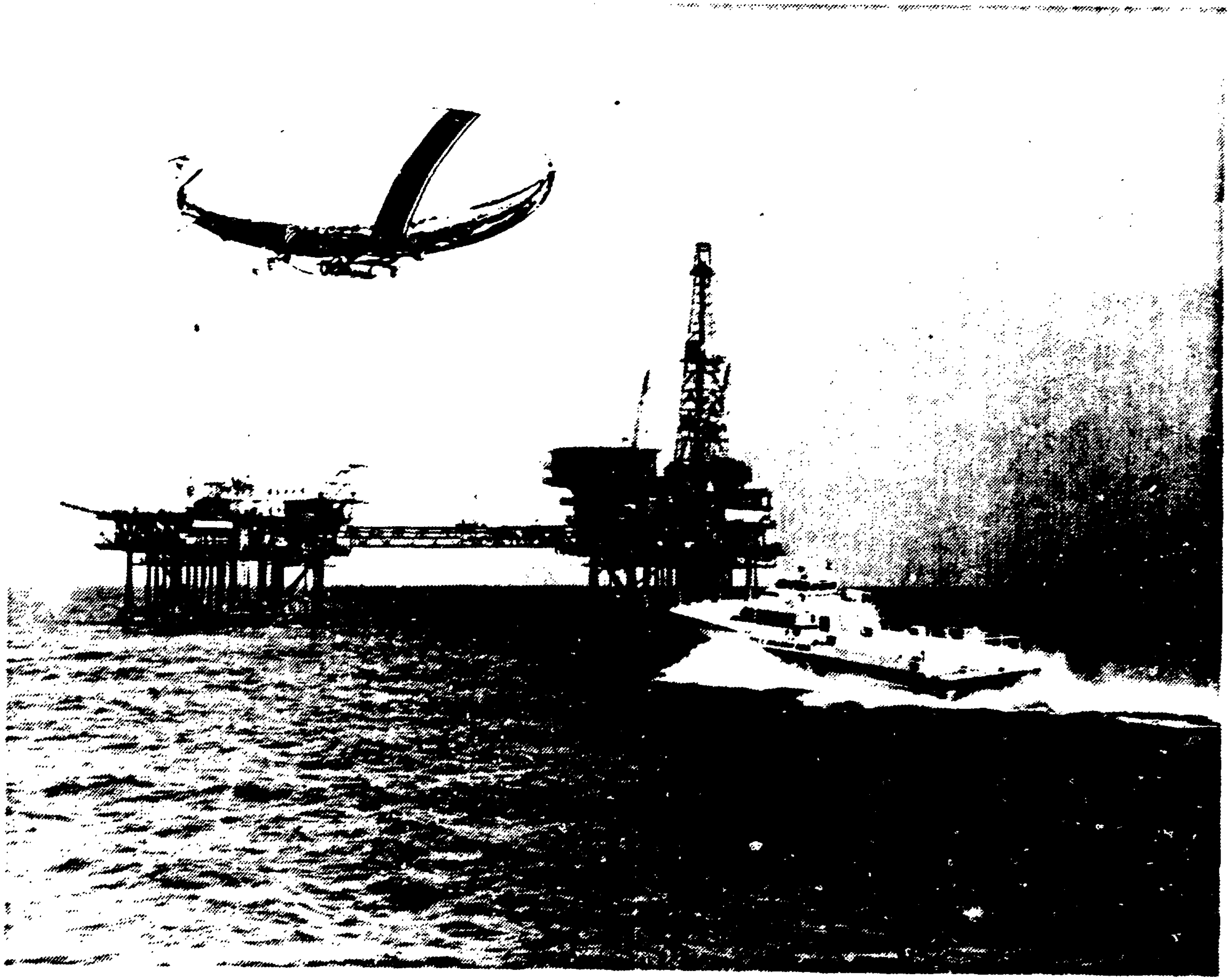


Figure 8 SIMULATED COAST GUARD MISSION MONITORING OFFSHORE OIL RIGS

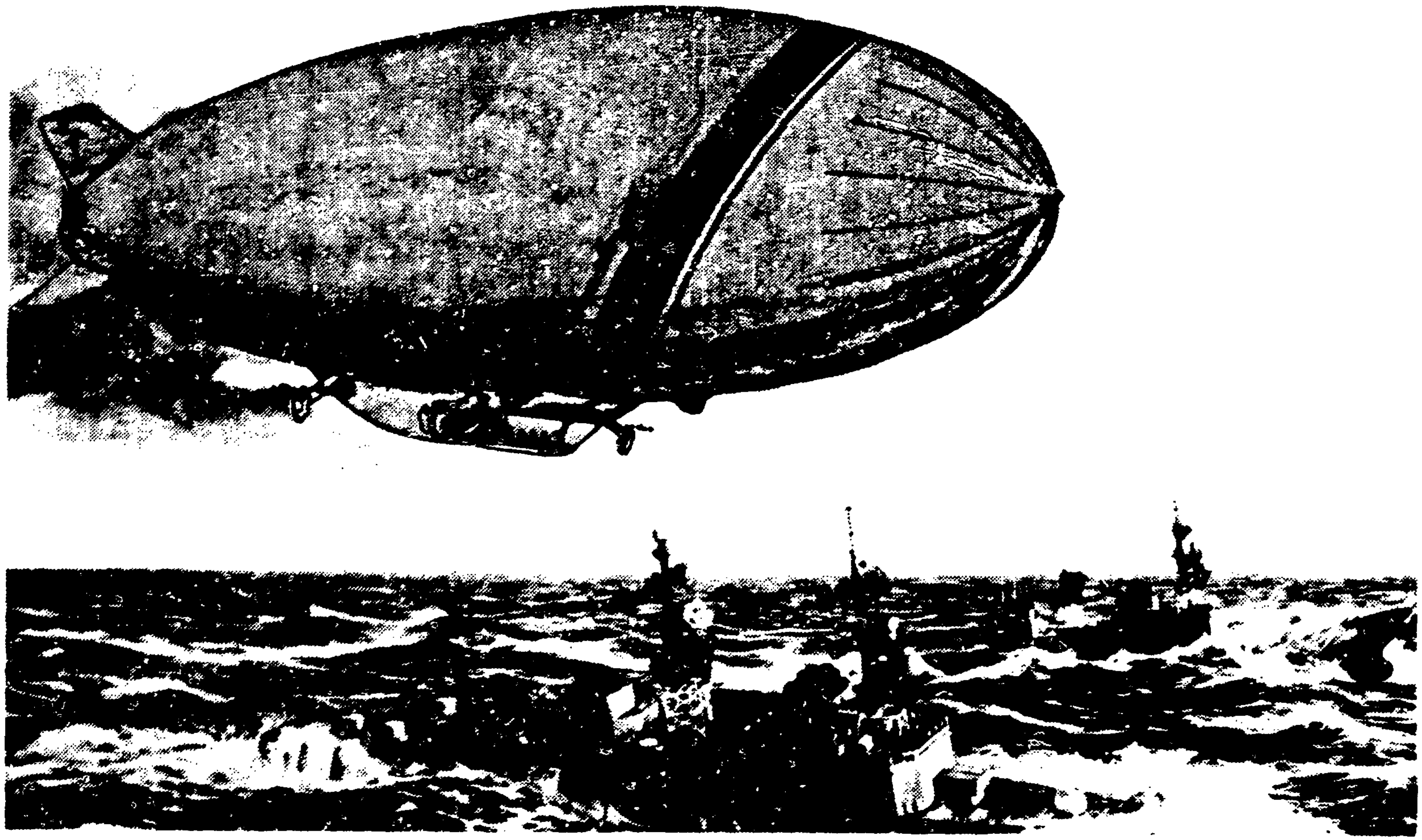


Figure 9 COAST GUARD AIRSHIP APPROACHING HOVER TARGET
(ARTIST CONCEPT)

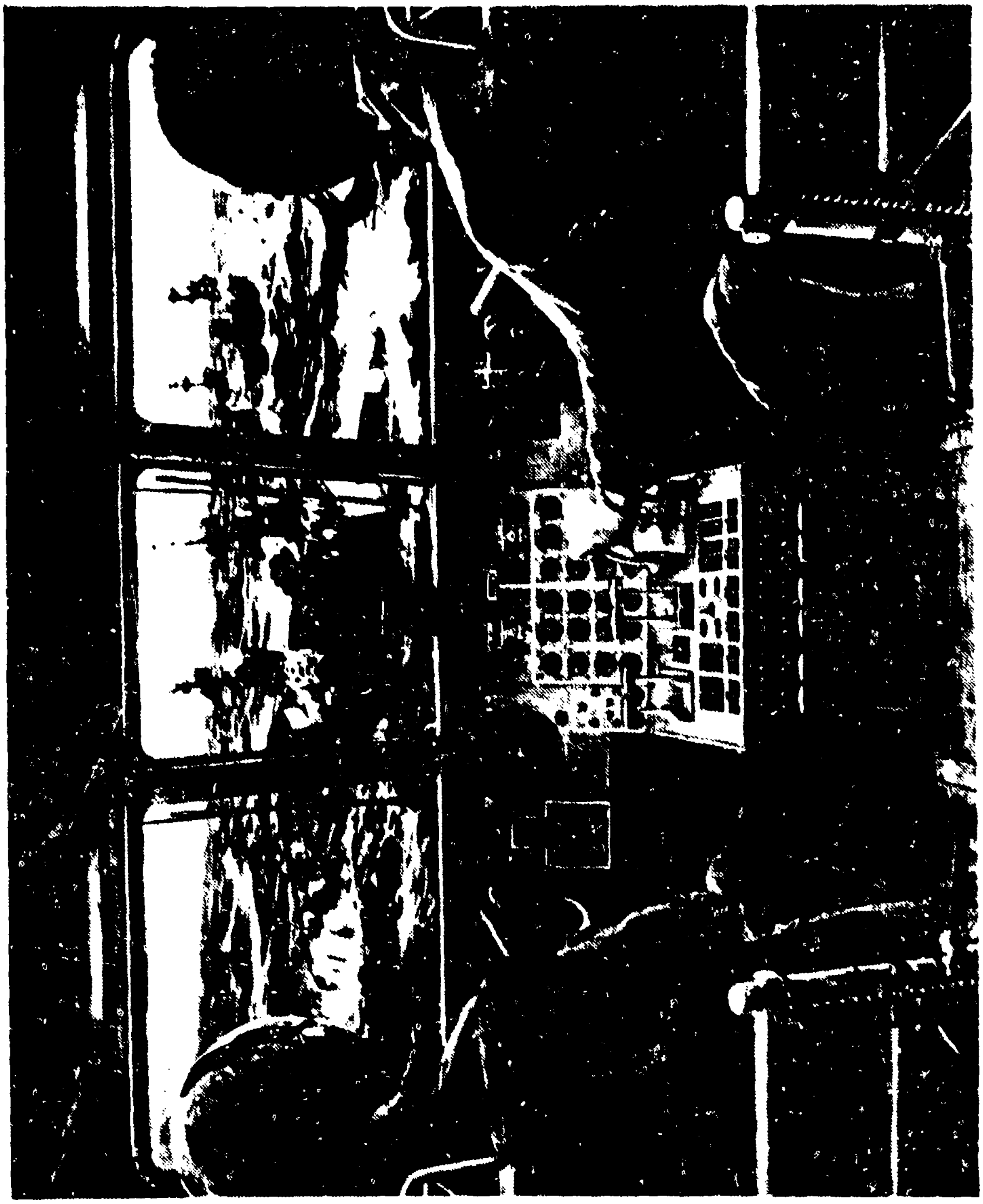


Figure 10 AIRSHIP COCKPIT VIEW OF LOW-SPEED APPROACH TO HOVER TARGET

Any airship gets lighter as it flies because it is using fuel. To maintain vertical equilibrium, a conventional airship can compensate in three ways:

a. By picking up water ballast (where possible)

b. By flying the airship at a decreasing positive angle of attack to reduce dynamic lift, or by flying at increasing negative angles of attack

c. By valving lifting gas (which is very undesirable).

In light winds during hover or at low speeds, very little dynamic lift would be available to the conventional airship. To compensate for fuel burned during hover, ballast would have to be picked up continuously. An alternative solution to this in the past has been the recovery of water from the engine exhaust gases; however, the recovery equipment is heavy and also creates drag.

Now if a rotor delivering vertically upward thrust is introduced, the situation is improved. By varying the thrust to match the heaviness of the airship, vertical equilibrium can be maintained. If the airship is light, ballast or a downward component of thrust is needed for equilibrium. Reversible thrust is, therefore, considered essential for precision hover. However, lateral and longitudinal components of thrust must also be available to resist the wind and gusts from any direction. Since these lateral components are produced by tilting the thrust vector, they are not independent of the vertical balance of forces. It follows that lateral equilibrium depends on the existence of a significant vertical component that depends on the heaviness or lightness of the airship, as well as gusting, when it reaches the hover point. This in turn depends on the amount of fuel consumed before the airship arrives at the hover point. If the mission requires transfer of personnel or equipment during hover, the vertical-thrust requirement is further complicated. Clearly, a vertical-thrust component must be available in either direction (up or down), depending on the situation, and at or near neutral buoyancy up and down thrust components of diagonally opposite rotors may be required simultaneously to maintain vertical equilibrium while developing lateral thrust. Even with this capability, further vertical, lateral, and longitudinal thrust variations are needed to compensate for gusting, which can come from any direction.

Large angular movements of a propeller or rotor are often impractical because of the high accelerations and gyroscopic forces which may be generated; this limits the usefulness of swiveling propellers or rotors. The Bell reversible-thrust quad-rotor concept solves these problems. Reversible-pitch propellers or rotors minimize the required angular tilting of the rotor plane, and with four rotors, lateral thrust near neutral buoyancy can be obtained by directing the thrust of the two diagonally opposite pairs of rotors in opposite (primarily vertical) directions. With only two rotors, this technique will result in an undesirable roll; in fact, equilibrium is possible only because of the natural pendulum stability of an airship.

There are other solutions to this problem, but they appear to be less desirable. For example, the negative-thrust requirement can be avoided by designing the MPA to fly heavier-than-air at all times, avoiding neutral buoyancy and using vertical rotor lift to stay aloft at low speeds, and dynamic lift from the hull at high speeds. This is possibly feasible for small payloads and fuel loads but would become very inefficient at large values as shown in the parametric tradeoff study (section 4). Alternatively, to minimize the heaviness of the MPA design, ballast would be required as payload was removed or fuel consumed. In this case, one of the desirable features, no ballast transfer, would be sacrificed. In addition, with the heavy-airship concept, the negative lift is not available to augment ground handling with an added downward force on the landing gear, as in the reversible-thrust concept.

In the case of an inadvertent engine failure, the quad-rotor reversible-thrust design has another advantage. If it occurs when the airship is heavy, not as much payload would have to be aborted since its lift is only partially dependent on rotor thrust. If the engine failure occurs when the airship is light, it has the advantage of abundant time to vent helium to achieve vertical equilibrium. At intermediate payloads engine failure should be less of a problem since the airship is usually closer to neutral buoyancy.

Oversized ballonets would be provided to handle the emergency condition where helium must be vented. The ballonets are not large weight items and will provide greater altitude capability with proportionally smaller payloads for high-altitude missions.

An advantage is seen, therefore, in using four rotors with reversible thrust, symetrically located with respect to the center of buoyant lift, to minimize roll moments otherwise expected with the power levels required for the subject missions. The control available with quad-rotor reversible thrust enables the MPA to hover over a stationary surface ship, or one moving in any direction, and to respond to changes in wind direction without having to change the heading of the airship. The concept also eliminates or minimizes the need for ballast transfer during a mission because it normally flies closer to neutral buoyancy, permits the airship to fly at a smaller angle of attack and to use less power and fuel in most situations (see section 4), and provides improved ground handling.

For reasons of accessibility during maintenance and repair, it does not appear desirable to locate the rotors at the elevation of the aerodynamic center of pressure in crosswinds. Since they will be lower, a small roll moment may be generated which can be balanced by the natural pendulum stability of the airship in roll.

Preliminary examination of the thrust requirements for the coastal patrol application suggests that the maximum thrust is normally required in the forward direction (although definition of lateral-thrust requirements may alter this initial expectation). To provide hover capability for VTOL and surface vessel boarding operations, a full 90-degree swivel of the rotor thrust in the pitch plane is then required. This is generally within the current state of the art as demonstrated by existing Bell multidirectional thrust aircraft including the XV-3 convertiplane VTOL, the twin-jet X-14 VTOL, the X-22A tri-service V/STOL, and the current NASA/Army XV-15 tilt-rotor aircraft. The XV-3 and X-14 can be found in appendix A, and the X-22A and XV-15 are shown in figures 11 and 2, respectively.

Another significant feature affecting the MPA configuration is the ability to land at sea (figure 5), if required. Several ways of doing this are conceivable. If the airship is slightly heavy, simple bag floats on the car, for example, are relatively light and simple but may require auxiliary devices to provide sufficient rolling and pitching stability. Floats near the bow and stern, and under the propulsion units (which must be well outboard because of envelope interference effects) are also possible. Heaving of individual floats in waves can be alleviated by making them extend vertically into the water, like spar buoys, to a depth where wave disturbances are relatively small (wave amplitudes diminish exponentially with depth). Design of such vertical floats, whether a hinged and/or extendable rigid type, or an inflatable fabric type filled partially with air and ballasted with water for stability and depth, initially appear attractive but may be somewhat heavy or complex compared to other approaches.

In addition to axial loads, they must withstand bending moments from the lateral forces exerted by the waves, and from water drag resistance to wind forces on the airship.

Because of its light weight and design simplicity, the float configuration currently selected for the MPA employs a combination of sea anchors and floats. In a normal heavy mode of operation, four flotation bags would extend from the fore and aft sections of the car. The sea anchors would be deployed from fore and aft locations on the envelope. In this way flotation is provided by the flotation bags, and stability is provided by the sea anchors.

In a normal light mode of operation, the flotation bags are not necessary and the airship would essentially be anchored in the desired position with the winching of the sea anchors providing the capability of vertically positioning the MPA. If weathervaning is desired, the airship would have to be ballasted for vertical equilibrium and moored only with a nose anchor.

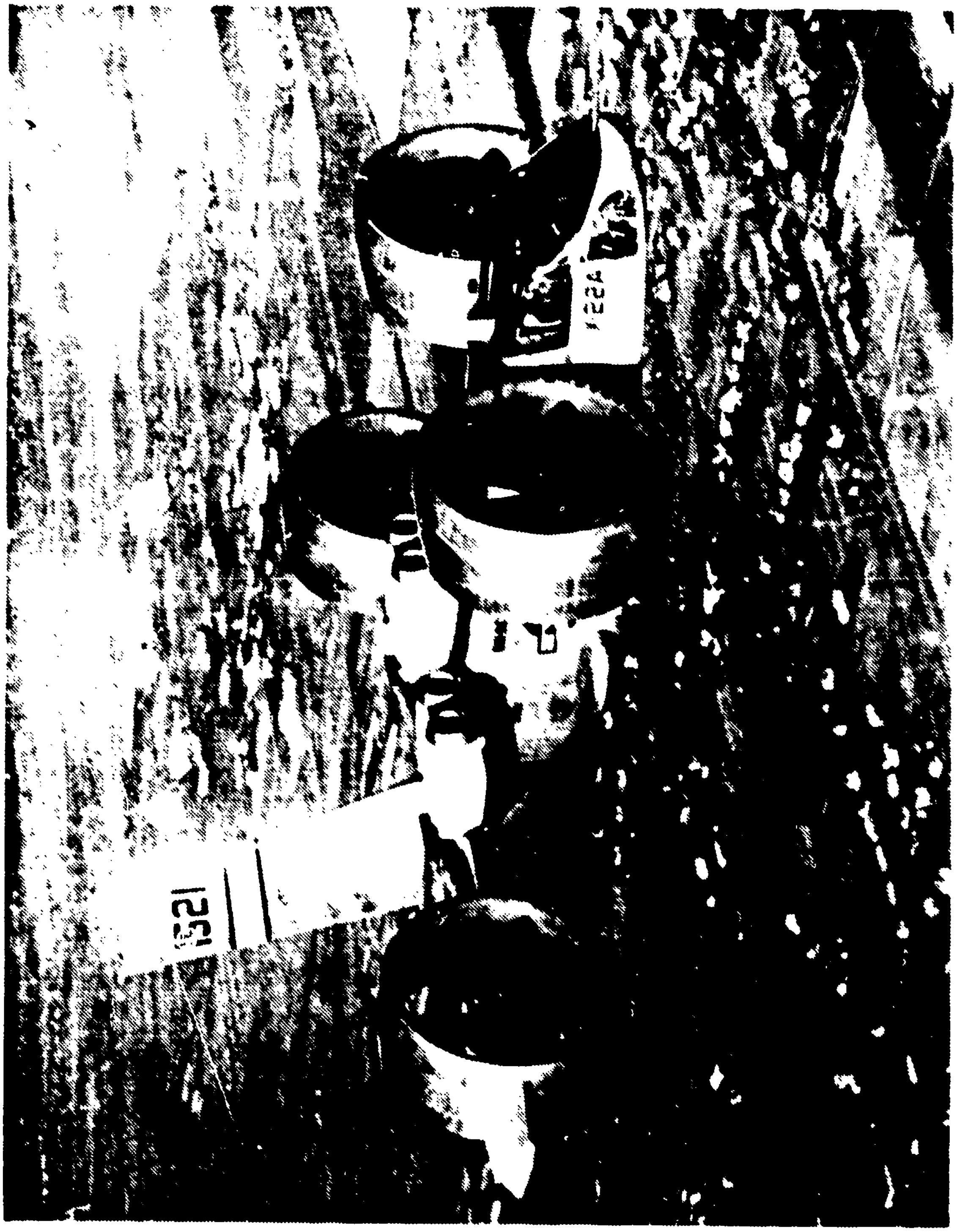


Figure 11 X-22A TRI-SERVICE V/STOL

Another operational variation of this concept, when the airship is heavy, would be to use the anchors together with positive thrust on the rotors. Near the surface of the water, the sea anchors are dropped and filled with water to hold the MPA down against the positive rotor thrust. In this way, the airship easily holds its position without the degree of pilot control required for normal hovering. The sea anchors also provide drag resistance to wind forces. Since the airflow is directed downward and the engine location is high, there should be little danger of water ingestion into the engines. Though fuel consumption may not be minimal, this use of sea anchors may be an excellent alternative to landing on rough water or trying to hover in gusty winds.

## SUBSYSTEM DESIGN TRADEOFFS

Several subsystem design tradeoffs were made and, although further study is needed to establish the final design, the results of these tradeoffs were used in the computer and the simplified manual airship sizing analyses. These subsystem tradeoffs included some state-of-the-art survey and some analysis to generally configure the subsystems.

The envelope slenderness ratio of about 4.5 is not necessarily optimum, and should be the subject of more detailed design study. The X-tail shown was found to provide the greatest stability in yaw, the smallest minimum turning radius, the ability to execute a 360-degree turn in the smallest amount of time, and the smallest power requirements of any of several tail configurations tested.[2] Similarly, the quad-rotor airship does have controllability without any tail at all, thus these advantages are not as significant as in a conventional airship. Other tail design considerations are that the larger the tail area, the more responsive it is to a crosswind gust during hover, and that possible wet snow accumulation on the tail may hamper operation of the control surfaces.

Test results from reference 2 indicated that the inverted Y-tail was comparable to the X-tail except that it did not turn the model as well. The inverted Y-tail would be superior to the X-tail as regards the danger of snow accumulation, but the X-tail appears to present less area for a crosswind gust to strike. However, in view of the comparable yaw stabilities, this difference is probably more apparent than real. Within the limits of the present study, the X-tail assumed seems as good as any; however, additional investigation will eventually be needed.

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[2] Albert Strumpf, *An Analysis of the Turning Characteristics of the XZP Airship Based Upon Underwater, Forced-Turning Model Experiments* (Stevens Institute of Technology, Report SIT-DL-54-534, October 1954).

A tricycle landing gear is shown, with the nose wheel under the pilot's compartment and the main wheels mounted off the aft engine outriggers. The latter are mounted inboard of the engines to avoid interference with the propulsion system, which must tilt, and are to be located to minimize outrigger bending moments while providing adequate roll stability. Roll stability on the ground is probably not an important consideration in locating the landing gear, however, since it can be provided by controlling vertical-thrust components, and has not been a problem with conventional airships on the mast.

The location of the rotors with respect to the envelope is a design parameter of considerable importance. Reference 1 includes some information of this type for a heavy-lift configuration with relatively large-diameter rotors in crossflow (figure 12). No data without crossflow is reported, and the results cannot be used without reservation. Negative values of $C_Z$ in figure 12 indicate upward forces on the hull, and positive values downward forces. A change of 1.0 in $C_Z$ corresponds approximately to the thrust of one rotor. The rotor thrust is always upward in figure 12, thus the aerodynamically best location for the rotors is in the upper part of the bottom half of the envelope, assuming that the same trend holds for other conditions than the 30-ft/sec crosswind for which figure 12 was obtained (reference 1).

Structurally, there are significant disadvantages in having the rotors placed so high. Unless some type of ring structure is used, the rotor support structure length is extended with an obvious increase in bending moment and weight. If the main landing gear is supported from the aft outrigger booms, the landing gear length, and consequently its weight, are increased.

With a tilt-rotor configuration such as that in figure 1, the centers of the rotors move upward as the propulsion units are rotated into the vertical-thrust attitude. A reasonable configuration is arrived at in figure 1 where the center of the rotors is approximately on a line 30 degrees below a horizontal axis through the envelope centerline and is, therefore, within the optimum zone indicated by figure 12. A preliminary analysis has indicated that a support such as is shown in figure 1 would be lighter than a complete ring supporting the outriggers and nacelles. However, a spoked ring has yet to be analyzed and might prove to be lighter. Structural rings in a pressure airship envelope may also have other advantages and disadvantages. For example, the cross section of a pressure airship is not truly circular, and in fact varies as a function of the envelope pressure and the loading. The ring would thus be subjected to loadings that would not exist if the ring were not there, and structural inefficiency must result. Further, the local loads on the envelope are undesirable both structurally and, probably, aerodynamically.

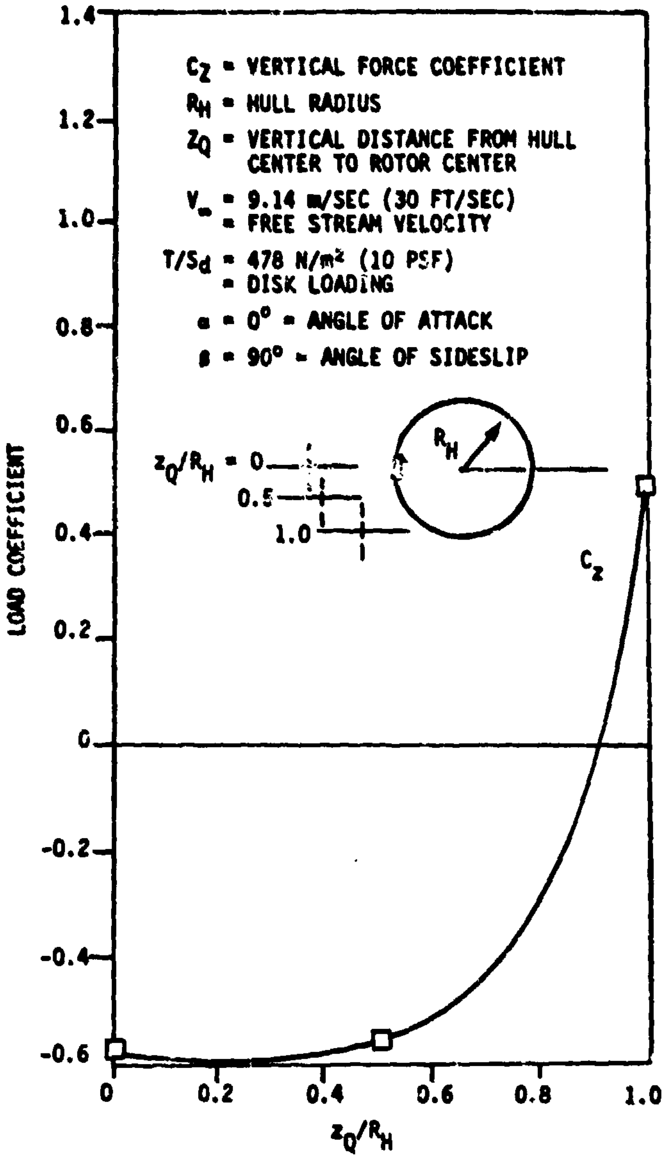

Figure 12 EFFECT OF ROTOR VERTICAL PLACEMENT ON HULL LOADS OF HEAVY-LIFT AIRSHIP IN CROSSFLOW (Ref 1)

The lateral position of the propulsion units is another variable of interest. Data presented in reference 1 indicates that, aerodynamically, the smaller the rotor clearance, the better. The minimum tip clearance tested was 0.43 times the rotor radius. Minimizing tip clearance also minimizes structural weight.

Nose mooring is assumed with an aft gear tie-down on a circular weathervaning track. Otherwise water ballast would be used for mooring where a circular track is not available.

Floats and/or sea anchors will be provided to give the MPA the ability to land on the sea near a surface craft for ease of boarding for inspection, or for assistance in emergency.

In addition, for the selected prototype design configuration, it was decided that the best initial prototype MPA point design should be configured with a current existing propulsion system to avoid a long and expensive propulsion system development program. Two Bell VTOL craft propulsion systems, the X-22A and the XV-15 (Bell Model 301), have been considered in particular (see appendix C). These systems represent the state of the art in tiltable, turboprop propulsion (see appendix D for Model 301 data). However, the computer parametric designs all used an ideal (rubberized) propulsion system, sized to fit each specific mission profile, to facilitate choice of a final vehicle and mission capability for a point design.

## 4. PARAMETRIC SIZE, WEIGHT, AND PERFORMANCE TRADEOFFS

As the mission definitions developed during the course of the program, it became apparent that the requirements of the various missions differed greatly, and led to a different MPA size for each mission. Although a fleet of eight different-size airships would be impractical, sizing an airship for each mission facilitates the evaluation of the cost of an airship to perform one, several, or all of the missions, according to priority.

Two methods were used for sizing the different airship configurations. One was a simplified manual design approach, and the other was a more complex computer design approach. The manual approach was first used to configure designs for the various missions. However, it quickly became evident that additional parameters would have to be traded off concurrently to be able to reflect a design sizing optimization. An initial attempt was made to use the CASCOMP program (developed by Boeing Vertol and modified by NASA) using a subsystem weight estimating relationship.[3] However, after reviewing the program, a number of program simplifications to make the program more adaptable for a parametric-tradeoff and sizing-optimization study were suggested. Moreover, not having a fully working program and being unfamiliar with the CASCOMP program development, it would be easier for Bell to develop an airship design program having sizing and performance as its primary objective. Also, since the Navy would be using CASCOMP, the Bell program could be used as a check on both the Bell manual airship designs and the Navy CASCOMP designs. Therefore, although the development of an airship sizing and performance computer program was beyond the scope of the current study program, it was decided to develop the program with company discretionary funds and, if the development was timely, the program could then be used to compare and enhance the manual airship design results. In retrospect, the computer program obviously became very useful since it yielded much more comprehensive parametric results. Therefore, because of its ability to quickly investigate many variations of the airship design parameters, the computer results are used for the primary parametric comparison of MPA point designs. In spite of its obvious limitations, the simplified design approach provides a useful independent check on the computer results and a convenient means of investigating aspects not covered by the computer program.

There are certain basic differences in the two approaches, the most important of which is that the simplified design approach develops configuations around one specific currently available power plant for all eight missions, so that the results are off-optimum. On the other hand, the computer program assumes the optimum engine to be available for each point design.

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[3] *Development of Weight Estimating Relationships for Rigid and Non-Rigid Heavy Lift Airships* (Goodyear Aerospace Corporation, NASA CR-151976, March 1977).

Therefore, since the computer approach has been used for the primary MPA comparison and evaluation, it is presented in the following paragraphs. For reference, the simplified manual design approach is presented in appendix G, together with a discussion on the comparison between the manual and computer design results.

The computer design program was developed so that the many variables affecting the MPA designs could be easily examined parametrically to determine optimum vehicle sizes, weight, and performance for the maritime patrol airship missions.

With a minimum of functional and debugging difficulties, the MPA computer program was developed to design any airship for any hover, tow, and flight conditions for any selected mission. The program operates by inputting rotor thrust to size the subsystems for hover, tow, and flight; it then iterates until the thrust level is achieved to meet all three conditions.

The primary features of the program are that it:

a. Designs airships of any buoyancy ratio

b. Designs for any amount of positive or reversible propulsive thrust

c. Uses modified CASCOMP subsystem weight equations

d. Adds fuel system tankage and empennage to above subsystem weights

e. Also adds extra car, air conditioning, and furnishings for added crew

f. Provides ballonet system for altitude capability

g. Provides propulsive thrust, horsepower, and weight as a function of velocity (based on historical data; see figure 13)

h. Provides positive and negative dynamic lift as function of angle of attack ($\alpha$)

i. Provides rotor lift and thrust as function of rotor tilt angle ($\phi$)

j. Provides flight performance as function of air density ($\rho$)

k. Derives airship lift and drag from previous existing airship data as function of envelope volume, horsepower, and speed

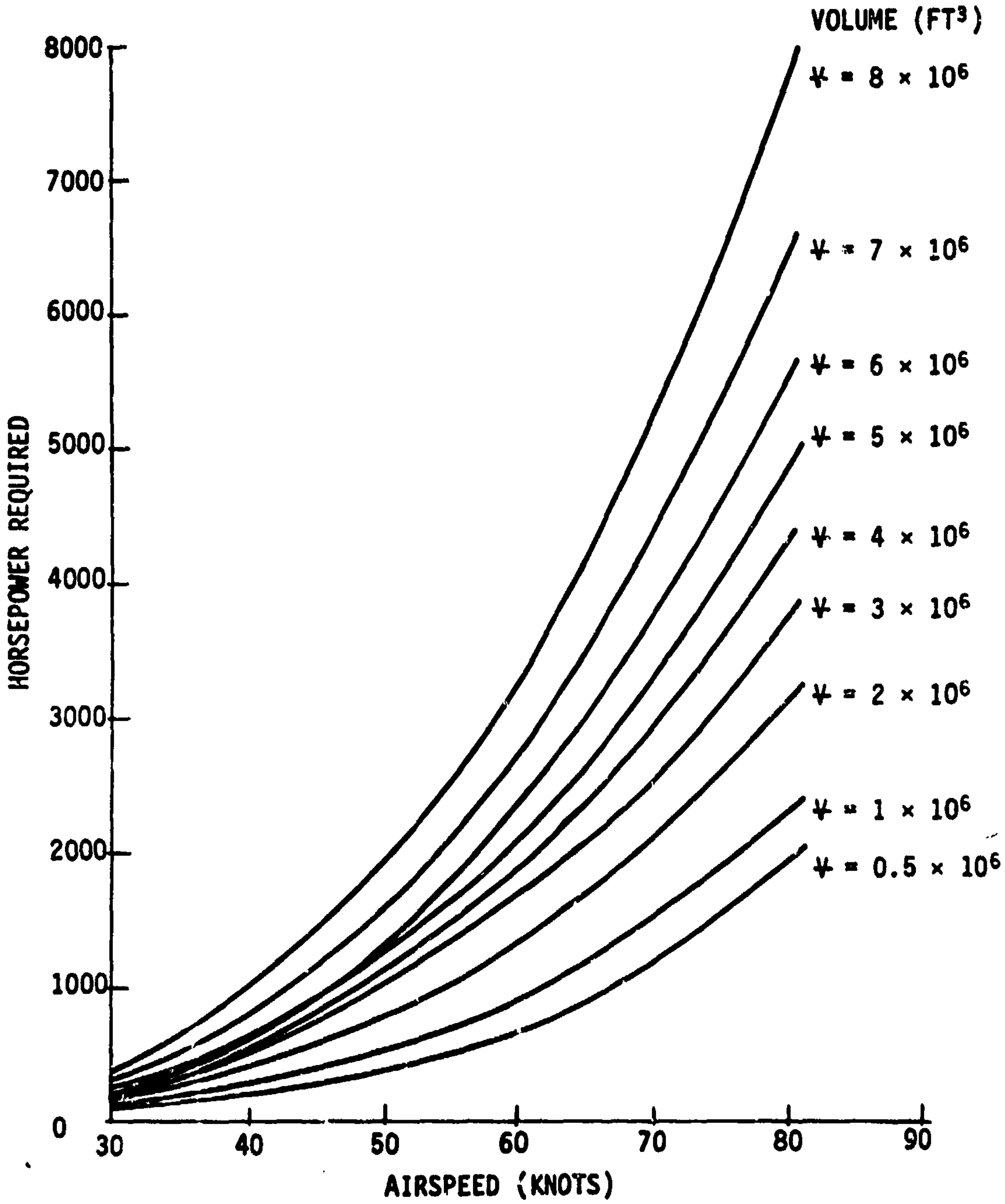


Figure 13 HORSEPOWER REQUIRED VERSUS AIRSPEED

l. Calculates fuel weights for specific mission profiles using a constant specific fuel consumption of 0.5 (see appendix H)

m. Derives hover-, cruise-, tow-, and dash-horsepower requirements, and sizes airship to provide for maximum condition.

A typical printout for the ELT mission is shown in table 3.

TABLE 3. ELT MISSION MPA WEIGHT AND ROTOR SIZING ESTIMATE

```
                                                              DATE    09/13/78

          R O T O R   D A T A                               F L I G H T   D A T A

NUMBER OF ROTORS                           4   *  MAXIMUM ALTITUDE                 5000.00 FT
NUMBER OF BLADES PER ROTOR                 3   *  MAXIMUM VELOCITY                   90.00 KT
ROTOR FIGURE OF MERIT                   0.75   *  CRUISE SPEED                       50.00
BLADE RADIUS (FT)                       7.00   *  LOITER SPEED                       30.00 KT
SOLIDITY RATIO                        0.1400   *  TOTAL ENDURANCE                    27.50 HR
BLADE CHORD (FT)                        1.17   *  RADIUS OF ACTION                  250.00 NM
ROTOR EFFICIENCY FACTOR                 0.85   *  TIME ON STATION                    11.00 HR
ROTOR LIFT-TO-USEFUL LOAD RATIO        0.583   *  CREW SIZE                             11 MEN
BLADE TIP SPEED (FPS)                 800.00   *  SPECIFIC FUEL CONSUMPTION           0.50 LB/HR/HP

           WEIGHTS AND LOADS                        AIRSHIP VOLUME,EMPTY WEIGHT ETC

MISSION PAYLOAD                 1049.00 LB  *  AIRSHIP VOLUME                        704083.4 CU.FT
                                               AIRSHIP EMPTY WEIGHT                  27194.79 LB
  EQUIPMENT                      734.00 LB  *    OUTRIGGERS                           1017.20 LB
   PERMANENT                     692.00 LB  *    INTERNAL SUPPORT STRUCTURE            809.15 LB
   EXPENDABLE                     42.00 LB  *    ENVELOPE                             6544.61 LB
                                                 SUSPENSION SYSTEM                    2020.98 LB
  PROVISIONS                     315.00 LB  *    BALLONETS AND AIR LINES               773.26 LB
   PERMANENT                       0.0  LB  *    MISCELLANEOUS ENVELOPE                765.70 LB
   EXPENDABLE                    313.00 LB  *    PRESSURE SYSTEM                      1141.17 LB
                                                 CONTROL CAR                          5500.00 LB
FIXED PAYLOAD                   4420.00 LB  *    LANDING GEAR                         2924.14 LB
FUEL                           13142.25 LB  *    FLIGHT CONTROLS                       800.74 LB
                                                 PROPULSION POD STRUCTURE              300.27 LB
DISPOSABLE LOAD                13499.25 LB  *    ROTOR SYSTEM                          810.98 LB
  FUEL                         13142.25 LB  *    DRIVE SYSTEM                          605.54 LB
  EXPENDABLE EQUIPMENT            42.00 LB  *    ENGINES                               638.53 LB
  EXPENDABLE PROVISIONS          315.00 LB  *    ENGINE INSTALLATION                   189.64 LB
                                                 INSTRUMENTS-NAVIGATION (FX.PLD)         0.0  LB
USEFUL LOAD                    22424.22 LB  *    INSTR.-ENG.-TRANS.-HYD.               746.10 LB
  DISPOSABLE LOAD              13499.25 LB  *    FUEL SYSTEM                           457.11 LB
  CREW                          2200.00 LB  *    ELECTRONICS              (FX.PLD)     0.0  LB
  PERMANENT EQUIPMENT            692.00 LB  *    EMPENAGE                              979.67 LB
  PERMANENT PROVISIONS             0.0  LB  *  LOAD LIFTED BY ENVELOPE               36632.52 LB
  FURNISHINGS                    478.34 LB  *  LOAD LIFTED BY ROTORS                 13188.49 LB
  AIR CONDITIONING              1136.63 LB  *  HORSEPOWER PER ROTOR FOR HOVER          687.33 HP
  FIXED PAYLOAD                 4420.00 LB  *  MAXIMUM POWER REQ D FOR DASH           2747.15 HP
```

## TABLE 3 (Cont)

### MISSION PERFORMANCE DATA

| TIME HRS. | FUEL USED LB | FUEL LEFT LB | ANGLE OF ATTACK DEG. | DYNAMIC LIFT LB | DYNAMIC DRAG LB | ALL MOTORS HP | TILT ANGLE DEG. | DRAG COEFF. | SPEED KT. | ALTIT. FEET |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.25 | 344. | 12798.6 | 0.0 | 0.0 | 0.0 | 2749.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.50 | 209. | 12589.8 | 10.00000 | 10530.6 | 4340.6 | 1670.2 | 61.94 | 0.0750 | 50.00 | 5000.0 |
| 0.75 | 204. | 12386.2 | 10.00000 | 10530.6 | 4340.6 | 1629.1 | 64.12 | 0.0750 | 50.00 | 5000.0 |
| 1.00 | 199. | 12187.2 | 10.00000 | 10530.6 | 4340.6 | 1592.2 | 66.34 | 0.0750 | 50.00 | 5000.0 |
| 1.25 | 195. | 11992.2 | 10.00000 | 10530.6 | 4340.6 | 1559.5 | 68.58 | 0.0750 | 50.00 | 5000.0 |
| 1.50 | 191. | 11800.9 | 10.00000 | 10530.6 | 4340.6 | 1530.6 | 70.84 | 0.0750 | 50.00 | 5000.0 |
| 1.75 | 188. | 11612.7 | 10.00000 | 10530.6 | 4340.6 | 1505.5 | 73.13 | 0.0750 | 50.00 | 5000.0 |
| 2.00 | 185. | 11427.2 | 10.00000 | 10530.6 | 4340.6 | 1483.9 | 75.43 | 0.0750 | 50.00 | 5000.0 |
| 2.25 | 183. | 11244.0 | 10.00000 | 10530.6 | 4340.6 | 1465.7 | 77.75 | 0.0750 | 50.00 | 5000.0 |
| 2.50 | 181. | 11062.6 | 10.00000 | 10530.6 | 4340.6 | 1450.9 | 80.07 | 0.0750 | 50.00 | 5000.0 |
| 2.75 | 180. | 10882.7 | 10.00000 | 10530.6 | 4340.6 | 1439.3 | 82.41 | 0.0750 | 50.00 | 5000.0 |
| 3.00 | 179. | 10703.9 | 10.00000 | 10530.6 | 4340.6 | 1430.9 | 84.76 | 0.0750 | 50.00 | 5000.0 |
| 3.25 | 178. | 10525.7 | 10.00000 | 10530.6 | 4340.6 | 1425.6 | 87.11 | 0.0750 | 50.00 | 5000.0 |
| 3.50 | 178. | 10347.7 | 10.00000 | 10530.6 | 4340.6 | 1423.4 | 89.46 | 0.0750 | 50.00 | 5000.0 |
| 3.75 | 174. | 10174.0 | 9.83157 | 10394.0 | 4260.4 | 1389.9 | 90.00 | 0.0736 | 50.00 | 5000.0 |
| 4.00 | 169. | 10005.4 | 9.61870 | 10220.2 | 4160.8 | 1348.8 | 90.00 | 0.0719 | 50.00 | 5000.0 |
| 4.25 | 164. | 9841.6 | 9.41344 | 10051.6 | 4066.5 | 1310.1 | 90.00 | 0.0703 | 50.00 | 5000.0 |
| 4.50 | 159. | 9682.4 | 9.21529 | 9887.9 | 3977.3 | 1273.8 | 90.00 | 0.0687 | 50.00 | 5000.0 |
| 4.75 | 155. | 9527.5 | 9.02380 | 9728.6 | 3892.6 | 1239.6 | 90.00 | 0.0673 | 50.00 | 5000.0 |
| 5.00 | 151. | 9376.5 | 8.83856 | 9573.7 | 3812.1 | 1207.4 | 90.00 | 0.0659 | 50.00 | 5000.0 |
| 5.25 | 147. | 9229.4 | 8.65918 | 9422.8 | 3735.6 | 1176.9 | 90.00 | 0.0646 | 50.00 | 5000.0 |
| 5.50 | 144. | 9085.9 | 8.48532 | 9275.7 | 3662.8 | 1148.1 | 90.00 | 0.0633 | 50.00 | 5000.0 |
| 5.75 | 140. | 8945.8 | 8.31666 | 9132.1 | 3593.4 | 1120.8 | 90.00 | 0.0621 | 50.00 | 5000.0 |
| 6.00 | 137. | 8808.9 | 8.15291 | 8992.0 | 3527.1 | 1094.9 | 90.00 | 0.0610 | 50.00 | 5000.0 |
| 6.25 | 134. | 8675.1 | 7.99380 | 8855.2 | 3463.9 | 1070.4 | 90.00 | 0.0599 | 50.00 | 5000.0 |
| 6.50 | 131. | 8544.3 | 7.83907 | 8721.4 | 3403.4 | 1047.0 | 90.00 | 0.0588 | 50.00 | 5000.0 |
| 6.75 | 128. | 8416.2 | 7.68851 | 8591.5 | 3345.3 | 1024.8 | 90.00 | 0.0578 | 50.00 | 5000.0 |
| 7.00 | 125. | 8290.7 | 7.54190 | 8462.4 | 3290.0 | 1003.6 | 90.00 | 0.0569 | 50.00 | 5000.0 |
| 7.25 | 123. | 8167.8 | 7.39903 | 8337.0 | 3236.9 | 983.5 | 90.00 | 0.0559 | 50.00 | 5000.0 |
| 7.50 | 121. | 8047.2 | 7.25973 | 8214.0 | 3185.9 | 964.2 | 90.00 | 0.0551 | 50.00 | 5000.0 |
| 7.75 | 118. | 7929.0 | 7.12381 | 8093.5 | 3137.0 | 945.8 | 90.00 | 0.0542 | 50.00 | 5000.0 |
| 8.00 | 116. | 7813.0 | 6.99113 | 7975.3 | 3090.0 | 928.2 | 90.00 | 0.0534 | 50.00 | 5000.0 |
| 8.25 | 114. | 7699.1 | 6.86154 | 7859.2 | 3044.8 | 911.4 | 90.00 | 0.0526 | 50.00 | 5000.0 |
| 8.50 | 112. | 7587.1 | 6.73488 | 7745.3 | 3001.3 | 895.3 | 90.00 | 0.0519 | 50.00 | 5000.0 |
| 8.75 | 110. | 7477.2 | 6.61104 | 7633.4 | 2959.4 | 879.9 | 90.00 | 0.0512 | 50.00 | 5000.0 |
| 9.00 | 108. | 7369.0 | 6.48998 | 7523.4 | 2919.1 | 865.1 | 90.00 | 0.0505 | 50.00 | 5000.0 |
| 9.25 | 106. | 7262.7 | 6.37130 | 7415.3 | 2880.3 | 850.9 | 90.00 | 0.0498 | 50.00 | 5000.0 |
| 9.50 | 105. | 7158.0 | 6.25518 | 7308.9 | 2842.8 | 837.2 | 90.00 | 0.0491 | 50.00 | 5000.0 |
| 9.75 | 103. | 7055.0 | 6.14143 | 7204.3 | 2806.7 | 824.1 | 90.00 | 0.0485 | 50.00 | 5000.0 |
| 10.00 | 101. | 6953.6 | 6.02994 | 7101.2 | 2771.8 | 811.5 | 90.00 | 0.0479 | 50.00 | 5000.0 |
| 10.25 | 100. | 6853.6 | 5.92062 | 6999.8 | 2738.1 | 799.4 | 90.00 | 0.0473 | 50.00 | 5000.0 |
| 10.50 | 343. | 6510.2 | 1.19050 | 6899.9 | 5728.7 | 2747.2 | 90.00 | 0.0306 | 90.00 | 5000.0 |
| 10.75 | 341. | 6168.8 | 1.13484 | 6554.5 | 5701.6 | 2731.3 | 90.00 | 0.0304 | 90.00 | 5000.0 |
| 11.00 | 108. | 6060.7 | 0.0 | 0.0 | 0.0 | 864.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11.25 | 78. | 5982.4 | 10.00000 | 3968.5 | 1010.9 | 626.4 | 40.26 | 0.0750 | 30.00 | 50.0 |
| 11.50 | 76. | 5906.3 | 10.00000 | 3968.5 | 1010.9 | 609.1 | 41.32 | 0.0750 | 30.00 | 50.0 |
| 11.75 | 74. | 5832.2 | 10.00000 | 3968.5 | 1010.9 | 592.7 | 42.39 | 0.0750 | 30.00 | 50.0 |
| 12.00 | 72. | 5760.1 | 10.00000 | 3968.5 | 1010.9 | 577.2 | 43.48 | 0.0750 | 30.00 | 50.0 |
| 12.25 | 97. | 5662.7 | 0.0 | 0.0 | 0.0 | 779.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12.50 | 83. | 5579.2 | 4.57023 | 5708.9 | 2363.9 | 667.9 | 90.00 | 0.0409 | 50.00 | 5000.0 |
| 12.75 | 83. | 5496.6 | 4.48550 | 5625.4 | 2343.0 | 660.7 | 90.00 | 0.0405 | 50.00 | 5000.0 |
| 13.00 | 82. | 5414.9 | 4.40199 | 5542.8 | 2322.7 | 653.8 | 90.00 | 0.0401 | 50.00 | 5000.0 |
| 13.25 | 81. | 5334.0 | 4.31966 | 5461.1 | 2303.0 | 647.0 | 90.00 | 0.0398 | 50.00 | 5000.0 |
| 13.50 | 80. | 5253.9 | 4.23848 | 5380.2 | 2283.9 | 640.5 | 90.00 | 0.0395 | 50.00 | 5000.0 |
| 13.75 | 79. | 5174.7 | 4.15841 | 5300.2 | 2265.2 | 634.2 | 90.00 | 0.0392 | 50.00 | 5000.0 |
| 14.00 | 79. | 5096.2 | 4.07941 | 5220.9 | 2247.1 | 628.0 | 90.00 | 0.0388 | 50.00 | 5000.0 |
| 14.25 | 78. | 5018.4 | 4.00146 | 5142.4 | 2229.6 | 622.1 | 90.00 | 0.0385 | 50.00 | 5000.0 |
| 14.50 | 77. | 4941.4 | 3.92452 | 5064.6 | 2212.4 | 616.3 | 90.00 | 0.0382 | 50.00 | 5000.0 |
| 14.75 | 76. | 4865.0 | 3.84857 | 4987.6 | 2195.8 | 610.7 | 90.00 | 0.0380 | 50.00 | 5000.0 |
| 15.00 | 76. | 4789.4 | 3.77357 | 4911.3 | 2179.6 | 605.3 | 90.00 | 0.0377 | 50.00 | 5000.0 |
| 15.25 | 75. | 4714.4 | 3.69950 | 4835.6 | 2163.8 | 600.0 | 90.00 | 0.0374 | 50.00 | 5000.0 |
| 15.50 | 74. | 4640.0 | 3.62634 | 4760.6 | 2148.5 | 594.9 | 90.00 | 0.0371 | 50.00 | 5000.0 |
| 15.75 | 74. | 4566.3 | 3.55405 | 4686.2 | 2133.6 | 589.9 | 90.00 | 0.0369 | 50.00 | 5000.0 |
| 16.00 | 73. | 4493.1 | 3.48261 | 4612.5 | 2119.0 | 585.0 | 90.00 | 0.0366 | 50.00 | 5000.0 |
| 16.25 | 73. | 4420.6 | 3.41201 | 4539.4 | 2104.9 | 580.3 | 90.00 | 0.0364 | 50.00 | 5000.0 |
| 16.50 | 331. | 4089.6 | 0.59921 | 4466.8 | 5553.2 | 2647.5 | 90.00 | 0.0296 | 90.00 | 5000.0 |
| 16.75 | 330. | 3760.1 | 0.51905 | 4135.9 | 5533.1 | 2636.2 | 90.00 | 0.0295 | 90.00 | 5000.0 |
| 17.00 | 51. | 3709.0 | 0.0 | 0.0 | 0.0 | 409.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 17.25 | 40. | 3669.0 | 9.23809 | 3758.2 | 1663.0 | 319.8 | 90.00 | 0.0489 | 30.00 | 50.0 |
| 17.50 | 39. | 3629.8 | 9.09414 | 3718.3 | 1636.9 | 313.4 | 90.00 | 0.0476 | 30.00 | 50.0 |
| 17.75 | 38. | 3591.4 | 8.95672 | 3676.1 | 1611.8 | 307.4 | 90.00 | 0.0468 | 30.00 | 50.0 |
| 18.00 | 38. | 3553.7 | 8.82266 | 3637.7 | 1587.6 | 301.5 | 90.00 | 0.0458 | 30.00 | 50.0 |
| 18.25 | 47. | 3506.7 | 0.0 | 0.0 | 0.0 | 375.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| 18.50 | 66. | 3441.0 | 2.48[illegible] | 3553.0 | 1938.5 | 525.7 | 90.00 | 0.0335 | 50.00 | 5000.0 |
| 18.75 | 65. | 3375.7 | 2.42[illegible] | 3487.3 | 1929.0 | 522.6 | 90.00 | 0.0333 | 50.00 | 5000.0 |
| 19.00 | 65. | 3310.8 | 2.36329 | 3421.9 | 1919.7 | 519.6 | 90.00 | 0.0332 | 50.00 | 5000.0 |

TABLE 3 (Cont)

```
19.25   65.  3246.2  2.30400  3337.0  1910.6  516.6  90.00  0.0330  50.00  5000.0
19.50   64.  3182.0  2.24839  3272.6  1901.0  515.0  90.00  0.0329  50.00  5000.0
19.75   64.  3118.1  2.18721  3220.3  1893.3  511.0  90.00  0.0327  50.00  5000.0
20.00   64.  3054.5  2.12953  3164.3  1884.0  508.3  90.00  0.0326  50.00  5000.0
20.25   63.  2991.3  2.07234  3100.8  1876.6  505.7  90.00  0.0324  50.00  5000.0
20.50   63.  2928.4  2.01443  3037.6  1868.4  503.1  90.00  0.0323  50.00  5000.0
20.75   63.  2865.9  1.95959  2974.7  1860.9  500.6  90.00  0.0322  50.00  5000.0
21.00   62.  2803.6  1.90360  2912.1  1853.3  498.2  90.00  0.0320  50.00  5000.0
21.25   62.  2741.6  1.84836  2849.0  1845.9  495.8  90.00  0.0319  50.00  5000.0
21.50   62.  2679.9  1.79336  2787.9  1838.7  493.5  90.00  0.0318  50.00  5000.0
21.75   61.  2618.5  1.73800  2726.2  1831.7  491.3  90.00  0.0317  50.00  5000.0
22.00   61.  2557.4  1.68483  2664.0  1824.9  489.1  90.00  0.0315  50.00  5000.0
22.25   61.  2496.5  1.63110  2603.6  1818.2  487.0  90.00  0.0314  50.00  5000.0
22.50   61.  2435.9  1.57794  2542.7  1811.7  484.9  90.00  0.0313  50.00  5000.0
22.75   60.  2375.5  1.52509  2482.1  1805.4  482.9  90.00  0.0312  50.00  5000.0
23.00   60.  2315.4  1.47262  2421.6  1799.2  480.9  90.00  0.0311  50.00  5000.0
23.25   60.  2255.5  1.42053  2361.7  1793.2  479.0  90.00  0.0310  50.00  5000.0
23.50   60.  2195.9  1.36881  2301.8  1787.4  477.2  90.00  0.0309  50.00  5000.0
23.75   59.  2136.5  1.31746  2242.1  1781.7  475.4  90.00  0.0308  50.00  5000.0
24.00   59.  2077.3  1.26645  2182.7  1776.2  473.4  90.00  0.0307  50.00  5000.0
24.25   59.  2018.3  1.21579  2123.6  1770.8  471.9  90.00  0.0306  50.00  5000.0
24.50   59.  1959.5  1.16540  2064.5  1765.5  470.2  90.00  0.0305  50.00  5000.0
24.75   59.  1900.9  1.11539  2005.0  1760.4  468.6  90.00  0.0304  50.00  5000.0
25.00   58.  1842.6  1.06564  1947.2  1755.5  467.0  90.00  0.0303  50.00  5000.0
25.25   58.  1784.4  1.01621  1888.0  1750.6  465.5  90.00  0.0303  50.00  5000.0
25.50   58.  1726.4  0.96749  1830.6  1745.9  464.0  90.00  0.0302  50.00  5000.0
25.75   58.  1668.5  0.91870  1772.6  1741.4  462.6  90.00  0.0301  50.00  5000.0
26.00   58.  1610.9  0.87030  1714.8  1736.9  461.2  90.00  0.0300  50.00  5000.0
26.25   57.  1553.4  0.82227  1657.1  1732.6  459.8  90.00  0.0299  50.00  5000.0
26.50   57.  1496.1  0.77445  1599.6  1728.4  458.5  90.00  0.0299  50.00  5000.0
26.75   57.  1438.9  0.72692  1542.3  1724.4  457.2  90.00  0.0298  50.00  5000.0
27.00   57.  1381.9  0.67967  1485.2  1720.4  456.[illegible]  90.00  0.0297  50.00  5000.0
27.25   57.  1325.1  0.63269  1428.2  1716.6  45[illegible]  90.00  0.0297  50.00  5000.0
27.50   11.  1314.2  0.0         0.0     0.0  [illegible]    0.0  0.0      0.0     0.0

   TOTAL CONSUMED FUEL=  11820.03  LB
```

The printout shows the input rotor data, the airship flight data, the mission payload and fuel weights, and loads inputs. It also shows the final airship volume and subsystem weights together with the load lifted by envelope, the load lifted by the rotors, the rotor horsepower for hover, and the power required for dash. The mission performance data shows the calculated increments of used and remaining fuel for every 15 minutes of operation. The program is set up to use dynamic lift for vertical balance up to an angle of attack limit of $\alpha = 10$ degrees. Therefore, the data shows the airship dynamic lift and drag, the airship drag coefficient at the specific angle of attack, the rotor tilt angle required to provide vertical equilibrium and forward thrust, the rotor horsepower, and the flight altitude input provided by the mission profile. At the end of the printout, it shows the fuel consumed, which is 90 percent of the total fuel load used to calculate the airship volume.

PROGRAM DESCRIPTION

This program for sizing the airship and its various components uses airship size and weight information taken from reference 3 (in which three quad-rotor airships of similar size were designed for a different application, and the weight of the various components was reduced to simple exponential functions of the form $w = A \cdot U^B$, where U is the useful load the rotors can lift and A, B are constant coefficients that are different for the various airship components).

In reference 3 useful load is defined to be the load lifted entirely by the rotors or, more generally, by the propulsion system. This means that the airship buoyant lift can accommodate only what is termed as airship empty weight. According to reference 3, this consists of 23 items, such as outriggers, star frame (equivalent in general to internal support structure), envelope, etc.

With the Bell reversible-thrust concept, the MPA is designed so that the buoyant lift supports the airship empty weight plus approximately 50 percent of the disposable load. The empty weight includes some items in excess of the 23 items of reference 3, such as the empennage, a larger control car, and fuel tanks. Additional furnishings and air conditioning, to accommodate a crew size larger than the fixed number of three used in all configurations of reference 3, are considered to be part of the useful load.

Instead of making the rotor thrust equal to the useful load, the rotor thrust is reduced to some fraction of the useful load. The purpose of this is to incorporate reversible thrust in order to get a lateral-thrust component during precision hover, with the airship near neutral buoyancy, to resist lateral wind drag. The reduction of vertical rotor lift this necessitates is offset by the reduction of the weight of rotor-thrust dependent weight items such as the propulsion system, outriggers, and support frame. Whether this weight reduction is greater or smaller than the thrust reduction is academic, since precision hover is a requirement that cannot be met by the quad-rotor design concept in reference 3 (which lacks the reversible-thrust feature) unless a large part of its useful load is ballast.

The specific items that can be influenced by the magnitude of rotor thrust are the outriggers, internal support structure, propulsion pod structure, rotor system, drive system, engines, and engine installation. The combined weight of these items (called propulsion system weight) is plotted against the useful load as defined in reference 3 (that is, against the load this propulsion system can lift) from the three airship configurations of reference 3, and the function,

$$W_{ps} = f_1(P) \qquad (1)$$

was established (see figure 14). Knowing the thrust required of a propulsion system, the weight ($W_{ps}$) of this propulsion system may be found from equation (1).

Furthermore, the three airship configurations in reference 3 have sizes $0.4873 \times 10^6$, $1.725 \times 10^6$, and $4.20 \times 10^6$ cubic feet, and their respective propulsion system weights are 13,892, 60,866, and 155,973 pounds. This establishes a second relationship,

$$W_{psg} = f_2(\forall) \tag{2}$$

that expresses a different propulsion system weight (one that lifts all but the empty weight of the airship) as a function of the airship volume, $\forall$ (see figure 15).

A third relationship may also be generated between the airship volume and the useful load defined in reference 3. All airship component weights, according to reference 3, are derived from equations of the form $W = A \cdot U^B$, where W is the weight of the component under consideration, U the useful load in tons, and A, B fixed numbers varying from component to component.

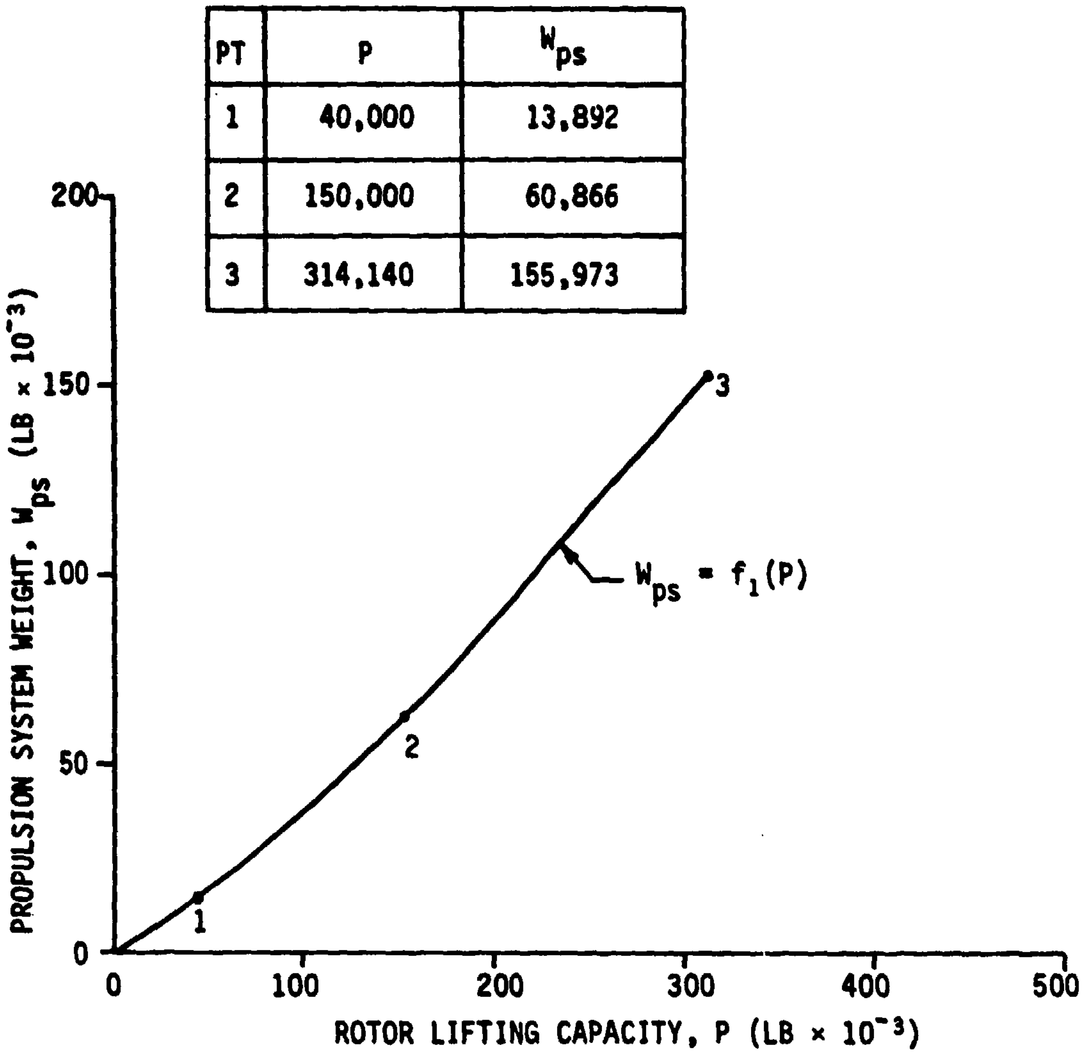
Given the volume of the airship, a companion U may be derived from the three configurations in reference 3. In fact, if the useful loads of 20, 75, and 157.07 tons are plotted against the corresponding volumes of $0.4873 \times 10^6$, $1.725 \times 10^6$, and $4.20 \times 10^6$ ft$^3$, the function,

$$U = f_3(\forall) \tag{3}$$

may be established (see figure 16).

The payload to be lifted by combined action of airship buoyant lift and rotors (propulsion system) are the mission payload ($P_M$) and fixed payload ($P_f$). To these two items the following must be added:

a. Fuel weight, $W_F$
b. Car weight increment
c. Crew weight increment
d. Furnishings weight increment
e. Air conditioner weight increment
f. Empennage weight, $W_E$ (not included in reference 3).



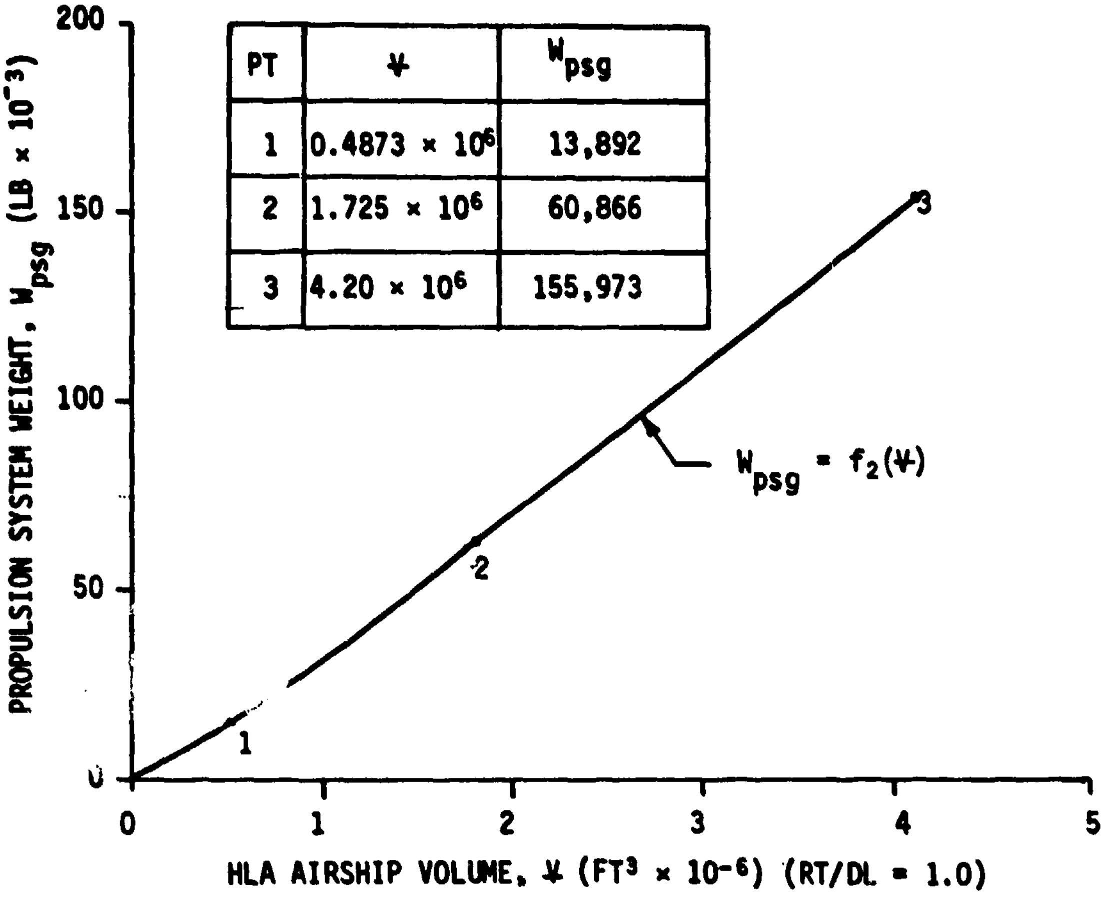
| PT | P | $W_{ps}$ |
|---|---|---|
| 1 | 40,000 | 13,892 |
| 2 | 150,000 | 60,866 |
| 3 | 314,140 | 155,973 |

APPROXIMATE EQUATIONS:

FOR $P \leq 150{,}000$ LB $W_{ps} = 5.316 \times 10^{-7}P^2 + 0.326037P$

FOR $P > 150{,}000$ LB $W_{ps} = 0.579426P - 26{,}048$

**Figure 14** PROPULSION SYSTEM WEIGHT VERSUS ROTOR LIFTING CAPACITY



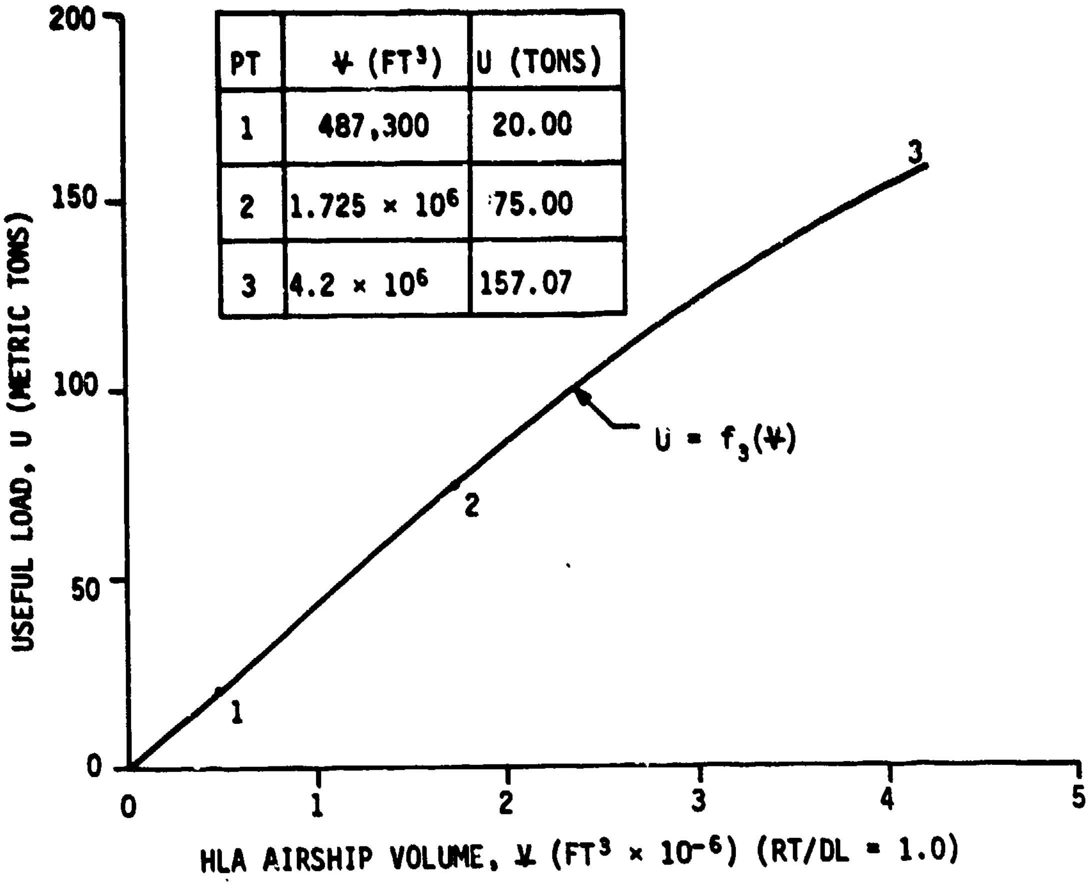
| PT | $\mathcal{V}$ | $W_{psg}$ |
|---|---|---|
| 1 | $0.4873 \times 10^6$ | 13,892 |
| 2 | $1.725 \times 10^6$ | 60,866 |
| 3 | $4.20 \times 10^6$ | 155,973 |

APPROXIMATE EQUATIONS:

FOR $\mathcal{V} < 1.725 \times 10^6$ FT³ $W_{psg} = 5.475 \times 10^{-9} \cdot \mathcal{V}^2 + 0.02584\ \mathcal{V}$

FOR $\mathcal{V} \geq 1.725 \times 10^6$ FT³ $W_{psg} = 0.038427 \cdot \mathcal{V} - 5421.0$

Figure 15 PROPULSION SYSTEM WEIGHT VERSUS AIRSHIP VOLUME FOR HLA WITH RT/DL = 1.0



| PT | $\mathcal{V}$ (FT³) | U (TONS) |
|---|---|---|
| 1 | 487,300 | 20.00 |
| 2 | $1.725 \times 10^6$ | 75.00 |
| 3 | $4.2 \times 10^6$ | 157.07 |

APPROXIMATE EQUATIONS:

FOR $\mathcal{V} < 487{,}300$ $U = 0.0000410425 \cdot \mathcal{V}$

FOR $\mathcal{V} \geq 487{,}300$ $U = 3.0375917 \times 10^{-12} \cdot \mathcal{V}^2 + 0.0000511573 \cdot \mathcal{V} - 4.2076549$

Figure 16 USEFUL LOAD* VERSUS AIRSHIP VOLUME FOR HLA WITH RT/DL = 1.0

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*In this relationship $U = f_3(\mathcal{V})$, the useful load U is supposed to be lifted entirely by the rotors.

The added weights described in items b through e above are due to a larger crew size than that considered in reference 3. These weights were in proportion to the crew size. For example, the car (1500 pounds according to reference 3 for a crew of three) was taken to equal 500 pounds times the number in crew.

Because of a more favorable load application, the landing gear weight has been reduced to 50 percent of the value calculated in reference 3. The useful load, therefore, may be defined by the following equation

$$U_L = P_M + P_f + W_F + W_{EX} + W_E - \tfrac{1}{2} W_{LG} \qquad (4)$$

where

$W_{EX}$ = Combined weight of items b through e

$W_{LG}$ = Weight of the landing gear.

An arbitrary factor k $(k \cdot S_1)$ is assumed, which determines the load $U_R = k \cdot U_L$ to be lifted by the rotors; the remainder $U_E = (1-k) \cdot U_L$ of the useful load is to be lifted by the envelope (buoyant lift).

PROGRAM SEQUENCE

The program sequence was as follows:

a. Assume a certain fuel weight ($W_F$) for the particular mission.

b. Assume a certain airship volume ($\forall$).

c. From equation (3), find U with $f_3$ given by figure 15.

d. From

$$W_{LG} = A_{LG} \cdot U^{B_{LG}} \qquad (5)$$

where $A_{LG} = 164.41$ and $B_{LG} = 1.0265$, find the landing-gear weight.

e. The empennage weight is based on figure G-3 of appendix G. Because of the additional control available by vectoring the rotor thrust, only half the indicated empennage area is assumed necessary. The weight of the empennage is assumed to be 1 lb/ft$^2$. For volumes greater than 500,000 ft$^3$, the weight is assumed to be given by

$$W_E = \frac{900 + 2.067 \times 10^{-3} \cdot \forall}{2} \quad . \qquad (6)$$

For smaller sizes, the curve of figure G-3 in appendix G is fitted by a parabola:

$$W_E = \frac{-9 \times 10^{-10} \times \mathcal{V}^2 + 3.867 \times 10^{-3} \cdot \mathcal{V}}{2} .$$

f. From equation (4), find $U_L$.

g. From $U_R = k \cdot U_L$ and $U_E = (1-k) \cdot U_L$, find $U_R$ and $U_E$ for an arbitrary k.

h. From equation (1), find the weight $W_{ps}$ of the propulsion system, using $f_\lambda$ given by figure 14.

i. From equation (2), find the weight $W_{psg}$ of the propulsion system corresponding to an airship of volume $\mathcal{V}$ (if this airship were to be a reference 3 airship, ie, an airship in which the entire useful load would be lifted by the rotors).

j. Use $W_{psg} - W_{ps} = U_E$ (not generally satisfied) to iterate from step b for the correct volume.

k. Knowing $\mathcal{V}$ and $U_L$, all airship component weights can be established from equations of the general form $W = A \cdot U^B$, as given in reference 3. Exceptions to this are the components of the propulsion system, which must be calculated from similar equations in which the base U must be the thrust $U_R$ of the rotors (converted to metric tons).

l. At this point, the mission performance starts. The mission time is divided into 15-minute periods; during each period the airship weight is considered constant. At the end of each period, however, the weight of the airship is reduced by the amount of fuel consumed during that period.

If the time period under consideration is a hover period, the required horsepower is calculated according to equations provided in appendix C of reference 3.

If the time period is forward propulsion, the air density, $\rho$, is calculated from a standard atmosphere subroutine for the particular altitude; then the lift and drag are calculated as follows. For forward flight, since dynamic lift is more efficient than rotor lift (in other words, for angles of attack less than -8 and more than +10 degrees, the thrust required to overcome the drag at a higher angle of attack is less than rotor lift to achieve vertical equilibrium), vertical equilibrium is achieved by increasing the flight angle of attack, provided that the airship angle of attack does not exceed the limiting values -8 and +10 degrees. If additional lift is required, the rotors will be tilted to provide the additional required vertical component. On the other hand, if the dynamic lift at these limiting angles is larger than required for vertical equilibrium, the program orients the airship automatically to the proper angle of attack, $\alpha$. This is handled by a subroutine, derived from lift-versus-speed curves for various angles of attack for an airship $1.0 \times 10^6$ ft$^3$ flying at sea level (the ZPG-2), properly adjusted for altitude and volume.

The drag is calculated from the equation

$$D = \tfrac{1}{2}\rho C_D V^2 (\forall)^{2/3} \qquad (7)$$

where

ρ = Air density at the particular altitude

V = Speed in ft/sec

$C_D$ = Drag coefficient handled by a subroutine based on figure 13 (drag versus speed for various airship volumes ranging from 0.5 to 8.0 million ft$^3$).[4] NOTE: For generation of this family of curves, maximum horsepower and speeds for historical airships have been used. Required horsepower for various speeds were calculated by the ratio of the third power of speed. Since all the ships have odd volumes, a cross-plot was made from which the required horsepower values for even thousands of cubic-foot volumes were read and plotted for the final figure. Finally, this coefficient is corrected for airship angle of attack according to figure G-6 of appendix G. Since it has been assumed in item e. that the empennage area is only half that of a conventional historical airship, for which the tail contributed 70 to 85 percent of the total lift due to angle of attack, it is further assumed that the lift picked up from the tilt rotors compensates for the reduced tail area.

m. With drag and lift (if any from the rotors), the resultant rotor thrust is calculated, then the horsepower required is calculated from the propeller horsepower equation

$$hp = \frac{T}{550(FM)}\left[\frac{V}{2} + \sqrt{\left(\frac{V}{2}\right)^2 + \frac{T}{2A\rho}}\right] \qquad (8)$$

---

[4] J. J. Vorachek, *Investigation of Powered Lighter-Than-Air Vehicles* (Air Force Cambridge Laboratories Contract No. F1962867C0047, Scientific Report No. 1, Goodyear Aerospace Corporation GER 13140, February 28, 1967).

where

T = Thrust (lb)

FM = Rotor figure of merit

V = Speed (ft/sec)

$\rho$ = Air density (slugs/ft$^3$)

A = Rotor disc area (ft$^2$).

n. With the horsepower (either for hover or forward propulsion) known, the fuel consumption can be calculated for the 15-minute period under consideration on the supposition that the specific fuel consumption is 0.5 lb/hp/hr.

o. The consumed fuel is deducted from the airship weight and the mission is proceeded by handling the 15-minute periods in much the same way as described in steps 1 through n.

p. In all missions, it is required that at the end of the mission 10 percent of the fuel be left over. This requirement is used to iterate from step a in order to derive the correct amount of fuel which was assumed in step a of this program sequence.

It should be noted that airship altitude effects, which tend to increase the volume and, hence, the empty weight of the airship, have been introduced early in the program by properly redefining the parameter $U_L$; in fact, $U_L$ must be increased by the weight of the fuel system ($W_{FS}$), which in this program was taken equal to 5 percent of the fuel weight, then the updated value of $U_L$ is determined from the equation

$$U_L' = \frac{U_L + W_{FS}}{\left(\frac{\rho}{\rho_o}\right) \times \left(1 - \frac{0.29h}{20,000}\right)} \qquad (9)$$

where $\rho$ and $\rho_o$ are air densities at altitude and sea level (SL) respectively, and h the altitude in feet (reference 3).

In order for the solution given by this program to be valid, the horsepower required for dash, or perhaps for other propulsion conditions such as towing or loitering at very low speeds in the beginning of the mission, should not be larger than the horsepower required for hover in the heaviest condition. If this happens, however, a larger value of k (see step g) is selected until these two horsepowers are brought as close to each other as possible.

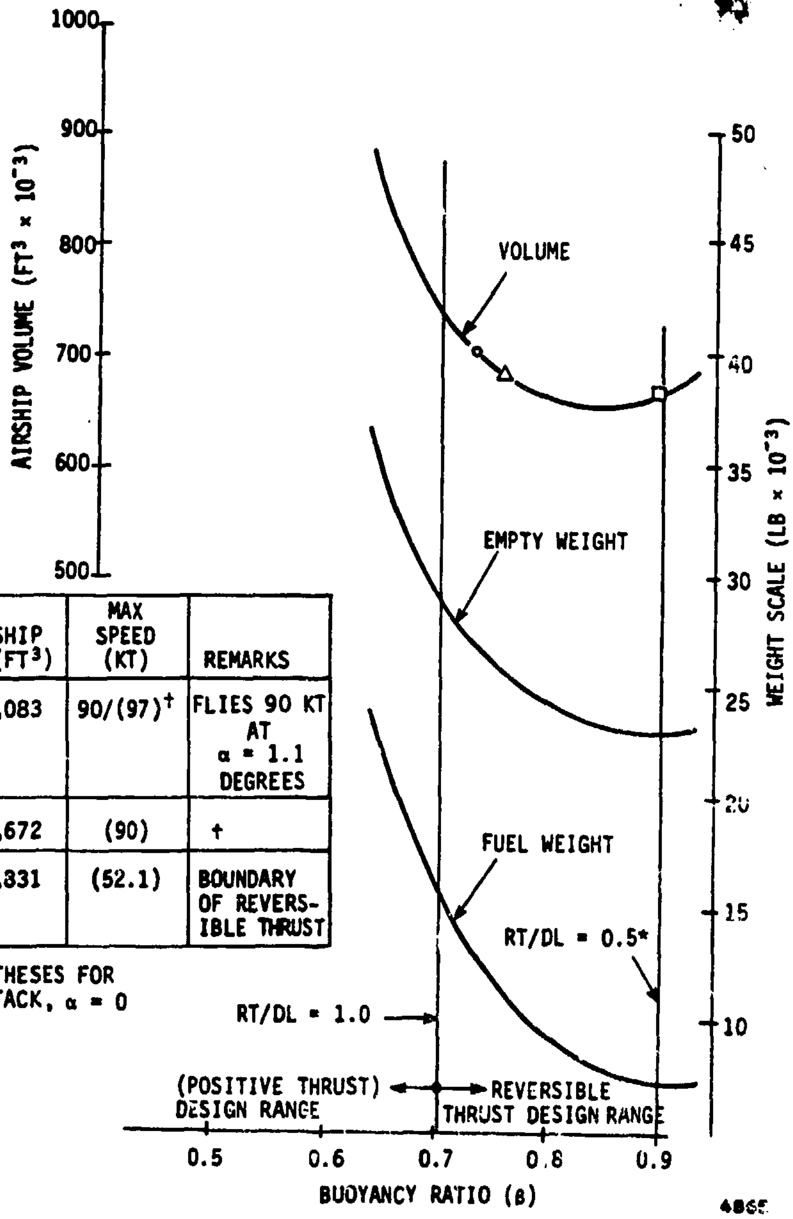
## COMPUTER DESIGN RESULTS

An airship for each of the eight different MPA missions described in appendix F was designed by the computer program (ASP) described in the previous two sections. All stated requirements are met and the results are summarized in table 4.

For each mission, variation of k (rotor-thrust-to-useful-load ratio) made possible an interesting parametric study. If airship volume is plotted against the buoyancy ratio (load lifted by envelope/maximum-gross-weight ratio), the curve for each mission has, in general, a low point that does not necessarily correspond to the design of the particular mission. All points give airships ability to hover, but the maximum attainable speed for each one is different. Table 5 gives volume, fuel weight, and other factors versus some values of k for the eight missions, and figures 17 through 24 give plots of volume, empty weight, and fuel weight for each of these missions. Moreover, in the data presented there is a slight discrepancy in the computer calculations for the off-design airship sizes with design speeds lower than those required to achieve the desired mission. As an example, the propulsion system weights were selected on the basis of the maximum required for either hover or forward design speed. However, the fuel consumption was calculated on the basis of the specific mission profile. Therefore, if the mission profile speed was greater than the maximum design speed, the computer simply calculated the fuel consumption at the rate/hp required to achieve the mission even though the actual power was not available in that design to get the mission speed.

A vertical line defining RT/DL (rotor-thrust-to-disposable-load ratio) for each mission can also be shown on these figures. It is interesting to note that lines RT/DL = 1.0 and RT/DL = 0.5 are the boundaries of the reversible-thrust concept when ballast is not carried. For an RT/DL less than 0.5, ballast is required; otherwise, if the disposable load is all used, the available downward thrust is insufficient to land the airship unless helium is vented. However, the thrust required for the specified forward speed normally keeps RT/DL above 0.5.

On the other hand, for an RT/DL greater than 1.0 the airship is always heavy, and the reversibility of the rotors is only needed for the precision-hover capability near neutral buoyancy. It follows that an airship without reversible thrust can operate without ballast only for values of RT/DL greater than 1.0. If RT/DL = 1.0, the airship becomes neutrally buoyant as the disposable load is expended (unless ballast is picked up), and then has the same control problems as conventional airships - inability to precision hover and the lack of low-speed control.

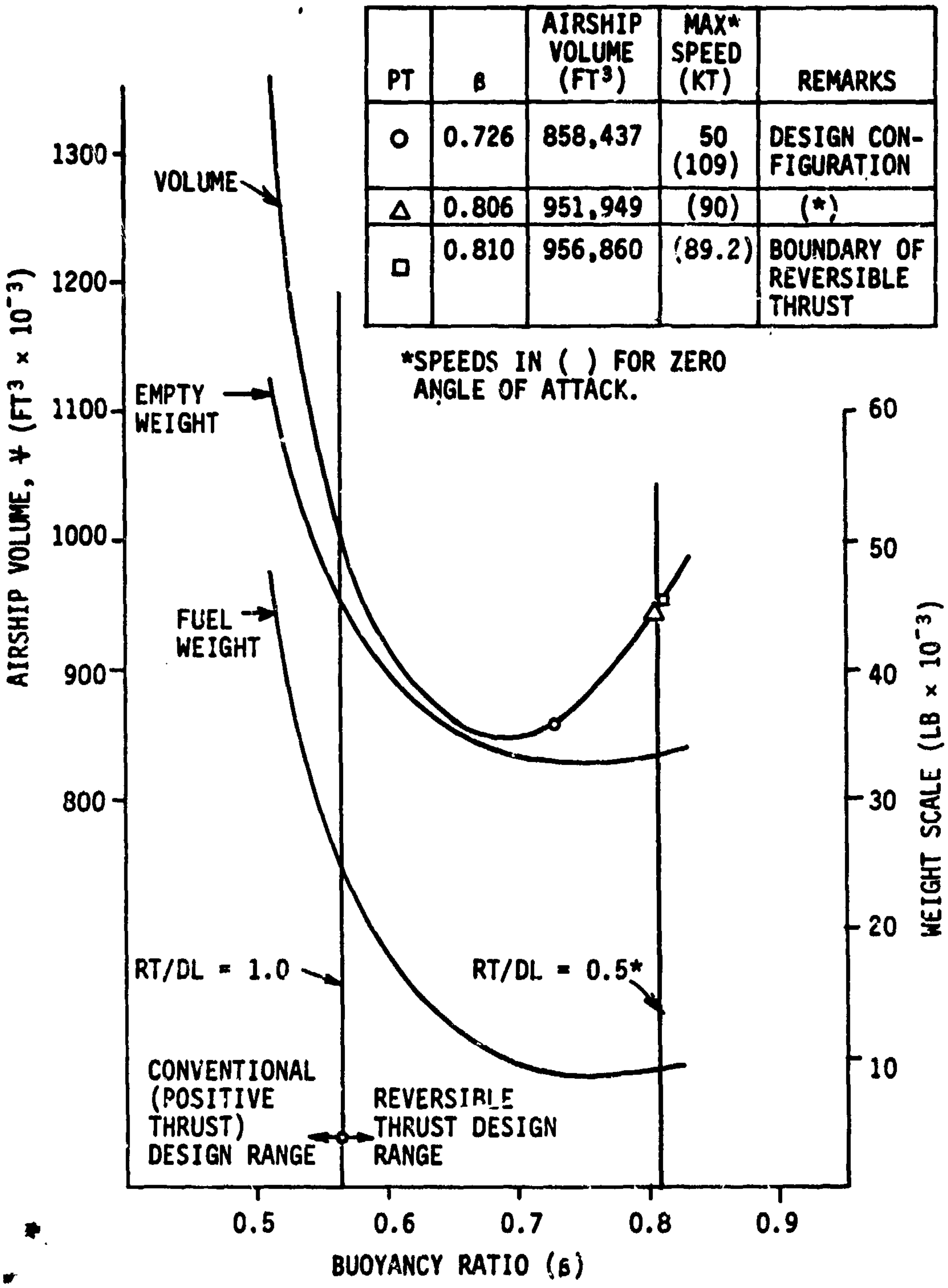


| POINT | β | AIRSHIP VOL (FT³) | MAX SPEED (KT) | REMARKS |
|---|---|---|---|---|
| ○ | 0.735 | 706,083 | 90/(97)† | FLIES 90 KT AT α = 1.1 DEGREES |
| △ | 0.759 | 685,672 | (90) | † |
| □ | 0.902 | 670,831 | (52.1) | BOUNDARY OF REVERSIBLE THRUST |

†NUMBERS IN PARENTHESES FOR ZERO ANGLE OF ATTACK, α = 0

*UPPER BOUNDARY OF REVERSIBLE THRUST

Figure 17 AIRSHIP VOLUME AND WEIGHT VERSUS BUOYANCY RATIO FOR ELT MISSION



| PT | β | AIRSHIP VOLUME ($FT^3$) | MAX* SPEED (KT) | REMARKS |
|---|---|---|---|---|
| ○ | 0.726 | 858,437 | 50 (109) | DESIGN CONFIGURATION |
| △ | 0.806 | 951,949 | (90) | (*) |
| □ | 0.810 | 956,860 | (89.2) | BOUNDARY OF REVERSIBLE THRUST |

*SPEEDS IN ( ) FOR ZERO ANGLE OF ATTACK.

*UPPER BOUNDARY OF REVERSIBLE THRUST

Figure 18 AIRSHIP VOLUME AND WEIGHT VERSUS BUOYANCY RATIO FOR MEP MISSION

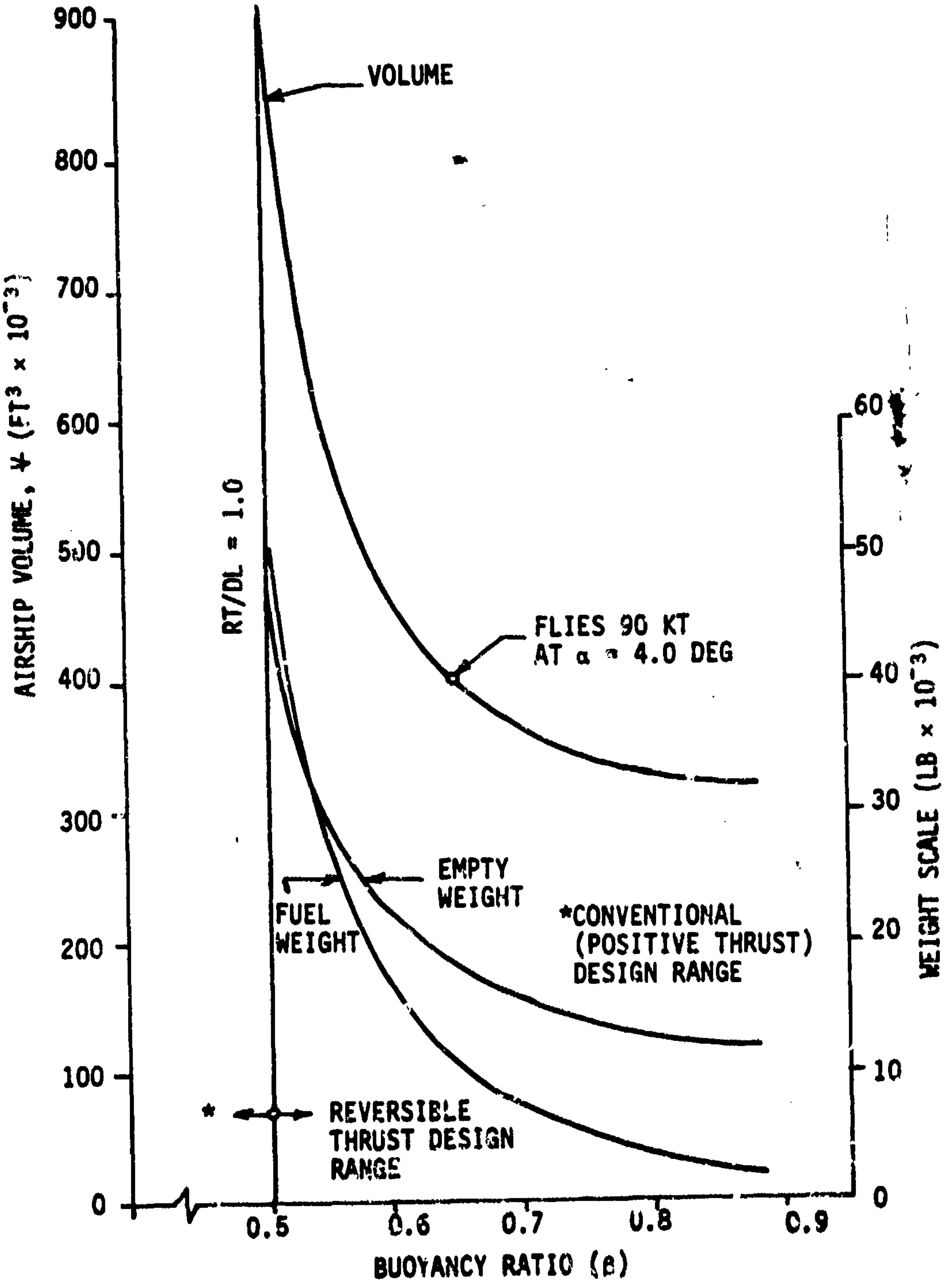


Figure 19 AIRSHIP VOLUME AND WEIGHT VERSUS BUOYANCY RATIO FOR SAR MISSION

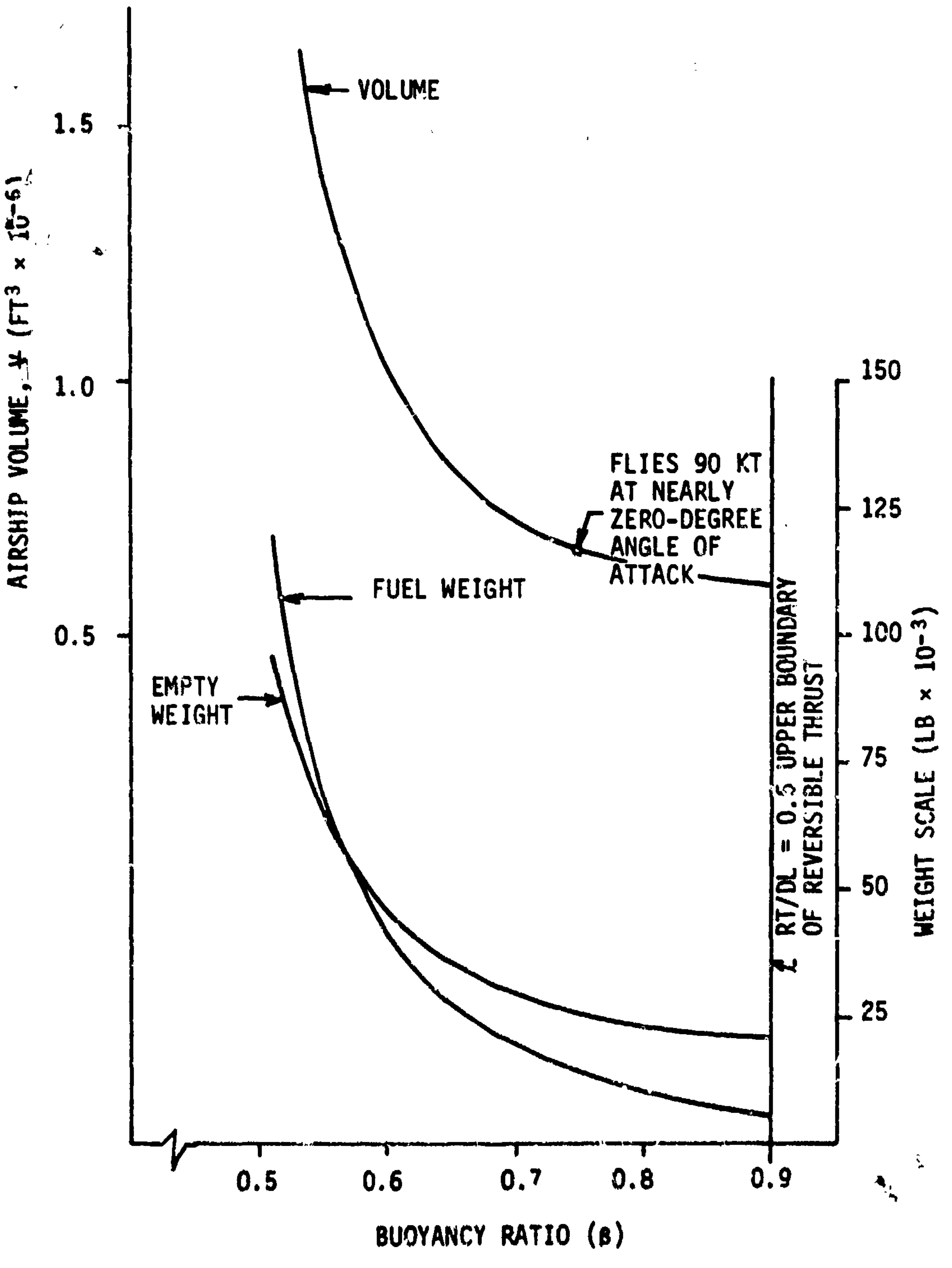
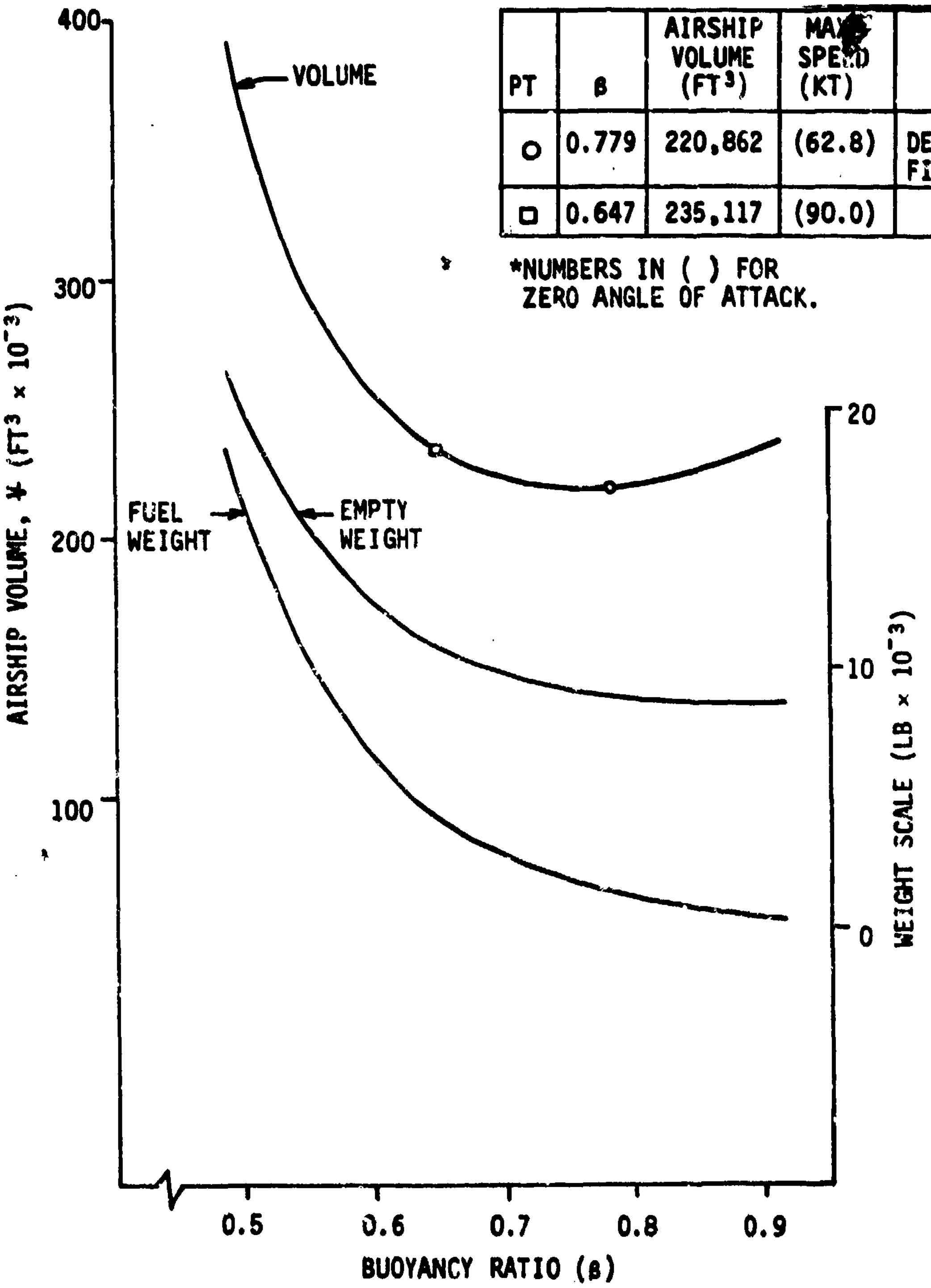


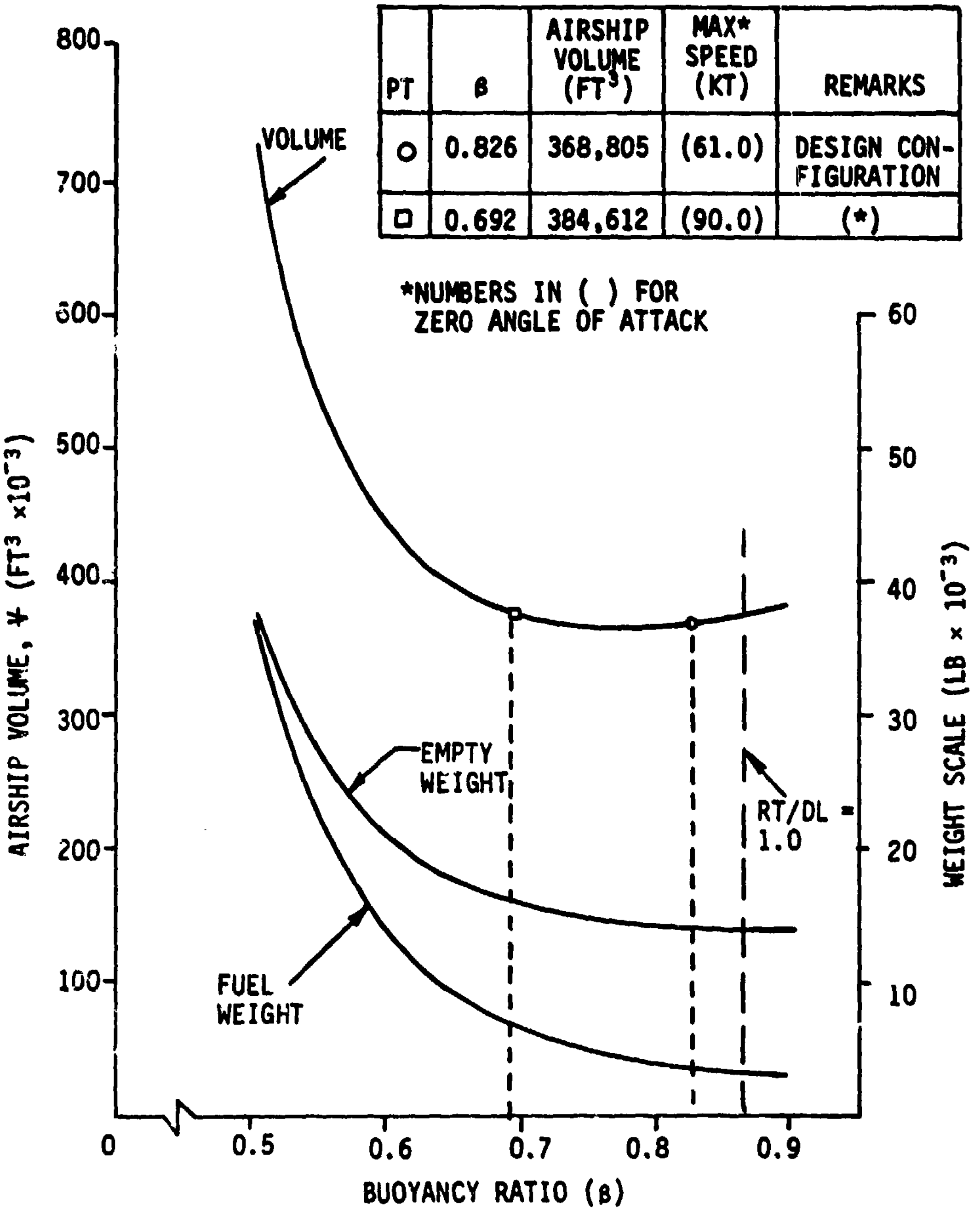
Figure 20 AIRSHIP VOLUME AND WEIGHT VERSUS BUOYANCY RATIO FOR MO/MP MISSION



| PT | β | AIRSHIP VOLUME (FT³) | MAX SPEED (KT) | REMARKS |
|---|---|---|---|---|
| ○ | 0.779 | 220,862 | (62.8) | DESIGN CONFIGURATION |
| □ | 0.647 | 235,117 | (90.0) | (*) |

*NUMBERS IN ( ) FOR ZERO ANGLE OF ATTACK.

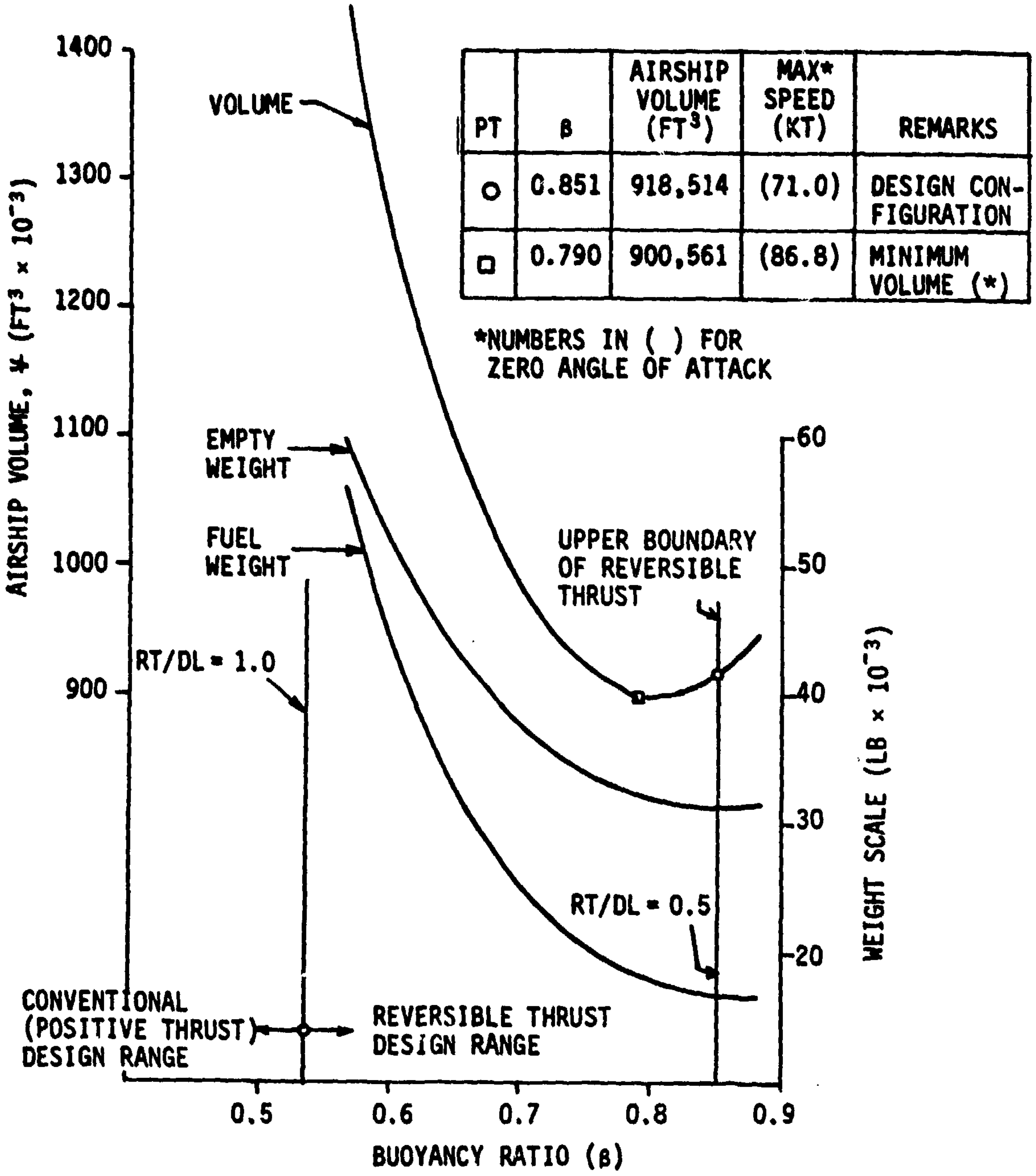
Figure 21 AIRSHIP VOLUME AND WEIGHT VERSUS BUOYANCY RATIO FOR PSS MISSION



| PT | β | AIRSHIP VOLUME (FT³) | MAX* SPEED (KT) | REMARKS |
|---|---|---|---|---|
| ○ | 0.826 | 368,805 | (61.0) | DESIGN CONFIGURATION |
| □ | 0.692 | 384,612 | (90.0) | (*) |

*NUMBERS IN ( ) FOR ZERO ANGLE OF ATTACK

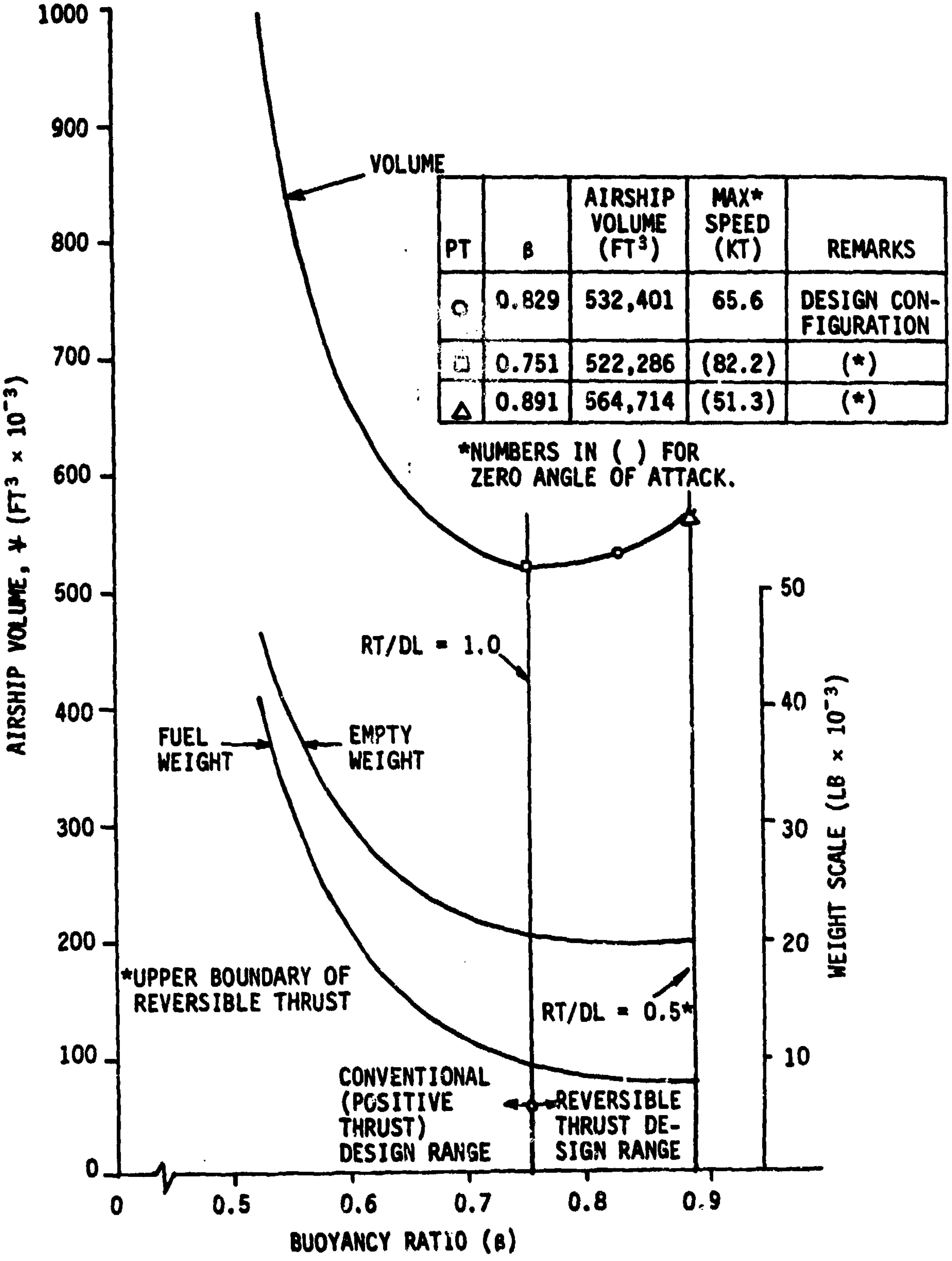
Figure 22 AIRSHIP VOLUME AND WEIGHT VERSUS BUOYANCY RATIO FOR A/N MISSION



| PT | β | AIRSHIP VOLUME ($FT^3$) | MAX* SPEED (KT) | REMARKS |
|---|---|---|---|---|
| ○ | 0.851 | 918,514 | (71.0) | DESIGN CONFIGURATION |
| □ | 0.790 | 900,561 | (86.8) | MINIMUM VOLUME (*) |

*NUMBERS IN ( ) FOR ZERO ANGLE OF ATTACK

Figure 23 AIRSHIP VOLUME AND WEIGHT VERSUS BUOYANCY RATIO FOR MSA MISSION



| PT | β | AIRSHIP VOLUME (FT$^3$) | MAX* SPEED (KT) | REMARKS |
|---|---|---|---|---|
| ○ | 0.829 | 532,401 | 65.6 | DESIGN CONFIGURATION |
| □ | 0.751 | 522,286 | (82.2) | (*) |
| △ | 0.891 | 564,714 | (51.3) | (*) |

*NUMBERS IN ( ) FOR ZERO ANGLE OF ATTACK.

Figure 24 AIRSHIP VOLUME AND WEIGHT VERSUS BUOYANCY RATIO FOR IO MISSION

## TABLE 4. MARITIME PATROL AIRSHIP COMPUTER DESIGN SUMMARY

| | MISSION | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ELT | MEP | SAR | MD/MP | A/N | IO | MSA | PSS |
| **Rotor Data** | | | | | | | | |
| Number of Rotors | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Number of Blades per Rotor | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Rotor Figure of Merit | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 |
| Blade Radius (ft) | 7.000 | 7.000 | 7.000 | 7.000 | 7.000 | 7.000 | 7.000 | 7.000 |
| Rotor Efficiency Factor | 0.850 | 0.850 | 0.850 | 0.850 | 0.850 | 0.850 | 0.850 | 0.850 |
| Rotor Lift/Useful Load | 0.583 | 0.555 | 0.674 | 0.506 | 0.370 | 0.376 | 0.327 | 0.449 |
| Blade Tip Speed | 800.0 | 800.0 | 800.0 | 800.0 | 800.0 | 800.0 | 800.0 | 800.0 |
| **Flight Data** | | | | | | | | |
| Maximum Altitude (ft) | 5000 | 5000 | 100 | 500 | 1000 | 5000 | 5000 | 1000 |
| Maximum Velocity (kt) | 90 | 50 | 90 | 90 | 50 | 60 | 60 | 40 |
| Cruise Speed (kt) | 50 | 50 | 60 | 40 | 50 | 60 | 40 | 40 |
| Loiter Speed (kt) | 30 | 30 | 30 | 30 | -- | -- | -- | 30 |
| Total Endurance (hr) | 27.5 | 12.5 | 13.5 | 26.5 | 17.0 | 20.5 | 35.5 | 8.25 |
| Radius of Action (nm) | 250 | -- | -- | -- | -- | -- | -- | -- |
| Time on Station (hr) | 11 | -- | -- | -- | -- | -- | -- | -- |
| Crew Size | 11 | 6 | 8 | 11 | 8 | 6 | 11 | 6 |
| Spec Fuel Consump (lb/hp/hr) | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |

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TABLE 4 (Cont)

| | MISSION | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ELT | MEP | SAR | MO/MP | A/N | IO | MSA | PSS |
| **Weights & Loads*** | | | | | | | | |
| Mission Payload | 3,249 | 17,952 | 2,490 | 6,520 | 2,944 | 3,000 | 3,341 | 1,817 |
| Fixed Payload | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 |
| Total Payload | 7,669 | 22,372 | 6,910 | 10,940 | 7,364 | 7,420 | 7,761 | 6,237 |
| Fuel | 13,142 | 8,894 | 10,945 | 14,201 | 3,786 | 7,978 | 16,772 | 1,493 |
| Disposable Load | 13,499 | 24,954 | 11,143 | 16,540 | 3,938 | 8,086 | 17,221 | 1,629 |
| Useful Load | 22,626 | 32,256 | 19,175 | 26,956 | 12,470 | 16,388 | 26,348 | 8,720 |
| Crew | 2,200 | 1,200 | 1,600 | 2,200 | 1,600 | 1,200 | 2,200 | 1,200 |
| Furnishings & A/C | 1,815 | 990 | 1,320 | 1,815 | 1,320 | 990 | 1,815 | 990 |
| Load Lifted by Envelope | 36,633 | 47,357 | 24,193 | 39,843 | 21,963 | 29,954 | 49,130 | 13,809 |
| Load Lifted by Rotors | 13,188 | 17,917 | 12,922 | 13,641 | 4,614 | 6,163 | 8,608 | 3,915 |
| Maximum Gross Weight | 49,821 | 65,274 | 37,115 | 53,484 | 26,577 | 36,117 | 57,788 | 17,724 |
| **Airship Volume ($ft^3$)** | 706,083 | 858,437 | 401,586 | 677,382 | 368,805 | 532,401 | 918,514 | 220,862 |
| **Maximum hp Required for Hover** | 2,749.3 | 4,306.3 | 2,664.0 | 2,896.6 | 548.5 | 853.8 | 1,424.8 | 427.1 |
| **Maximum hp Required for Forward Flight** | 2,747.2 | 2,126.5 | 2,611.1 | 2,895.4 | 546.0 | 835.3 | 1,031.3 | 428.2 |

*All figures shown in Weights & Loads section are lb.

TABLE 4 (Cont)

| | MISSION | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ELT | MEP | SAR | MO/MP | A/N | IO | MSA | PSS |
| Airship Empty Weight* | 27,195.0 | 33,018.8 | 17,940.3 | 26,528.4 | 14,106.8 | 19,729.4 | 31,440.3 | 9,003.9 |
| Outriggers | 1,017.2 | 1,633.7 | 965.6 | 1,039.3 | 274.3 | 453.6 | 609.4 | 203.5 |
| Intern Support Struct | 809.2 | 1,200.0 | 772.2 | 819.5 | 287.2 | 440.2 | 541.9 | 222.4 |
| Envelope | 6,544.6 | 8,973.3 | 3,390.3 | 6,124.4 | 3,096.9 | 5,329.0 | 8,799.5 | 1,655.2 |
| Suspension System | 2,021.0 | 2,771.0 | 1,046.9 | 1,891.2 | 956.3 | 1,645.6 | 2,717.3 | 511.1 |
| Ballonets & Air Lines | 773.3 | 1,060.2 | 400.6 | 723.6 | 365.9 | 629.6 | 1,039.7 | 195.6 |
| Misc Envelope | 765.7 | 1,049.9 | 396.7 | 716.5 | 362.3 | 623.5 | 1,029.5 | 193.7 |
| Pressure System | 1,141.2 | 1,564.7 | 591.2 | 1,067.9 | 540.0 | 929.2 | 1,534.3 | 288.6 |
| Control Car | 5,500.0 | 3,000.0 | 4,000.0 | 5,500.0 | 4,000.0 | 3,000.0 | 5,500.0 | 3,000.0 |
| Landing Gear | 2,924.1 | 4,006.4 | 1,518.1 | 2,736.8 | 1,387.1 | 2,383.6 | 3,927.8 | 742.7 |
| Flight Controls | 800.7 | 1,061.1 | 458.4 | 754.9 | 424.5 | 686.5 | 1,028.6 | 246.7 |
| Propeller Pod Structure | 300.3 | 482.7 | 285.0 | 306.8 | 80.7 | 133.6 | 179.7 | 59.9 |
| Rotor System | 811.0 | 1,303.0 | 769.8 | 828.6 | 218.4 | 361.3 | 485.5 | 162.0 |
| Drive System | 605.5 | 970.5 | 574.9 | 618.6 | 164.5 | 271.4 | 363.8 | 122.2 |
| Engines | 638.5 | 883.2 | 612.2 | 641.8 | 287.4 | 412.6 | 471.0 | 231.0 |
| Engine Installation | 159.6 | 220.8 | 153.1 | 160.5 | 71.9 | 103.2 | 117.8 | 57.8 |
| Instr-Eng-Trans-Hyd | 746.1 | 824.8 | 726.1 | 731.6 | 724.0 | 841.0 | 751.9 | 656.2 |
| Empennage | 979.7 | 1,569.4 | 732.2 | 1,156.3 | 676.2 | 1,086.7 | 1,504.1 | 380.8 |
| Fuel System | 657.1 | 444.7 | 547.2 | 710.1 | 189.3 | 398.9 | 838.6 | 74.6 |

*All figures shown are lb.

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TABLE 5. SOME VALUES OF k VERSUS VOLUME, FUEL WEIGHT FOR EIGHT MISSIONS

| CASE | k | VOLUME ($FT^3$) | FUEL (LB) | GROSS WEIGHT (LB) | β BUOYANT LIFT-TO-GW RATIO | MAXIMUM ATTAINABLE VELOCITY (KT) | ROTOR THRUST @ V = 0 (LB) | EMPTY WEIGHT (LB) | RT/DL |
|---|---|---|---|---|---|---|---|---|---|
| | | | | ELT MISSION | | | | | |
| 1 | 0.158 | 690,172.7 | 7,352.4 | 40,058.8 | 0.933 | 40.87 | 2,668.4 | 23,222.5 | 0.346 |
| 2 | 0.266 | 661,284.8 | 7,456.5 | 39,936.6 | 0.887 | 53.68 | 4,500.9 | 22,996.1 | 0.576 |
| 3 | 0.359 | 652,619.4 | 8,138.6 | 40,974.1 | 0.846 | 63.99 | 6,328.7 | 23,351.5 | 0.745 |
| 4 | 0.412 | 654,995.5 | 8,821.5 | 42,130.1 | 0.821 | 69.94 | 7,541.1 | 23,824.7 | 0.822 |
| 5 | 0.464 | 662,942.2 | 9,751.5 | 43,755.0 | 0.796 | 76.10 | 8,929.3 | 24,519.4 | 0.883 |
| 6 | 0.516 | 677,306.4 | 10,985.8 | 45,950.7 | 0.770 | 82.62 | 10,556.9 | 25,481.0 | 0.931 |
| 7 | 0.561 | 695,533.2 | 12,377.0 | 48,444.9 | 0.747 | 88.87 | 12,274.[illegible] | 26,584.0 | 0.964 |
| 8 | 0.583 | 706,083.4 | 13,142.3 | 49,821.0 | 0.735 | 91.99 | 13,188.5 | 27,194.8 | 0.977 |
| 9 | 0.604 | 718,381.7 | 14,001.9 | 51,369.9 | 0.724 | 95.24 | 14,168.1 | 27,884.0 | 0.988 |
| 10 | 0.719 | 843,303.2 | 21,416.4 | 65,006.9 | 0.658 | 117.23 | 22,217.9 | 34,106.5 | 1.020 |
| 11 | 0.856 | 1,342,396.1 | 49,943.7 | 114,733.4 | 0.564 | 172.01 | 49,999.7 | 56,305.7 | 1.014 |
| | | | | MSA MISSION | | | | | |
| 1 | 0.258 | 949,256.[illegible] | 16,793.9 | 58,004.7 | 0.883 | 62.74 | 6,80[illegible] | 31,634.9 | 0.395 |
| 2 | 0.324 | 919,494.7 | 16,758.8 | 57,772.4 | 0.852 | 70.68 | 8,525.7 | 31,437.6 | 0.495 |
| 3 | 0.327 | 918,514.[illegible] | 16,77[illegible].8 | 57,788.1 | 0.851 | 71.04 | 8,608.1 | 31,440.3 | 0.500 |
| 4 | 0.454 | 900,560.8 | 18,269.6 | 60,180.4 | 0.790 | 86.80 | 12,653.9 | 32,334.8 | 0.676 |

TABLE 5 (Cont)

| CASE | k | VOLUME ($FT^3$) | FUEL (LB) | GROSS WEIGHT (LB) | β BUOYANT LIFT-TO-GW RATIO | MAXIMUM ATTAINABLE VELOCITY (KT) | ROTOR THRUST @ V = 0 (LB) | EMPTY WEIGHT (LB) | RT/DL |
|---|---|---|---|---|---|---|---|---|---|
| MSA MISSION (Cont) | | | | | | | | | |
| 5 | 0.519 | 917,968.1 | 20,196.9 | 63,516.2 | 0.757 | 95.97 | 15,447.1 | 33,743.3 | 0.748 |
| 6 | 0.557 | 936,784.7 | 21,777.9 | 66,280.5 | 0.736 | 102.01 | 17,467.1 | 34,926.6 | 0.786 |
| 7 | 0.582 | 953,217.7 | 23,042.6 | 68,498.1 | 0.723 | 106.32 | 18,998.1 | 35,879.6 | 0.809 |
| 8 | 0.707 | 1,098,788.5 | 33,095.2 | 86,113.0 | 0.650 | 133.29 | 30,168.2 | 43,441.8 | 0.899 |
| 9 | 0.829 | 1,432,365.7 | 55,561.6 | 124,860.2 | 0.576 | 179.08 | 54,013.2 | 59,722.6 | 0.964 |
| PSS MISSION | | | | | | | | | |
| 1 | 0.194 | 238,124.4 | 489.5 | 16,504.8 | 0.909 | 37.90 | 1,493.8 | 8,788.4 | 2.389 |
| 2 | 0.292 | 230,598.6 | 804.4 | 16,847.5 | 0.861 | 47.98 | 2,349.0 | 8,816.1 | 2.500 |
| 3 | 0.393 | 222,762.5 | 1,168.0 | 17,259.5 | 0.809 | 57.43 | 3,297.9 | 8,864.4 | 2.528 |
| 4 | 0.449 | 220,862.2 | 1,492.7 | 17,723.6 | 0.779 | 62.77 | 3,915.1 | 9,003.9 | 2.405 |
| 5 | 0.459 | 220,763.4 | 1,565.1 | 17,833.1 | 0.774 | 63.77 | 4,038.2 | 9,041.2 | 2.374 |
| 6 | 0.464 | 220,740.5 | 1,602.9 | 17,891.1 | 0.771 | 64.28 | 4,101.1 | 9,061.3 | 2.360 |
| 7 | 0.601 | 226,116.2 | 2,998.2 | 20,146.6 | 0.695 | 78.55 | 6,147.5 | 9,920.9 | 1.961 |
| 8 | 0.766 | 252,270.9 | 6,398.0 | 25,686.9 | 0.606 | 99.94 | 10,328.6 | 12,197.9 | 1.614 |
| 9 | 0.941 | 391,020.3 | 18,605.3 | 47,374.5 | 0.487 | 141.45 | 24,309.7 | 21,542.2 | 1.297 |

TABLE 5 (Cont)

| CASE | k | VOLUME (FT$^3$) | FUEL (LB) | GROSS WEIGHT (LB) | β BUOYANT LIFT-TO-GW RATIO | MAXIMUM ATTAINABLE VELOCITY (KT) | ROTOR THRUST @ V = 0 (LB) | EMPTY WEIGHT (LB) | RT/DL |
|---|---|---|---|---|---|---|---|---|---|
| SAR MISSION | | | | | | | | | |
| 1 | 0.260 | 319,848.7 | 1,988.6 | 22,092.6 | 0.880 | 47.45 | 2,652.2 | 11,874.1 | 1.213 |
| 2 | 0.364 | 322,743.8 | 2,980.7 | 23,649.0 | 0.828 | 58.90 | 4,077.2 | 12,438.3 | 1.282 |
| 3 | 0.468 | 333,868.1 | 4,503.3 | 26,155.8 | 0.772 | 70.90 | 5,954.2 | 13,422.5 | 1.267 |
| 4 | 0.599 | 366,593.4 | 7,786.3 | 31,712.9 | 0.698 | 88.67 | 9,592.4 | 15,696.6 | 1.201 |
| 5 | 0.623 | 376,255.1 | 8,660.45 | 33,207.9 | 0.683 | 92.44 | 10,515.5 | 16,317.5 | 1.187 |
| 6 | 0.643 | 385,611.8 | 9,504.8 | 34,652.2 | 0.671 | 95.88 | 11,405.6 | 16,917.4 | 1.170 |
| 7 | 0.674 | 401,586.3 | 10,944.9 | 37,115.1 | 0.652 | 101.38 | 12,922.2 | 17,940.3 | 1.160 |
| 8 | 0.775 | 502.758.2 | 19,412.7 | 51,670.0 | 0.585 | 125,85 | 21,431.[illegible] | [illegible],027.3 | 1.093 |
| 9 | 0.871 | 910,307.5 | 51,486.1 | 107,823.3 | 0.510 | 183.27 | 52,880.3 | 47,[illegible].3 | 1.004 |
| IO MISSION | | | | | | | | | |
| 1 | 0.235 | 566,680.2 | 7,697.0 | 36,083.1 | 0.895 | 50.58 | 3,789.5 | 19,976.1 | 0.[illegible]86 |
| 2 | 0.355 | 536,255.0 | 7,894.8 | 36,028.9 | 0.839 | 63.44 | 5,795.9 | 19,724.1 | 0.724 |
| 3 | 0.376 | 532,401.3 | 7,977.8 | 36,117.2 | 0.829 | 65.55 | 6,163.4 | 19,729.4 | 0.762 |
| 4 | 0.478 | 520,507.8 | 8,670.4 | 37,114.0 | 0.780 | 75.98 | 8,158.6 | 20,033.6 | 0.929 |
| 5 | 0.565 | 523,212.2 | 9,821.6 | 39,064.3 | 0.736 | 85.50 | 10,292.6 | 20,832.6 | 1.037 |
| 6 | 0.665 | 552,792.9 | 12,412.3 | 43,758.1 | 0.683 | 98.58 | 13,856.7 | 22,935.8 | 1.107 |
| 7 | 0.794 | 644,956.0 | 18,819.2 | 55,572.3 | 0.611 | 120.68 | 21,624.7 | 28,343.2 | 1.142 |
| 8 | 0.927 | 996,509.0 | 40,827.5 | 95,814.5 | 0.524 | 167.51 | 45,619.7 | 46,577.0 | 1.114 |

TABLE 5 (Cont)

| CASE | k | VOLUME (FT$^3$) | FUEL (LB) | GROSS WEIGHT (LB) | β BUOYANT LIFT-TO-GW RATIO | MAXIMUM ATTAINABLE VELOCITY (KT) | ROTOR THRUST @ V = 0 (LB) | EMPTY WEIGHT (LB) | RT/DL |
|---|---|---|---|---|---|---|---|---|---|
| A/N MISSION | | | | | | | | | |
| 1 | 0.213 | 386,664.4 | 3,017.7 | 25,682.6 | 0.903 | 44.20 | 2,498.1 | 13,981.0 | 0.789 |
| 2 | 0.336 | 371,356.9 | 3,558.9 | 26,268.1 | 0.843 | 57.45 | 4,119.0 | 14,025.2 | 1.110 |
| 3 | 0.370 | 368,805.1 | 3,786.0 | 26,576.7 | 0.826 | 60.95 | 4,613.6 | 14,106.8 | 1.172 |
| 4 | 0.467 | 366,250.7 | 4,716.4 | 27,972.6 | 0.776 | 71.32 | 6,263.5 | 14,572.2 | 1.287 |
| 5 | 0.503 | 367,583.7 | 5,191.9 | 28,730.0 | 0.757 | 75.32 | 6,981.3 | 14,854.1 | 1.307 |
| 6 | 0.592 | 376,425.0 | 6,760.5 | 31,264.6 | 0.708 | 86.02 | 9,140.0 | 15,860.1 | 1.322 |
| 7 | 0.753 | 427,814.4 | 12,296.0 | 40,732.3 | 0.612 | 111.00 | 15,801.6 | 19,752.4 | 1.269 |
| 8 | 0.908 | 724,937.7 | 36,714.4 | 83,072.6 | 0.504 | 165.96 | 41,207.4 | 37,674.3 | 1.117 |
| MEP MISSION | | | | | | | | | |
| 1 | 0.351 | 983,202.3 | 9,470.7 | 66,918.1 | 0.828 | 80.47 | 11,517.0 | 34,085.5 | 0.451 |
| 2 | 0.470 | 898,261.3 | 8,661.2 | 65,118.9 | 0.769 | 94.10 | 15,064.4 | 33,095.7 | 0.609 |
| 3 | 0.555 | 858,437.1 | 8,893.6 | 65,274.3 | 0.726 | 103.66 | 17,917.1 | 33,018.8 | 0.718 |
| 4 | 0.655 | 850,240.3 | 10,889.3 | 68,617.3 | 0.673 | 116.32 | 22,426.5 | 34,366.0 | 0.832 |
| 5 | 0.718 | 869,692.3 | 13,446.0 | 73,105.4 | 0.638 | 125.76 | 26,435.3 | 36,297.4 | 0.896 |
| 6 | 0.849 | 1,018,559.5 | 25,170.8 | 94,026.5 | 0.562 | 152.11 | 41,214.0 | 45,493.8 | 1.000 |
| 7 | 0.920 | 1,360,795.8 | 47,599.9 | 133,574.8 | 0.511 | 181.10 | 65,269.4 | 62,612.9 | 1.025 |

## TABLE 5. (Cont)

| CASE | k | VOLUME (FT$^3$) | FUEL (LB) | GROSS WEIGHT (LB) | β BUOYANT LIFT-TO-GW RATIO | MAXIMUM ATTAINABLE VELOCITY (KT) | ROTOR THRUST @ V = 0 (LB) | EMPTY WEIGHT (LB) | RT/DL |
|---|---|---|---|---|---|---|---|---|---|
| MO/MP MISSION | | | | | | | | | |
| 1 | 0.219 | 596,931.5 | 5,548.8 | 39,255.4 | 0.898 | 55.6 | 4,014.5 | 20,951.6 | 0.509 |
| 2 | 0.328 | 606,724.9 | 7,510.5 | 42,379.0 | 0.843 | 66.5 | 6,644.3 | 22,113.5 | 0.675 |
| 3 | 0.435 | 636,766.2 | 10,711.3 | 47,651.4 | 0.786 | 82.1 | 10,196.3 | 24,185.1 | 0.781 |
| 4 | 0.506 | 677,381.9 | 14,201.1 | 53,484.5 | 0.745 | 94.3 | 13,641.2 | 26,528.4 | 0.825 |
| 5 | 0.538 | 702,628.1 | 16,281.3 | 56,967.0 | 0.726 | 100.5 | 15,632.3 | 27,930.7 | 0.840 |
| 6 | 0.640 | 823,982.6 | 26,114.6 | 73,382.0 | 0.661 | 124.7 | 24,861.8 | 34,512.4 | 0.874 |
| 7 | 0.738 | 1,074,519.5 | 46,585.9 | 107,181.5 | 0.591 | 162.6 | 43,819.1 | 47,840.6 | 0.896 |
| 8 | 0.836 | 1,992,958.8 | 121,229.9 | 229,556.2 | 0.512 | 247.3 | 111,968.2 | 95,571.4 | 0.906 |

## 5. MPA POINT DESIGN SELECTION

The MPA point design selection must be made primarily on the basis of the mission requirements and related costs. Obviously, any airship size can be built within the range of sizes being considered for the MPA missions. It is, of course, impractical to recommend that a different airship be built for each mission. In fact, a single design which would perform all of the missions would be most desirable. However, the size would necessarily be as large as the largest airship of the group, and possibly larger. If costs are a driving factor for the first prototype airship, it may be practical to build a smaller airship that will accomplish the higher priority missions. The selection must consider the mission needs, other means to accomplish the mission, and the value of the mission.

However, although an effort is made here to select the best design for an initial, multimission MPA point design selection, the final selection must be made with consideration of cost and mission parameters that are beyond the scope of the work in this program.

Figure 25 shows the computer airship size, or volume, as a function of buoyancy ratio ($\beta$ = buoyant lift/gross weight) for different MPA missions. It can be seen in the figure that there is a rather well defined optimum size for each mission. It also shows that the minimum airship volume for all the various missions occurs between buoyancy ratios of 0.70 and 0.90.

Figure 17 shows the airship volume, empty weight, and the fuel weight as a function of buoyancy ratio for the ELT mission, which has the highest priority of the eight missions. The lower the buoyancy ratio, the greater the thrust required for the airship to hover. However, the greater the thrust capability, the greater the dash speed capability. Therefore, the dash speed and volume both increase as the buoyancy ratio decreases. The insert on the figure indicates the top speed capability for three specific designs on the curve. Figure 26plots the airship dash speed versus volume for the various MPA missions.

For the ELT mission, the airship weight is not minimum with the minimum envelope volume. Figure 17 shows that the minimum vehicle weight occurs at a somewhat higher buoyancy ratio. Therefore, since cost is usually a direct function of vehicle weight, the lowest airship weight would tend to determine the minimum vehicle cost. For the ELT mission, however, a 90-knot-dash-speed requirement establishes the required propulsion system weight and thrust, which in turn determine the minimum airship size for that propulsion system. The buoyancy ratio for this design turned out to be 0.759 (figure 17).

Figure 17 also shows the range of airship sizes and buoyancy ratios where reversible thrust is required if ballast or ballast transfer is not desired (ie, the vertical lines of RT/DL = 1.0 and 0.5. At design values of RT/DL < 0.5, the

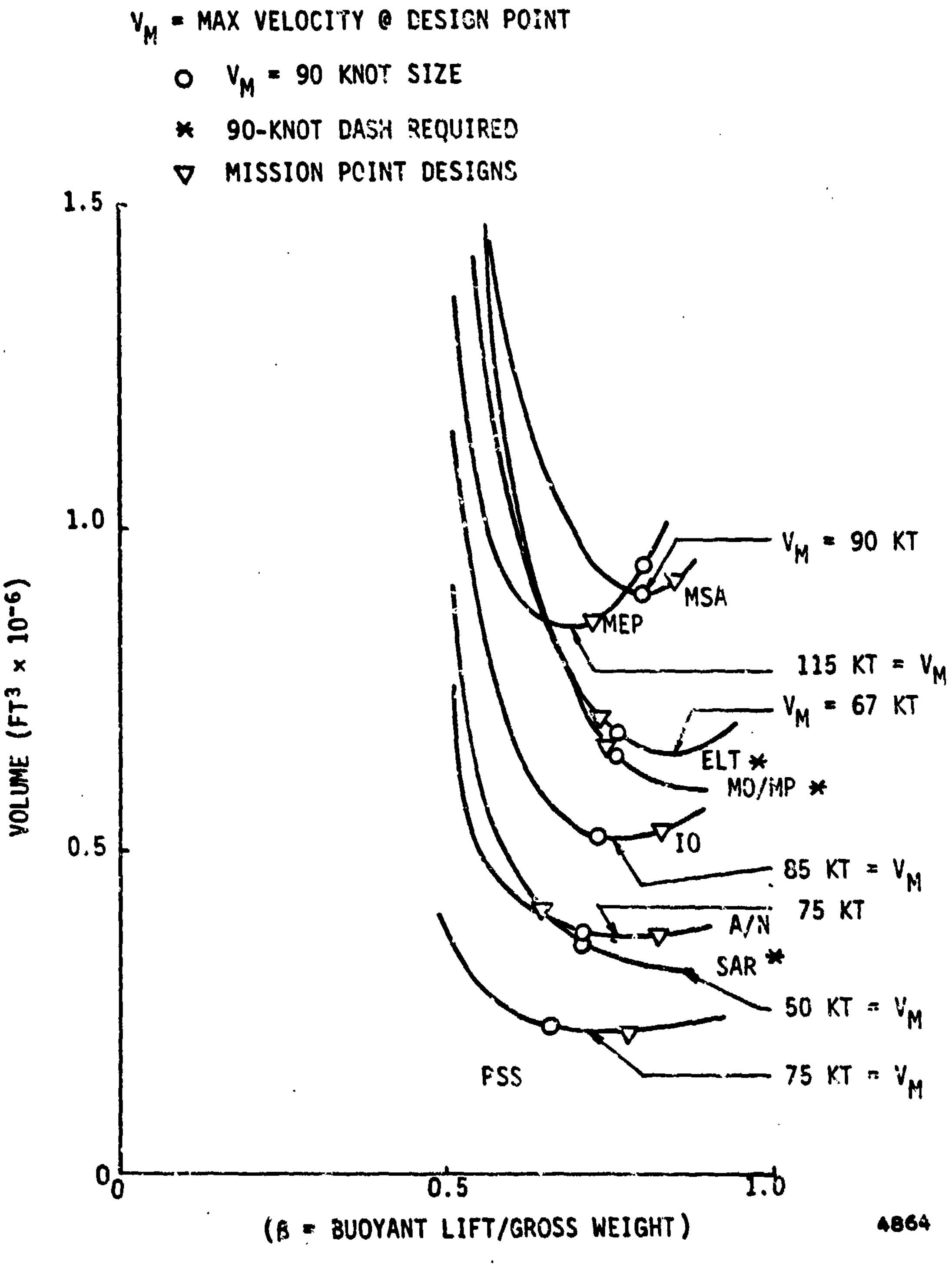

Figure 25 AIRSHIP VOLUME VERSUS BUOYANCY RATIO FOR VARIOUS MPA MISSIONS

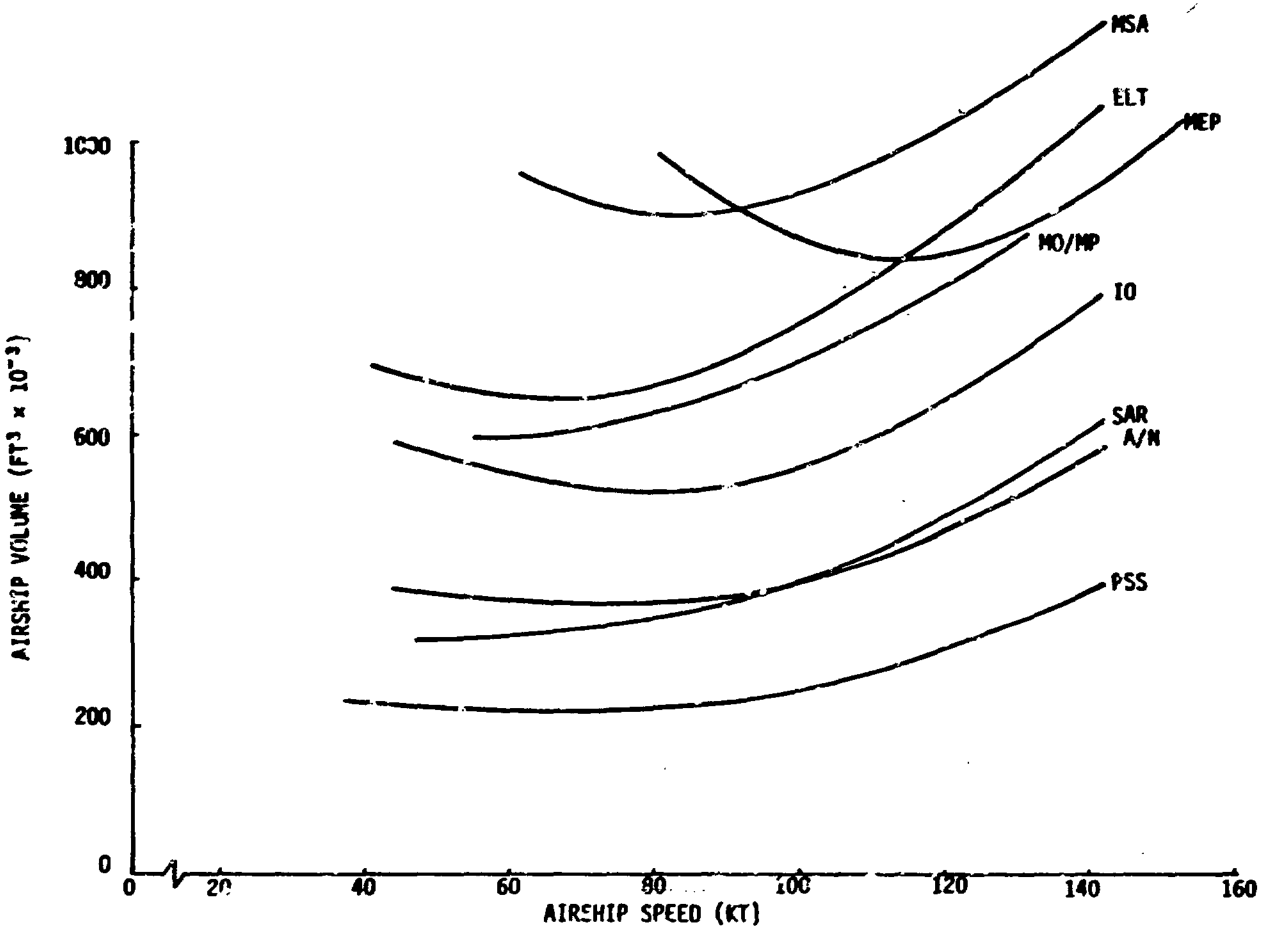

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Figure 26 AIRSHIP VOLUME VERSUS MAXIMUM ATTAINABLE SPEED FOR VARIOUS MISSIONS

reversible-thrust design will also require a small amount of ballast since, in this case, the thrust would still not be sufficient to overcome the ship lightness when the disposable load has been utilized and/or dropped off. At values of RT/DL > 1.0, the MPA is basically heavy at all times, even when the disposable load has been dispensed. When always heavy, the airship obviously does not need ballast for vertical equilibrium; however, it is needed to develop lateral thrust capability and ground controllability in lieu of reversible thrust.

A comparison of the MPA computer design results with historical airship unit weight versus volume is shown in figure 27. As expected, with more efficient structural weights, the MPA unit weights fall somewhat below the historical averages. The same trend is evident in figure 28 where the useful load is plotted versus volume. In figure 28, the MPA airship designs generally show a greater useful lift for the same volume; the PSS and the A/N missions are exceptions.

In summary, the following are several primary study results:

a. All eight missions can be VTOL with a volume of 920,000 $ft^3$.

b. All eight missions can be handled with a volume of 860,000 $ft^3$ if a dynamic takeoff can be utilized for the MSA mission.

c. Six MPA missions (ELT, MO/MP, SAR, IO, A/N, PSS) can be handled with an airship volume of 706,000 $ft^3$ and a propulsion thrust of 13,000 pounds. The MSA mission can be handled at two-thirds mission duration. MEP payload cannot be lifted in VTOL.

d. The reversible-thrust MPA concept not only inherently provides greater controllability but also provides a significantly smaller and more economical airship than conventionally heavy or neutrally buoyant airships.

However, for the purposes of making the best current point design selection, the ELT mission has the highest priority. A review of the results in figures 25, 26, and 27 indicates that the ELT size will probably be able to accomplish all missions except MSA (seventh priority) and MEP (second priority). By reducing the amount of oil recovery devices per trip for the MEP mission, however, the mission requirement could be reduced to the capability of the ELT-size MPA. The MEP mission could then be carried out, although less effectively than contemplated when the MEP mission profile was originally specified. Similarly, the MSA mission might be shortened to require less endurance, after which an airship of the ELT size would be able to carry out the reduced mission.

The ELT airship size of 706,000 $ft^3$ is therefore tentatively recommended. However, the final prototype selection will necessarily have to depend on the results of a more detailed missions study and design effort in conjunction with detailed projections of life-cycle cost analysis, including initial costs, and operation and maintenance costs.

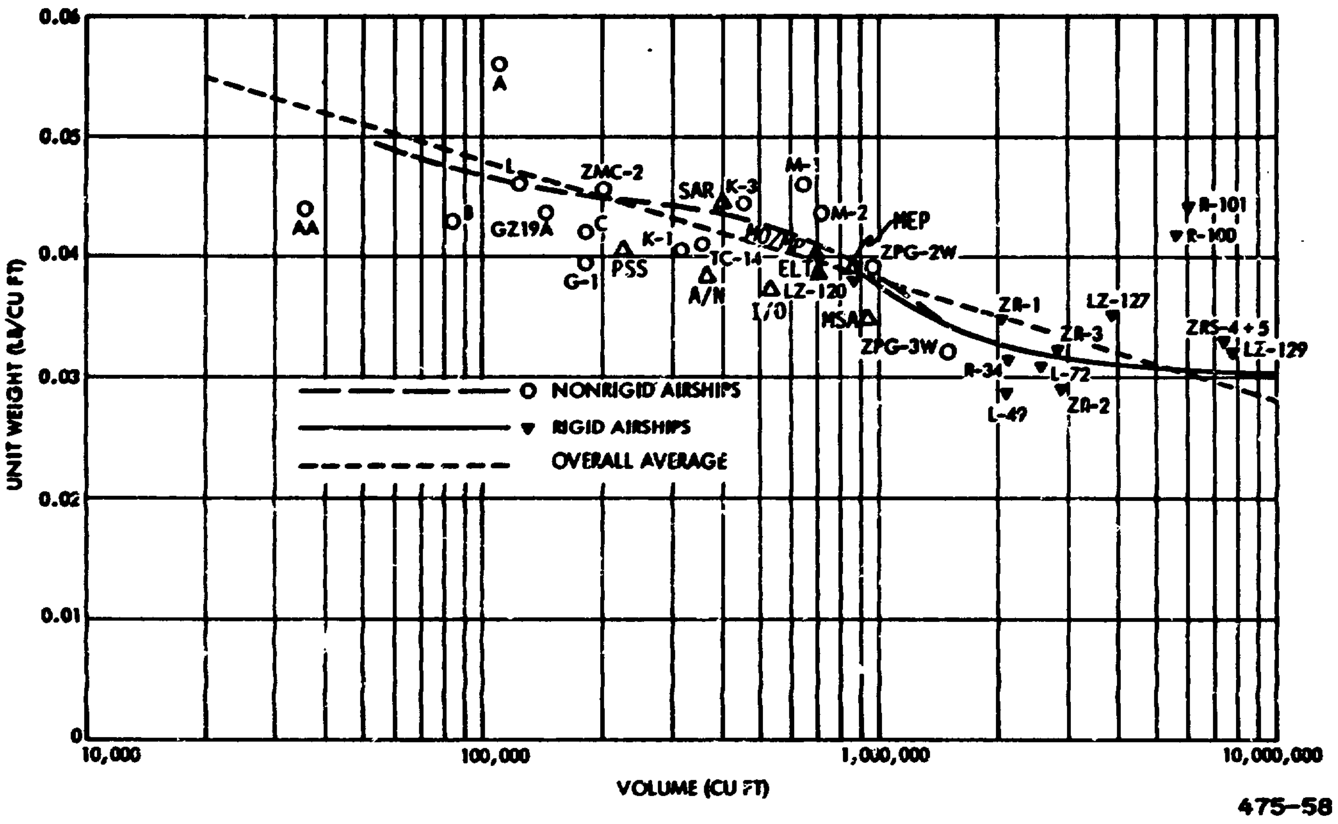

Figure 27 COMPARISON OF MPA COMPUTER RESULTS WITH HISTORICAL AIRSHIP UNIT WEIGHT VERSUS VOLUME

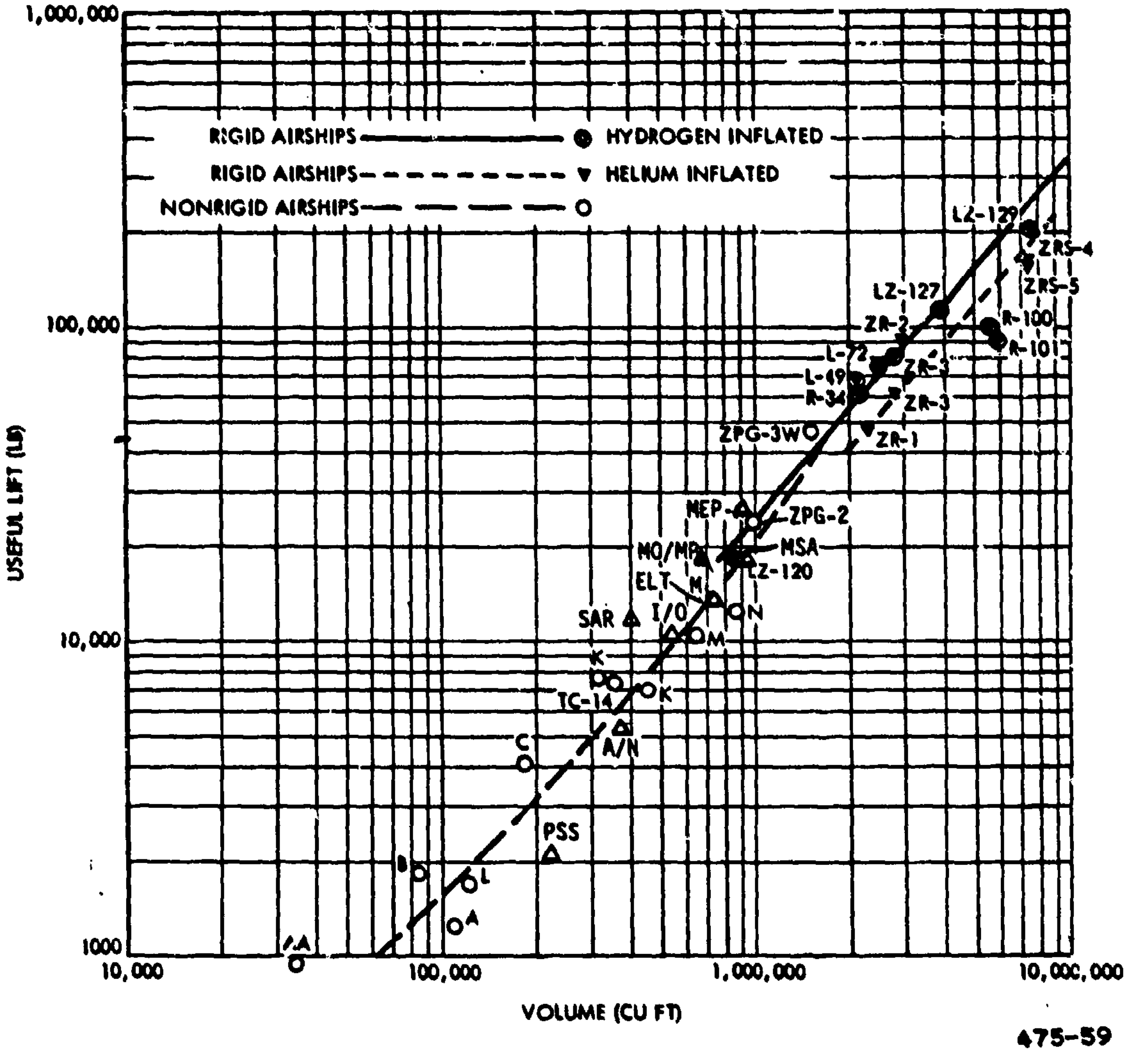

Figure 28 COMPARISON OF MPA COMPUTER RESULTS WITH HISTORICAL AIRSHIP USEFUL LIFT VERSUS VOLUME

## 6. CONCLUSIONS

The following conclusions and recommendations have evolved as a result of this study:

a. MPA designs look entirely feasible and will be able to accomplish any or all of the missions considered herein.

b. With the application of recent Bell innovations and modern technology, it appears possible to eliminate the primary traditional limitations of previously existing airships, ie, hover and low-speed control, ballast transfer requirements, and ground handling.

c. No technological breakthroughs are necessary to develop an MPA design.

d. Modern computer math model simulation engineering makes it possible to optimize the size and volume and propulsion system for the airship for either specific or multiple-mission requirements.

e. The Bell reversible-thrust airship design provides the maximum controllability and minimum airship size and cost for a specific mission.

f. The simplified Bell airship sizing and performance (ASP) computer program provides a very flexible airship design evaluation capability.

g. Flexibility of the ASP computer program indicates that greater use should be made and that further subsystem refinements and life-cycle costing should be incorporated into the program.

h. Computer designs of smaller, more controllable, higher-speed airships, that indicate lower costs, should be fully investigated.

## 7. RECOMMENDATIONS

The following are recommendations for the near-future, follow-on development effort of the MPA:

a. The current, Bell ASP computer program should be used to establish the basic parametric trends for MPA sizing and performance.

b. The weight relationship in the ASP computer program should be modified to improve the program flexibility. Although the program has already modified the reference 3 weight relationships to eliminate some inconsistencies, it is felt that the subsystem weights can be more simply related directly to their basic functions rather than being tied to the magnitude of the useful load. As an example, the envelope weights should be a function of the envelope volume, the engine weights should be a function of the rated horsepower, and the propulsion system support structure weight should be a function of propulsion thrust. Originally, they were all equated to a function of $W = AU^B$, where A is a factor and B is an exponent of the useful load, U. The values of A and B are different for different subsystems. However, the usefulness of this function is limited because the subsystems vary in their relationship to the useful load for different airship missions or concepts.

c. The methods of establishing subsystem design weights should also be evaluated further. Although the current methods are very useful in terms of showing performance and sizing trends, improvements to reflect more accurate subsystem weight relationships would improve the absolute values of the computer results. The program could also be made to reflect future design trends by incorporating factors for expected subsystem weight improvements as a function of time. Present weight estimates, however, should represent the current state of the art to best reflect the weight, size, and performance of airships that would be currently designed.

d. Life-cycle costing should be incorporated into the ASP program. The program should include prototype or first-unit costs, as well as multiple-unit costs, based on standard learning curves. Operating and maintenance costs should also be included to provide the operational portion of the life-cycle costs.

e. The performance and fuel utilization of specific MPA designs should be examined for a range of payloads and missions other than those for which the MPA were designed. This study will establish the range of payloads and missions for which any specific airship design can be effectively utilized.

f. The effects of airship heaviness (gross-weight-to-buoyant-lift ratio, GW/BL) on structural weight should be investigated since the load factor varies substantially as a function of heaviness[5]. The increase in structural weight due to increases in bending moment resulting from increasing heaviness must be considered in the design. It does not appear that references 3 and 6 have adequately taken this into account, although those airships have been generally designed to be quite heavy.

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[5] *Parametric Study of Dynamic Lift Aerostats for Future Naval Missions* (Goodyear Aerospace Corporation, GER 13564, January 31, 1968) AD-833958.

[6] *Feasibility of Modern Airships--Phase II* (Goodyear Aerospace Corporation, NASA CR-151917, September 1976) volume I, book I.

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3. *Development of Weight Estimating Relationships for Rigid and Non-Rigid Heavy Lift Airships* (Goodyear Aerospace Corporation, NASA CR-151976, March 1977).

4. J. J. Vorachek, *Investigation of Powered Lighter-Than-Air Vehicles* (Air Force Cambridge Laboratories Contract No. F1962867C0047, Scientific Report No. 1, Goodyear Aerospace Corporation GER 13140, February 28, 1967).

5. *Parametric Study of Dynamic Lift Aerostats for Future Naval Missions* (Goodyear Aerospace Corporation, GER 13564, January 31, 1968) AD-833958.

6. *Feasibility of Modern Airships--Phase II* (Goodyear Aerospace Corporation, NASA CR-151917, September 1976) volume I, book I.

# APPENDIX A

## BELL AEROSPACE TEXTRON
## RENDEZVOUS 40

[illegible]

**textron Bell Aerospace**

BELL AIRCRAFT CORP.

*Original Elmwood Avenue plant in Buffalo, N.Y.*

Vol. XIV/No. 2/July 1975

**rendezvous**

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**textron Bell Aerospace**

BUFFALO, NEW YORK 14240

Textron's Bell Aerospace Division is proud to devote this issue of Rendezvous to the history of the company. Founded 40 years ago on July 10, 1935, as Bell Aircraft Corp., the company continues today as a leader in aerospace pioneering. Bell's part of the nation's first 200 years is an exciting story of achievement, from the first U. S. jet to development toward the 100-knot Navy of the future.

JOBS and money were scarce in 1935 when Consolidated Aircraft announced it would shut down its successful Buffalo, N. Y. operation and move to San Diego. Although good positions and a secure future awaited them in California, four friends decided to stay behind and gamble on the creation of a new aircraft company.

Heading the group was Lawrence Dale Bell, son of a hardware store proprietor who, from his grammar school days when history was made at Kitty Hawk, N.C., had focused his dreams on the sky. For 20 years Bell had been a top executive in the fledgling aircraft industry, having been vice president and general manager for both the Glenn L. Martin Co. in California and later Consolidated Aircraft of Buffalo.

Seven years after joining Consolidated, Larry Bell saw an opportunity when that firm decided to make the California move. He convinced three associates at Consolidated, Ray P. Whitman, assistant general manager, Robert J. Woods, a top aeronautical engineer, and his secretary, Irene Bernhardt, to remain in Buffalo to join him in forming a new company. Bell reasoned that the facilities and Buffalo's trained craftsmen which Consolidated would leave behind were available if sufficient start-up money could be found. On July 10, 1935, Bell Aircraft was incorporated.

Bell, as president, and Whitman, as first vice president and treasurer, walked from door to door seeking investors. While they were pounding the pavements in search of money, Bob Woods, the new firm's chief design engineer, was back in the tiny, second floor offices in the old Consolidated plant working on plans. Immediately upon incorporation, Larry Bell had sold $50,000 worth of stock to close friends. But the firm had incorporated for $500,000 and Bell knew he had to sell at least another $300,000 worth of stock to be in business. The deadline for the sale of stock was September. The entire month of July was spent in futile attempts to raise even another nickel. Around the first of August, Bell obtained another $10,000 from a local retail store owner. That broke the logjam and other stock orders followed.

With the money in the bank, Bell Aircraft took over the 40,000 square feet of space formerly occupied by Consolidated on Elmwood Avenue and installed $35,000 worth of equipment. It was late September and Bell Aircraft now had working capital. All it needed was a contract and a customer. They weren't long in coming. The Army asked Bell to install an Allison V-1710 engine in an A-11 attack plane being built by Consolidated Aircraft. The price on the contract was only $25,000, yet it too broke another logjam and was the start of Bell Aircraft's rise in the aviation industry. Fifty men were hired to start the contract.

Larry Bell and Ray Whitman continued their relentless pursuit of new orders while Bob Woods continued to accumulate plans for a revolutionary airplane design. Woods' design was the YFM-1 Airacuda, a long range fighter with two pusher propellers and radical remote control armament consisting of a 37-millimeter cannon mounted in each engine nacelle. In addition to the armament, Woods later incorporated an innovation which years later was the accepted design in all aircraft —the tricycle landing gear for easier handling on takeoffs and landings.

*YFM-1 Airacuda*

In May 1936, before it celebrated its first birthday, Bell Aircraft received an Army contract for $403,057 to build an experimental model of the Airacuda. Meantime, earlier in the year, Bell was awarded a whopping $800,000 contract from the Navy to fabricate wing panels and other parts for the Catalina flying boats of Consolidated Aircraft.

Eventually, the Army ordered 14 Airacudas, yet, in spite of this, the contract proved a losing proposition for Bell. The 14 were the only Airacudas ever built. When put into the air, the new design indicated it was just too advanced in every way. In addition, the two Allison pusher engines were far underpowered for the craft itself.

While the Airacuda was being assembled for delivery to the Army, Woods was designing a brand new fighter which was destined for immortality—the P-39 Airacobra —a single engine craft capable of unheard of speeds approaching 400 miles an hour.

The revolutionary P-39 was a boon to Bell Aircraft Corporation. In 1939 the Army, after observing the flight tests at Wright Field, officially accepted the airplane.

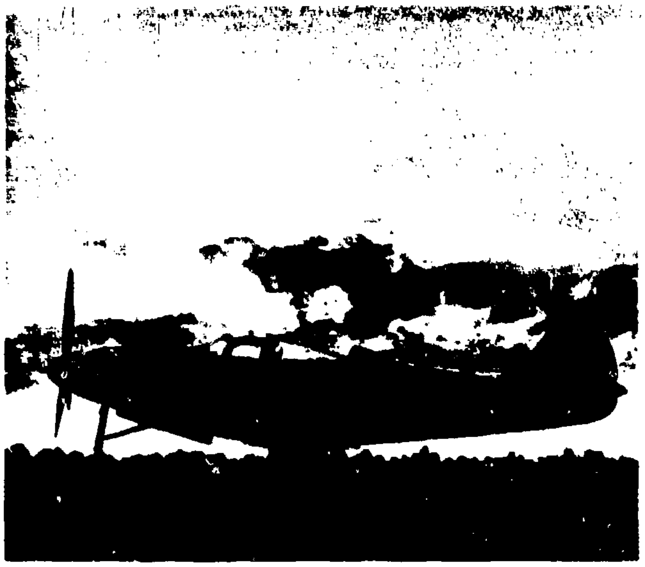
At the time the Army contract was received by Bell World War II exploded in Europe. Vice President Harry L. Collins came back to Buffalo with a $9 million order for 200 Airacobras from the French, two million of it in cash. For the first time since its formation, Bell Aircraft had elbow room in its treasury. But as this order was coming to fruition, France fell before the Nazi onslaught. Larry Bell relied on his selling emissary once again and prevailed upon the British to take over the French contract.

In October 1940 two significant milestones were passed in the rapid growth of Bell Aircraft. With a host of dignitaries on hand, ground was broken for the $1,050,000 plant in Wheatfield, N. Y. Two days later, on Columbus Day, the first production model of the P-39 Airacobra was delivered to the Army Air Corps at Wright Field.

On January 19, 1940, the Bell Airacobra had performed successfully at an Army Air Corps demonstration at Bolling Field in Washington, D. C. It was the first P-39 to roll off the Bell assembly line as a result of the Army order the previous year. A few weeks later that same plane, with Captain George E. Price at the controls, was going through its paces above the Buffalo Airport for the benefit of visiting Army brass.

The cold February winds and the high altitudes had frozen the plane's landing gear. Larry Bell, himself, on the ground, ordered Captain Price to bail out. The pilot ignored the instructions. To allow the plane to crash would set Bell Aircraft and the Army Air Corps back many, many months. Price made a belly landing and escaped unhurt.

The Airacobra was leading Bell Aircraft to spectacular heights. More than 10,000 Airacobras were eventually produced by Bell. But obsolescence was the Airacobra's

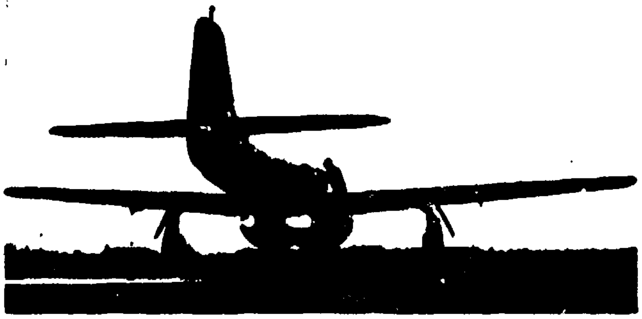


**Flying Artillery**

*The P-39 carried a cannon nearly twice the size of the 20mm armament available on other aircraft. Bell put the engine behind the pilot and installed the cannon in the propeller shaft. The Soviet Union achieved startling results with the Airacobra, using it in low-level attacks against Nazi tanks. The 37mm cannon was large enough to knock tanks out of action, and the aircraft's rugged design was able to absorb a large amount of battle damage.*

fate, for even before the entry of the United States into the war, the military was thinking of jet propelled aircraft.

ON Labor Day 1941 Bell went to Washington for a conference with his long-time friend, Gen. H. H. "Hap" Arnold. Could Bell Aircraft build an experimental fighter plane with jet propulsion instead of the conventional propellers? The answer was yes. By the end of the month General Arnold had cleared the red tape and Bell Aircraft received a contract for the construction of three experimental jet planes known as the XP-59 and later as the P-59 Airacomet.



*P-59 Airacomet*

Three weeks after Bell leased a former automobile plant on Buffalo's Main Street for the experimental jet work, the Japanese bombed Pearl Harbor. On Monday, December 8, 1941, as President Franklin D. Roosevelt was asking Congress to declare war on the Axis powers, General Arnold in Washington was on the telephone to Larry Bell in Buffalo.

"How would you really like to go to work?" the general asked Bell. Bell Aircraft was rolling fighter planes off the assembly line at the rate of more than 20 a day, yet a bigger challenge was waiting. Bell was unhesitating in his answer and a few days later the company was awarded a contract to produce the huge B-29 bomber at a plant to be built in Marietta, Ga.

The company entered yet another field in 1941, when Bell hired a man named Arthur Young for helicopter development work to be conducted in a small shop in Gardenville, N. Y., about 20 miles south of Buffalo.

Young hired a mathematician named Bartram Kelley and a handful of craftsmen and set to work. War had erupted and it was only a matter of months before the United States became involved directly. Development of the helicopter was of secondary importance.

Production of the Airacobra and its successor, the advanced model P-63 Kingcobra, important as it was, was not the most significant event to take place at Bell during the early days of World War II. The jet age was ushered in when, in September 1942, Bell delivered the first jet-propelled plane to the Army at Muroc, Calif. First flight of America's first jet came on October 1, 1942.

*P-63 Kingcobra*

On the eve of the company's eighth birthday, Bell announced it would be subdivided into three divisions —the Niagara Frontier for the development and production of fighter aircraft and the development of the helicopter, the Ordnance Division for the production of guns, gun mountings and shells, and the Georgia Division for production of B-29s.

Ordnance production grew at such a rapid pace that the Bell Ordnance Division moved its entire operation to a plant in Burlington, Vt. Within a matter of weeks, the Burlington plant was turning out a huge Army order for M-7 gun mount adapters.

The Niagara Frontier Division was turning out fighter planes in record numbers, and in Georgia the first of 663 B-29 Superfortresses was being readied for action. But in the little garage in Gardenville, perhaps an even more significant scene was being enacted. Arthur Young and Bart Kelley had completed their first flying model of a helicopter. Floyd Carlson, the test pilot, had taken this experimental craft on several test runs.

Back at his drawing boards, Bob Woods was working on the XP-77, an all plywood fighter plane. The world was aflame with war, and fear of an ultimate shortage of aluminum for the construction of flying craft, produced the idea of building a plane made entirely of wood. The all wood XP-77 was built and successfully test flown.

In 1944 and until V-J Day in 1945 the Bell Aircraft Corporation hit its peak production. In mid-1944 the last Airacobra came off the production line at Wheatfield and the Superforts were being built at the rate of two a day in Marietta. Employment hit a new high of 50,000.

But the war's end brought with it a drastic cutback. In the matter of a few months employment was cut back from 50,000 to less than 3,000. The impact was tremendous.

The B-29 plant in Marietta was closed down, leaving Bell with its plant at Wheatfield, in which it consolidated all its Buffalo operations, and the one in Burlington. Eighteen months later, the Burlington Division was closed.

In order to keep the corporation from complete collapse, Larry Bell played the ace he had been keeping in the hole. He went out to sell the helicopter. In a few weeks he had orders for three models. The Army Air Force wanted the five-place, 600-horsepower Model 48; the Army and the Navy both asked for delivery of the Model 47A, a two-place craft; and there were civilian orders for the 47B, a commercial model in the 47 series.

Early in March 1946, the Model 47 series was granted the first commercial certification by the Civil Aeronautics Administration. Two months later the same craft was granted the first manufacturing type certificate.

The helicopter came of age in 1951 with the outbreak of the Korean War. More than two-thirds of all the helicopters flown in Korea were made by Bell. An estimated 20,000 wounded United Nations troops were evacuated to safety by Bell helicopters and another 1,000 fighting men were rescued by helicopter.

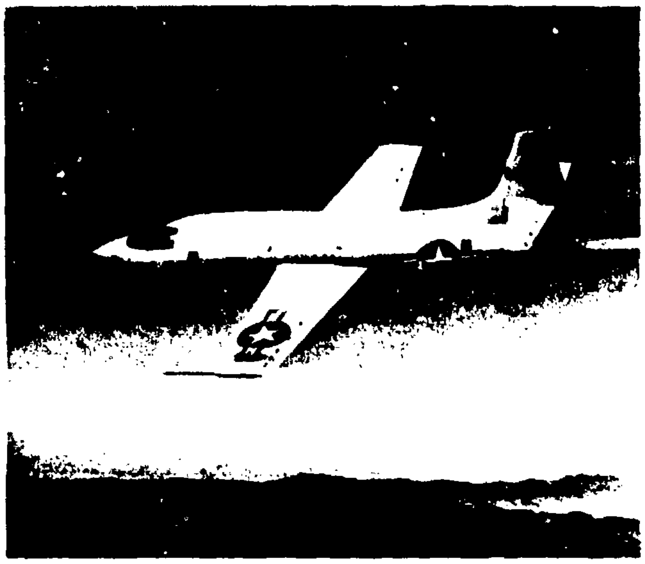
In May of 1951 ground was broken for a helicopter production facility outside of Fort Worth, Texas. A few months earlier, Harvey Gaylord had been named vice president for helicopter operations.

While Bell helicopters were gaining recognition throughout the world, the company's design engineers were busily sketching an experimental, rocket-powered plane to be known as the X-1. Taking the basic concepts of the P-59 and the newer P-83 jet-powered craft, Woods realized that contemporary jet engines would not provide the thrust needed at high altitudes. If the X-1 was to fly at altitudes where the atmosphere was thin, it needed a new and extraordinary propulsion system. Thus, Woods designed the X-1 around a rocket engine.

On October 14, 1947, the Bell X-1, with Air Force Capt. Charles Yeager at the controls, was dropped from the belly of a B-29 "mother ship" and sped off to a record speed faster than sound. No man before had travelled faster than 750 miles an hour. What Captain Yeager's speed was on that maiden voyage, the military never revealed. But less than a year later Yeager was clocked at the unheard of speed of 967 miles an hour. The sound barrier had been broken and the assault on speed records continued at a fantastic rate.

The world's first supersonic flight in 1947 gained for Larry Bell, Captain Yeager and Bell Aircraft the coveted Collier Trophy.

Not only did the Bell X-1 and modified X-1A attack speed records, they also were used to attain altitude records. In the years after the first supersonic flight, there were continuing competitions for one new record after another. The X-1 hit an altitude record of more than 70,000 feet and, late in 1953, the X-1A, again with Chuck Yeager, by then an Air Force major, at the controls, flashed through the sky over Edwards Air Force Base in California at 1,650 miles an hour — two and a



**First Movable Tail**

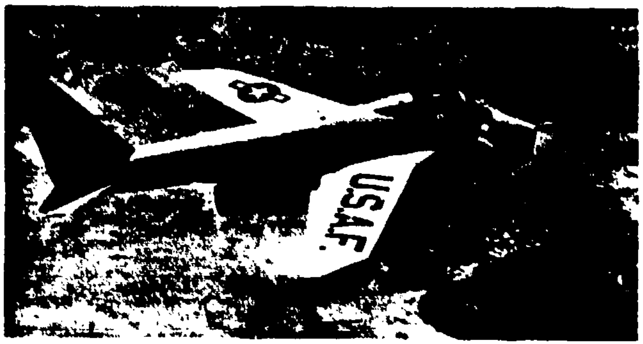
*In late 1974, Charles E. Yeager, then an Air Force brigadier general, recalled that the early X-1 experiments showed the need for the movable tail that is standard on today's high speed aircraft. A few years later, the movable tail section was designed into the F86 jet "which dominated the Russian MIG 15 in the Korean War," General Yeager told members of the Lawrence D. Bell Chapter, Air Force Association, in Buffalo.*

half times the speed of sound. This flight earned him the Harmon International Trophy, aviation's highest award.

BECAUSE of its pioneering in the field of supersonic flight, the Bell X-1 was selected to be enshrined in the Smithsonian Institution in Washington where it shares prominence with Bell's P-59, this country's first jet-powered airplane.

Indicative of a new emphasis on research and development at Bell was the fact that in 1950, as the Korean War heightened, two-thirds of Bell's engineering manhours were spent in the fields of guided missiles and rocket engines. Bell was working on assignments for the Air Force and Navy to develop variations of the guided missile including air-to-surface, air-to-air, surface-to-surface, and surface-to-air. Late in the year the Air Force began to use the Bell radio-controlled Tarzon bomb in Korea.

In June 1951 the Bell X-5, the first plane with a variable wing sweepback, was tested successfully, thus opening a new path in aircraft design.

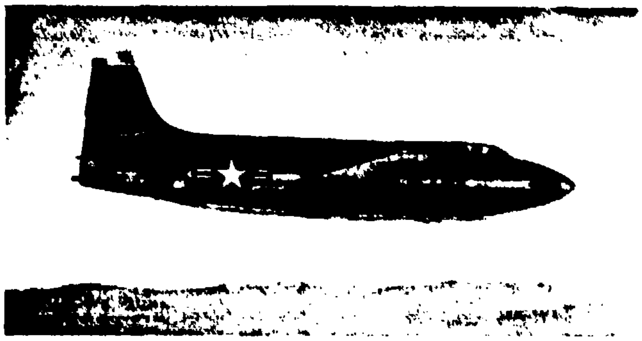


*X-5*

In 1952 a significant change was made in the company's top-level management. Larry Bell remained as president and general manager, and Ray Whitman as first vice president. Leston P. Faneuf, who had been secretary-treasurer, was given additional duties as assistant general manager. William G. Gisel, a native of Jamestown who had been with Bell since 1940, was named comptroller.

Larry Bell called the year 1954 "the most satisfactory in the company's history, in many respects." As Bell Aircraft rounded out its first 20 years, the company's payroll approached the $100 million figure.

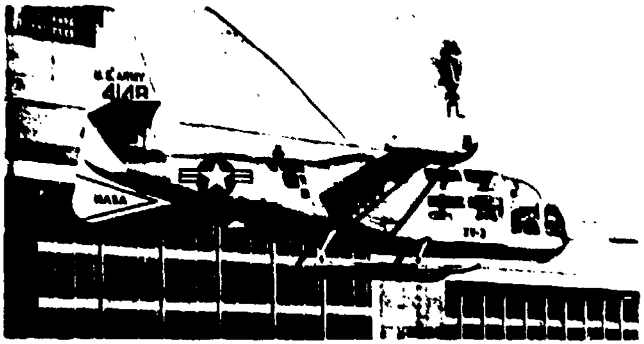
The Bell X-1A, which the year before set a speed record of 1,650 miles an hour, was taken aloft by Air Force Major Arthur Murray who set an altitude record of 90,000 feet.



*X-1A*

Bell engineers announced the development of an electronic remote control system which could land guided missiles, and the company received a contract from Boeing to produce nacelles for the mammoth B-52 Stratofortress.

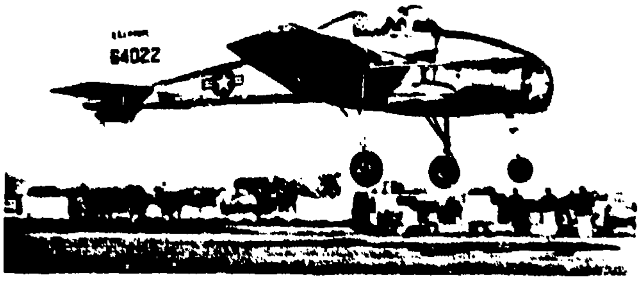
That same year the company announced two new and radical designs by the engineering staff. They were the Bell Air Test Vehicle and the XV-3. The ATV was a jet-propelled airplane which could take off and land vertically without changing its horizontal altitude. The XV-3 was a "convertiplane" which used the helicopter principle for takeoffs and landings, yet once airborne was really a fixed wing craft.



*XV-3*

The ATV was a monument to Bell's independent engineering. While nearly every technological advance in aviation that day and age was being carried out under government contract, the first VTOL was built exclusively with company funds. Bell's design engineers were positive it would work, and the company provided the wherewithal to prove it.

As a result of the Air Test Vehicle program, Bell's independent proposal to build the X-14 VTOL for the Air Force was approved. Using a deflected-thrust technique to attain its VTOL capability, the twin-jet X-14 made its first hovering flights in 1957 and transition flights in 1958. Besides providing important VTOL design technique data, the X-14 was sent to National Aeronautics and Space Administration's Ames Research Center, where it is still flying as a basic research aircraft.



*X-14*

On October 1, 1954, Larry Bell announced he was stepping down as general manager of the Bell Aircraft Corp., but that he would remain as president of the corporation. He was succeeded as general manager by Leston P. Faneuf who also retained the position of treasurer. William G. Gisel assumed the duties of secretary of the company.

Thus, a little shy of 20 years after he founded the firm, Larry Bell began to go into retirement. In the time since he founded the corporation July 10, 1935, Larry Bell had seen his dream grow from an initial investment of $500,000 to a company with assets of $53,500,000.

Early in 1955 the Air Force placed its stamp of approval on the Rascal air-to-ground guided missile. In the spring of that year the Navy announced that Bell engineers had developed an automatic, all-weather landing system which could land fighter planes on aircraft carriers automatically. The Navy gave Bell the green light to produce a working system. In two years, both the Bell VTOL and the all-weather automatic landing system were in use, and the Strategic Air Command established an entire squadron equipped with the Rascal missile.

*Early Automatic All-Weather Landing System*

In the fall of 1955 the supersonic Bell X-2 was launched at Edwards Air Force Base in California. The X-2 was the first airplane designed to explore the thermal or heat barrier and was the last in Bell's series of supersonic planes. Before it was destroyed in a crash in September 1956, the X-2 established unimagined speed and altitude records. In the summer of 1956 Air Force Lt. Col. Frank K. Everest, Jr., flew the X-2 faster than 1,900 miles an hour. A few weeks later another Air Force pilot, Capt. Ivan Kincheloe took the same plane to a height of 126,200 feet. On the X-2's final flight on September 27, 1956, Capt. Milburn Apt achieved a speed of 2,148 miles an hour.

*X-2*

LARRY Bell died October 20, 1956, ending a 44-year career during which he carved a prominent niche in aviation. His removal from the scene he dominated for so long necessitated a major corporate reorganization. Named to succeed the founder was Leston P. Faneuf who had been general manager since 1954.

Bell Helicopter Corp., a wholly-owned subsidiary in Texas, was formed in 1957 with Harvey Gaylord its president.

Bell Aircraft continued to make aerospace history when its Agena rocket engine was installed as the second stage rocket in an Air Force classified satellite program. In February of 1959 the first launching, a polar orbiting satellite, was successfully undertaken.

During the year, Harvey Gaylord, who had been president of the Bell Helicopter Corp., was elected president of the parent Bell Aircraft Corp. to succeed Leston Faneuf who continued as chairman of the board. William G. Gisel, who was corporate vice president and treasurer, was appointed general manager of the Niagara Frontier Division. He succeeded Ray P. Whitman, who retired at the end of 1959 after serving the company since it was founded.

The year 1960 was Bell Aircraft Corporation's Silver Anniversary, a significant "Year of Change."

The first half of the year saw Bell receive two government contracts totalling slightly more than $23 million. The first was a contract from Pan American World Airways to set up a test range near Fort Huachuca, Ariz., to try to determine a solution for the Army's communications-electronics interference problems.

A short while later the Navy asked Bell to build four of the all-weather, automatic landing systems. The Bell automatic landing systems were to be installed on Navy aircraft carriers and two other systems would be land-based for pilot training.

On July 2, 1960, the entire multi-million dollar defense business of the corporation was purchased by an industrial giant, Textron Inc. of Providence, R. I.

At the time of the acquisition, G. William Miller, president of Textron, said:

"For Textron, the addition of Bell fulfills a long-standing desire to take a more active part in national security programs. As a member of the Textron group, Bell now possesses resources with great potential. Its scientific competence has been demonstrated by a record of accomplishments. Modern facilities are at its disposal. Adequate capital is available to sustain and implement its programs."

The new corporation became the Bell Aerospace Corp., divided into three separate and autonomous divisions — the Bell Aerosystems Co., with headquarters in Buffalo; the Bell Helicopter Co. of Fort Worth, Texas, and the Hydraulic Research and Manufacturing Co., of Burbank, Calif.

**Textron Visitors**

*In 1967, the first public demonstration of the X-22A aircraft brought corporate and division officers together in Buffalo. From left, G. William Miller, William G. Gisel and Harvey Gaylord. By the time the X-22A was flying, Bell was well into its various programs for the NASA Apollo lunar exploration effort. Another program that year was early development of a Minuteman III propulsion system rocket engine.*

Harvey Gaylord, president of Bell Aircraft, was named president of the Bell Aerospace Corp., and William G. Gisel, who had been vice president and treasurer of the former company, was named president of Bell Aerosystems Co.

Gisel was a seasoned executive with 20 years experience with the company prior to his elevation to the presidency of Bell. Born in Jamestown, N. Y. in 1916, he was graduated from Miami University at Oxford, Ohio, in 1937, and returned to Jamestown where he worked three years before joining Bell in 1940.

All-weather landing systems were being readied for the Navy by the newly-formed Avionics Division which was given the additional task of supplying digital velocity meters and miniature accelerometers for the nation's satellite and missile programs.

The new Aerospace/Rockets Division completed tests on a rocket engine which used liquid fluorine and liquid hydrogen as propellants. The success of the Agena rocket engine in various satellite launchings was unparalleled.

Late in 1960, Bell, which had been doing some independent research in the air cushion vehicle field (XHS-1), unveiled a vehicle built under Navy contract (XHS-2) which glided over land or water on a cushion of air. A year later the Navy awarded Bell a contract to build a 65-foot research craft weighing approximately 35 tons to be known as the SKMR-1 Hydroskimmer.

Bell's reaction control system, an earlier version of which had been installed on the X-1A, was an integral part of the Mercury manned space flights. Bell reaction controls also were installed in the record-shattering X-15 rocket research airplane and the Centaur space vehicle.

Closer to earth, Bell was working on a much smaller personal rocket lift device known as a Rocket Belt which a man could carry on his back enabling him to soar over 60 foot obstacles. Concurrent with the research in this field was the development of the Zero Gravity Belt, a personal propulsion device for maneuvering a man in space.

But it was in the rapidly advancing field of space technology that Bell was making its name known throughout the world. Bell reaction controls were on the spacecraft in which Astronaut John Glenn made the first American orbital space flight early in 1962. Bell's Agena engine started, stopped and restarted in space, with the aid of a Bell digital velocity meter, to send Ranger 4 to the moon that year. The same Agena engine and digital velocity meter were aboard the Mariner 2 spacecraft which made the first successful fly-by of the planet Venus in 1962.

*Agena engine production*

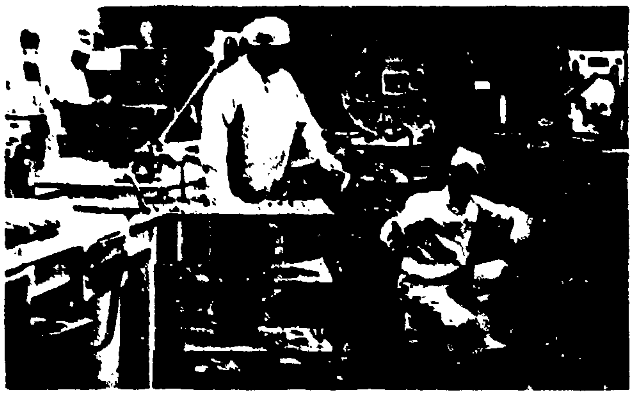
As Bell technology continued to grow, so did the physical facilities of the firm. In 1962 a research laboratory was established in Tucson, Ariz., for the study of electronics and electromagnetic systems and a 75,000 square foot addition, providing space for 700 engineering personnel, was started at Bell's main plant.

THE Agena spacecraft was selected by NASA to serve as the target vehicle for Gemini. For this, Bell modified the Agena engine to give it a multiple restart capability and added a secondary propulsion system to the spacecraft to apply vernier speed adjustments and orient propellants in the fuel tanks.

A contract was awarded Bell to design and construct two Lunar Landing Research Vehicles to establish the feasibility of utilizing such systems for training astronauts in lunar landing techniques.

Within the year, Bell was awarded contracts by NASA and the Grumman Aircraft Engineering Corp., prime contractor for the construction of the Apollo Lunar Module (LM). The first was a contract to develop the ascent engine for LM which would be used to lift the space explorers off the moon for their return trip to earth. The second was a contract to design and build positive expulsion tanks for Apollo's reaction control system.

To work on these various space projects, Bell expanded its facilities to include a new "clean room," a 23,000 square foot area completely dust free eliminating, for testing purposes, the introduction of any foreign elements into component parts of rocket engines or space systems.



*Bell clean room*

The Avionics Division, in 1963, was awarded a government contract to design and produce the stabilizing and navigating components of a highly sophisticated airborne camera to be used in the preparation of maps and charts.

The ground testing and, toward the end of the year, the actual flight testing of the Lunar Landing Research Vehicle was conducted successfully at NASA-Edwards, Calif.

Bell entered the second half of the 1960s on the crest of a "technological explosion" that was to not only put men on the moon, but was to foster a new era of military strategic and tactical systems capability. The period, however, was to be characterized also by a leveling off of aerospace and defense spending that was to have a significant effect on all members of the industry, including Bell. It was a time of retrenchment and re-evaluation of markets with a premium on prime and/or major subcontractor contracts.

Realizing that competition for aerospace and defense business would be stiffer than ever before, President Gisel in the summer of 1964 was already gearing Bell for the squeeze. First on the agenda was a streamlining of operations, involving the first major overhaul of the management organization since its formation under Textron four years earlier. The move entailed the complete restructuring of the company along functional lines, rather than by product lines as before.

Five main technology areas were established: Propulsion Systems and Components, Aerospace Systems, Electronic (electromechanical and electromagnetic) Systems, Air Cushion Vehicles and Advanced Technology. During the realignment, top management was also firming up future business policies. Fundamental was a decision to maintain the aerospace and defense area as the company's primary market. Commercial and other markets would be sought only when they were a natural outgrowth of the company's aerospace work.

Particular attention would be directed toward study contracts having a potential for hardware follow-on in overall systems or major sub-system areas where a well-balanced engineering, research and manufacturing capability is at a premium.

Within the defense market, Bell would pursue as a matter of first priority the advanced Intercontinental Ballistic Missile area as a logical extension of the company's outstanding background in rocket engines and propellant tankage, particularly as related to pre-packaged liquid propulsion systems.

Other targets identified within the defense area included the application of the company's maturing structural optimization, data processing, and composite material technologies to the development of new tactical aircraft airframes; the application of Air Cushion Vehicle technology to military needs in the area of amphibious assault and riverine warfare vehicles; and the continued development of a Vertical/Short Takeoff and Landing (V/STOL) technology base, as well as all-weather avionic and airborne target location systems.

Aerospace efforts would be directed at continued contributions in hardware and technology to the Apollo manned lunar landing program and to such phases of Apollo Applications Program as the Orbiting Space Station and Space Shuttle.

Now known as the "workhorse of the space age," the Agena marked its 15th anniversary in space on February 28, 1974. Having registered an unparalleled number of space age "firsts," Agena in 1969 had helped place the heaviest satellite ever into a synchronous orbit, 19,300 miles above the earth's equator.

THE most important development of 1968, however, came when President Gisel announced on August 11 that the company had been selected by the Air Force to build and test an advanced liquid system for the Minuteman III ICBM.

Designated the Post Boost Propulsion System (PBPS) and consisting of small liquid rocket motors and associated propellant tankage, the PBPS is designed for extremely high reliability as well as long term storage and easy field maintenance. In late 1969 the company's performance enabled it to become an Air Force asso-

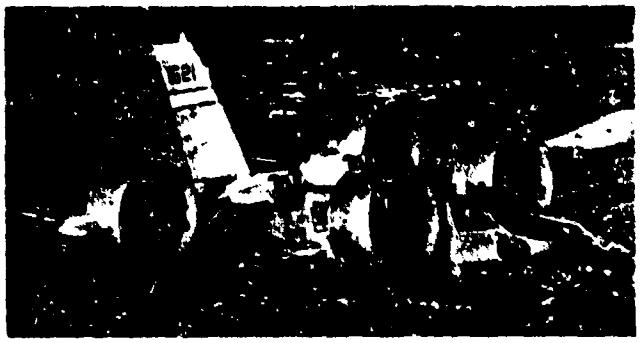
*Agena launch*

*Minuteman III*

ciate prime contractor for the production of advanced Minuteman propulsion systems.

Much of the propulsion technology resulting from Agena and the pre-packaging technology from its Minuteman system has since led to the company's outstanding competitive position today in the field of prepackaged liquid rocket propulsion systems, wherein an engine and fully-filled propellant tanks are sealed into a single unit that can be integrated with a variety of payloads and will endure long-term storage.

Innovation — long a Bell trademark — was never better exemplified than in May of 1965 with the unveiling of the X-22A Tri-Service V/STOL research aircraft. The world's only dual-tandem, ducted-propeller aircraft, the jet-powered X-22A is a unique marriage of airframe design and avionic technology.


*X-22A*

Built by Bell for all three branches of the Armed Services under a contract administered by the U. S. Navy, the X-22A has continued a research program that has not only proved the feasibility of the concept but has been responsible for much of the data gathered on the mechanical and aerodynamic characteristics of V/STOL aircraft in general.

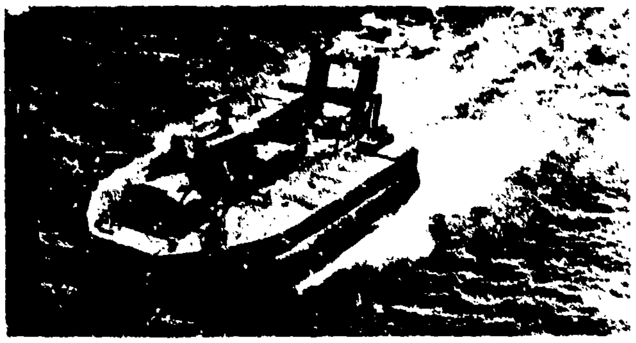
For Bell and other Apollo team members, the remarkable success of the first manned lunar landing on July 20, 1969, climaxed one of the most awesome technological efforts in the history of mankind.

Delivered to NASA in October 1967, the first of three Lunar Landing Training Vehicles built by Bell for the space agency was used extensively by Apollo 11 commander Neil A. Armstrong prior to his historic mission. Armstrong's success in overriding the guidance computer that was taking the Apollo 11 LM directly into a boulder-strewn landing site has been attributed, in part, to his LLTV training.

Following one of his final training flights, Armstrong noted the LLTV's "excellent job of capturing the handling characteristics of the LM, adding that it had helped him build a "very high level of confidence in the overall lunar landing maneuver."

As the ascent engine propelled the LM into lunar orbit for rendezvous and docking with the Apollo command module, astronauts relied on experience gained from yet another Bell trainer—the Lunar Module Rendezvous Simulator (LMRS). Delivered to NASA in September 1965, the system was first used to train Gemini astronauts before being modified in 1968 to meet Apollo astronaut training and engineering needs.

In May 1968, a year after the order had been placed, three Bell-built armed and armored SK-5 ACVs were delivered to the Army. After crew training at Aberdeen Proving Ground in Maryland, the craft were deployed in Vietnam, initially for a one-year trial period and then for an indefinite tour of duty.


*SK-5*

At the same time the company was accelerating research on a jet-powered version of its famed Rocket Belt. Designated the Jet Flying Belt, its development was augmented by an Army contract awarded in January 1966.

On April 7, 1969 the unique back-pack system completed its historic first manned free flight. Subsequent flight tests further verified the system's ability to propel man in free flight over significant distances for a variety of special tactical military missions.

*Rocket Belt*

*Jet Belt*

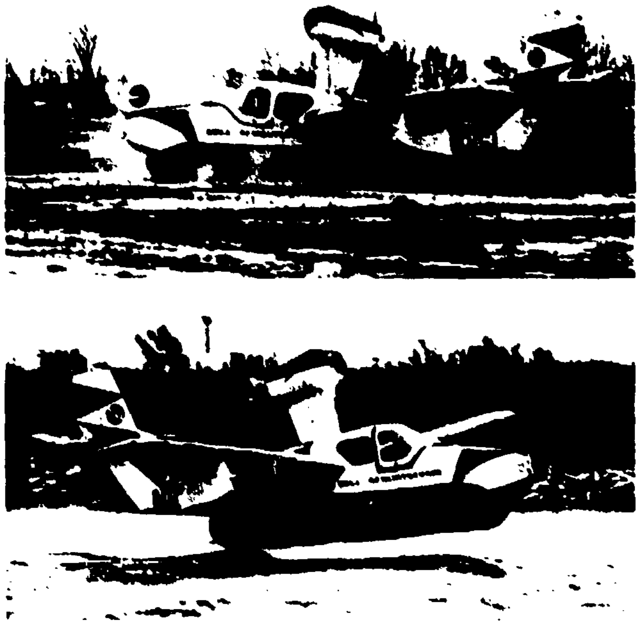
Backed by an avionics technological base that had been growing steadily since its Rascal missile days, Bell in the late 1960s became involved in several highly sophisticated target location and fire control programs for the U. S. Army. Among them is the Visual Airborne Target Locator System (VATLS) that in 1968 completed a successful demonstration program in Vietnam.

The Army's new Multi-Weapon Fire Control System incorporated a Bell Stabilized Optical Sight (SOS) that enables helicopter gunners to automatically pinpoint, track and direct fire upon stationary and moving ground targets. In January 1969, the gyro-stabilized SOS system was formally accepted by the Army's Frankford Arsenal as qualified for integration with the overall prototype fire control system developed for the Huey UH-1B helicopter.

Concurrent with its work on the UH-1, Bell in late 1968 began work on a similar SOS system for the Army's newest and fastest helicopter gunship—the HueyCobra.

In addition to its responsibility for the Army's electromagnetic environmental test facility in Arizona, Bell began working in 1968 on an above-rotor helicopter communications antenna subsystem for use in conjunction with the Army's new tactical communications satellite (TACCOMSAT) network. Under its Army contract, Bell developed a feasibility model antenna system for flight testing.

Bell established an Air Force application for the air cushion principle when it equipped an LA-4 testbed aircraft with an experimental Air Cushion Landing System (ACLS) and initiated a highly successful series of take-off and landing tests in 1967. Later, the Air Force Systems Command's Flight Dynamics Laboratory funded a program of ACLS terrain taxiing and flight tests that demonstrated the system's ability to travel over ice, snow, mud, a plowed farm field and tree stumps as well as conventional runways. In September 1969, the ACLS completed a series of overwater takeoff and landing tests on Lake Erie, near Buffalo.

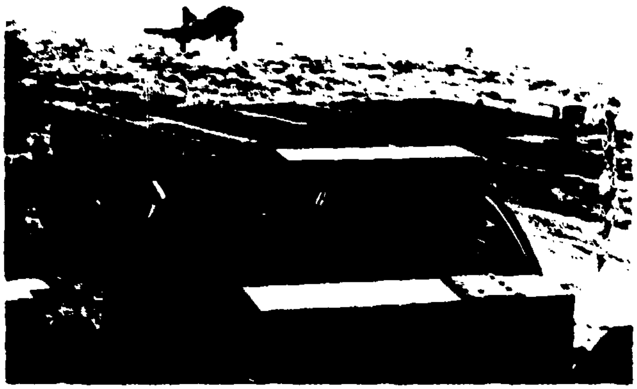


*LA-4 ACLS lands anywhere*

A recognized leader in impact erosion research, Bell in 1968 completed installation of a Mach 3 whirling arm test cell and other apparatus that company engineers are using today to measure the destructive effect of high speed particle impacts on aerospace materials.

Data resulting from impact erosion research will be used to safeguard the all-weather structural integrity of future super- and hypersonic aircraft, by not only leading to a better understanding of the impact erosion phenomenon, but by promoting the development of new impact erosion resistant materials for use in aircraft leading edges and jet engine air intake areas.

Foremost among the company's Navy programs was the AN/SPN-42 All-Weather Carrier Landing System. Refined during the last half of the decade, the system was declared operational aboard the U.S.S. Saratoga in July 1969, making the carrier the first to have a completely operational and fully automatic aircraft landing capability.



*AN/SPN-42 All-Weather Automatic Carrier Landing System*

A digitized outgrowth of the Bell-developed AN/SPN-10 landing system of the late 1950s, the SPN-42 underwent extensive land and sea trials during which fighter pilots made thousands of hands-off automatic test landings.

Growing concern within the Navy over an aging and outdated tactical capability in the mid-1960s added impetus to Bell's air cushion vehicle programs. As a result the Navy deployed three Bell SK-5 Patrol Air Cushion Vehicles (PACVs) to Vietnam in 1966 for test and evaluation. The craft were later transferred to the U. S. Coast Guard for evaluation.

In September 1967, shortly after President Gisel announced formation of a special team to study additional applications of the company's ACV technology, the Navy and the Commerce Department's Maritime Administration selected Bell to conduct a conceptual design study for a 100-ton Surface Effect Ship (SES).

Based on the same principle as an ACV, the SES, has solid sidewalls to help contain the air bubble upon which the craft rides and, therefore, is not amphibious. In 1968, elements of the Navy and the Maritime Administration were combined to form the U. S. Joint Surface Effect Ships Program Office (JSESPO). This agency awarded Bell one of two contracts for implementation of a 100-ton test craft program.

Bell established a new operation in New Orleans at NASA's Michoud Assembly Facility complex, a site selected on the basis of its year-around accessibility to the Mississippi River and the Gulf of Mexico for all-important salt-water testing purposes.

Indicative of its faith in the future the company in 1965 instituted a program for new and upgraded facilities. Among the major projects was the construction at the main plant of a 28,000-square foot Air Cushion Vehicle Laboratory, a 100,000-square foot engineering office addition, a 13,000-square foot chemistry laboratory, a 7,530-square foot addition to the Electronic Data Processing Center, the modernization of a 13,000-square foot Rocket Engineering Building and an 8,500-square foot Minuteman load and check facility at the company's Rocket Test Center.

*Chemistry Laboratory*

The Bell ACV Laboratory is one of the few in the world designed and built exclusively for air cushion research and development. It houses a 10,000-square foot model test pool and a unique 50-foot diameter whirling arm test basin.

Since the beginning, the driving force at Bell has been its people. In many ways Bell's people have also reflected the company's change over the past 40 years from mass production to research/development and limited production.

BELL Aerosystems had a name change on January 3, 1970, becoming Textron's Bell Aerospace Division. The program in New Orleans became New Orleans Operations of Bell Aerospace, and the same change took place with the Arizona Operations.

Early in 1971, Bell announced the acquisition of facilities in Grand Bend, Ontario, where an associate company — Bell Aerospace Canada Division of Textron Canada Ltd., develops and builds air cushion vehicles.

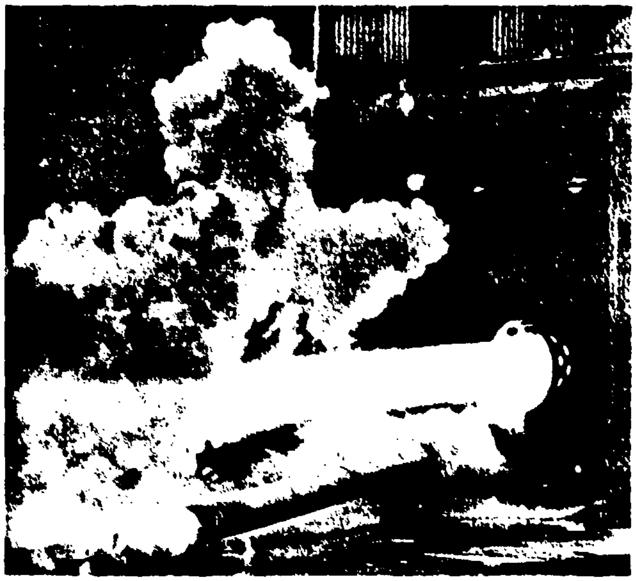
Textron announced in November 1973 that its Dalmo Victor Division near San Francisco had been made an operating unit of Bell Aerospace. Dalmo Victor, which produces electro-magnetic defense systems, aerospace antennas and electro-optical equipment, is headed by John H. Pamperin.

Textron President G. William Miller said "the combination of these long-established and profitable aerospace divisions will strengthen and broaden the capability of both."

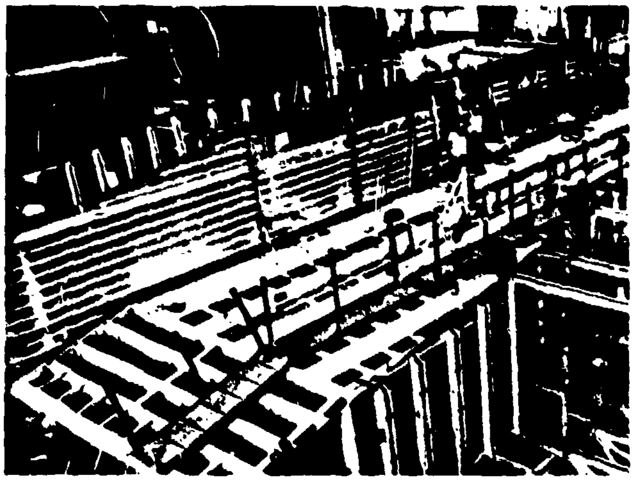
Bell and Dalmo Victor had worked together on a number of projects before the merger. Dalmo Victor is the nation's leading manufacturer of electronic equipment — Airborne Integrated Defense Systems (AIDS) — which enables the military pilot to protect his aircraft from enemy attack.

At Grant's Pass, Oregon, Dalmo Victor's Oregon Technical Products subsidiary produces a variety of electro-mechanical products.

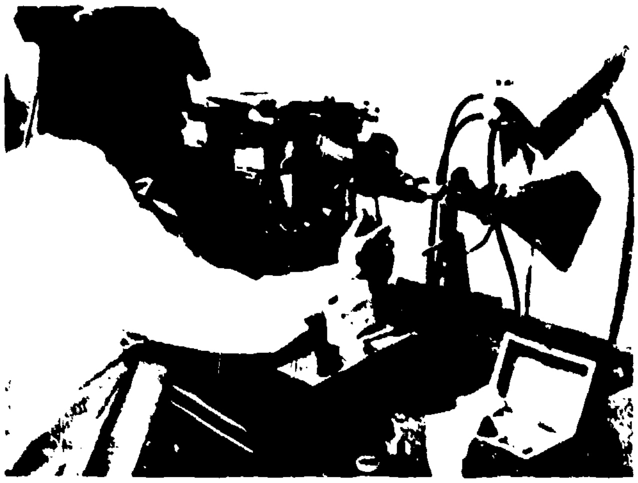
Norton C. Willcox was promoted in 1971 to executive vice president-Administration, and later Lawrence P. Mordaunt advanced to executive vice president-Operations. John J. Kelly, who had come to Bell in 1966 as a manufacturing manager, was promoted to several positions, including vice president of Employe Relations and Services for the Niagara Frontier facilities and then vice president and general manager of the New Orleans Operations.



*Rocket Test*

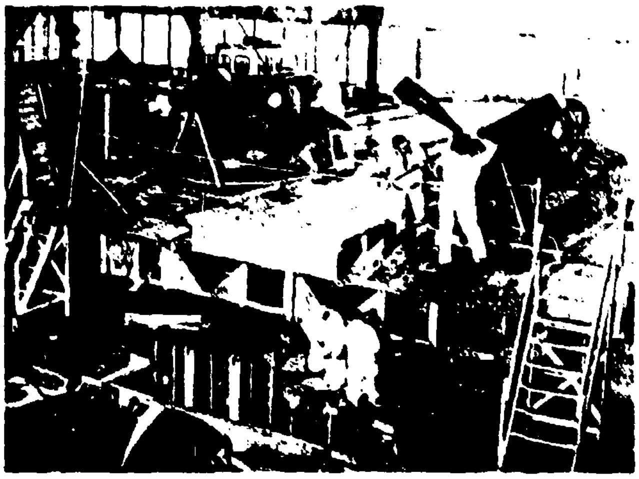


*New Orleans Operations*



*Dalmo Victor Operations*

*Arizona Operations*



*Bell Aerospace Canada*

In New Orleans, work continued on major ACV and SES programs. The SES-100B was launched in 1971 and began a series of highly successful tests that included, on April 16, 1974, setting a world SES speed record of 80 knots (92 miles per hour).

Later the same year, Bell was awarded a $36-million contract to conduct an advanced development program for the U. S. Navy's proposed 2,000-ton SES. The contract included design, development and testing of full-scale subsystems and components for the large SES.

New Orleans Operations also continued work under Navy contract for the development and fabrication of the 160-ton Amphibious Assault Landing Craft (AALC) JEFF (B). This project is part of a continuing Navy program to provide high-speed, amphibious assault landing craft for the future. The 50-knot operating speed of the JEFF (B) is five times faster than conventional landing craft.

As the Apollo moon exploration continued through the early 1970s, Bell was repeatedly praised for the performance of its contributions to this effort. Singling out the Lunar Landing Training Vehicle in December 1971, President Gisel said:

"All Bell employes may take pride in the role of the LLTV in the lunar exploration program. Each moon landing is a once-in-a-lifetime experience for Apollo astronauts. Yet they must fly the LM like veterans . . . The LLTV gives them the experience they need."

In Grand Bend at the same time, initial trials with a 45-ton ACV, the Voyageur, were proving the potential of versatile, flatdeck ACVs for a wide range of future applications.

By 1975, Voyageurs were at work with the Canadian Coast Guard in Montreal, at the Yukon River in Alaska and were providing the first regular wintertime freight service for communities along Quebec's Lower North Shore. Another, smaller ACV, the 17-ton Viking, was also under development at the Bell Aerospace Canada plant in Grand Bend.

The major production program for the Niagara Frontier facilities through the late 1960s and into the 1970s was the Minuteman III PBPS, also known as the Propulsion System Rocket Engine (PSRE). This one product had brought more than $700-million in business to Bell by mid-1974, when the U. S. Air Force Space and Missile Systems Organization acclaimed the PSRE as "a dream come true."

"The PSRE's development paved the way for low-cost modernization of the Minuteman force," said SAMSO. "As a 'bus' for MIRV (multiple independently-

**World Record Holder**

*The SES-100B set a new world record for Surface Effect Ships on April 16, 1974. The 100-ton test craft achieved a speed of more than 80 knots (92 miles per hour) during a mission at Panama City, Florida.*

*Speed records are nothing new for the Bell-built craft. In 1973, the SES-100B was the first SES to achieve a speed of 75 knots.*

targeted reentry vehicle) payloads, PSRE has substantially increased the capability of America's missile defense without the need for a large construction program to match the Soviet Union's numerical superiority in ICBMs."

The U. S. Coast Guard operated two former Navy SK-5 ACVs in San Francisco for more than two years after receiving the craft in 1970, and found them to be versatile and cost effective. The craft were credited as "a very effective means for solving nearly all mission demands" when combined with regular surface craft.

The Canadian Coast Guard was making similar discoveries with its ACVs, and added an ACV application that had never been considered before—icebreaking.

R. G. Wade, superintendent for ACV engineering in Canada's Ministry of Transport, explained that the Voyageur was traveling at about 15 knots over hard, unbroken ice when the crew noticed standing waves about four feet high were following the craft. The ice was violently cracking in these waves.

A year later, an ACV crew at Montreal used a Voyageur to break up a 3½-mile ice jam in a river north of the city, avoiding annual spring flooding in 1975. Properties along the shore were saved an estimated $3-million in flood damage.

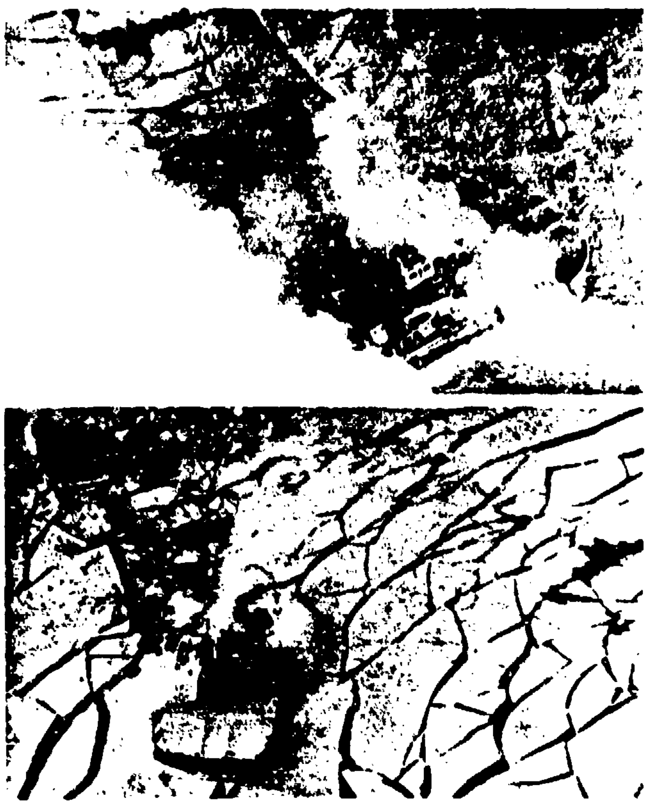
Among the major programs under development at Bell in the 1970s is the Microwave Landing System (MLS). Bell teamed with the Bendix Corporation in 1971 to compete with nine original teams in development of the MLS for the Federal Aviation Administration. In early 1975, the Bendix/Bell team had succeeded in winning initial phases of the competition, and the FAA was on its way toward ordering prototype MLS systems from Bendix/Bell and a competitor team headed by Texas Instruments.

In the early 1970s, Bell also entered a major new technology with great future potential — high energy lasers. By 1975, the company was working under several contracts for development of laser technology.

Through the years, first under Larry Bell and today under President Gisel, Bell has continued its record of pioneering achievements. On April 11, 1975, yet another "first" was added when the 20-ton XC-8A aircraft, equipped with an Air Cushion Landing System developed and built by Bell, made its first cushion landing.

The U. S. Air Force at Wright-Patterson Air Force Base, Ohio, termed the successful first tests "an important achievement in the advancement of aerospace technology."

Similar words could have been used nearly 40 years earlier when an airplane known as the Airacuda made its first tests with a tricycle landing gear.



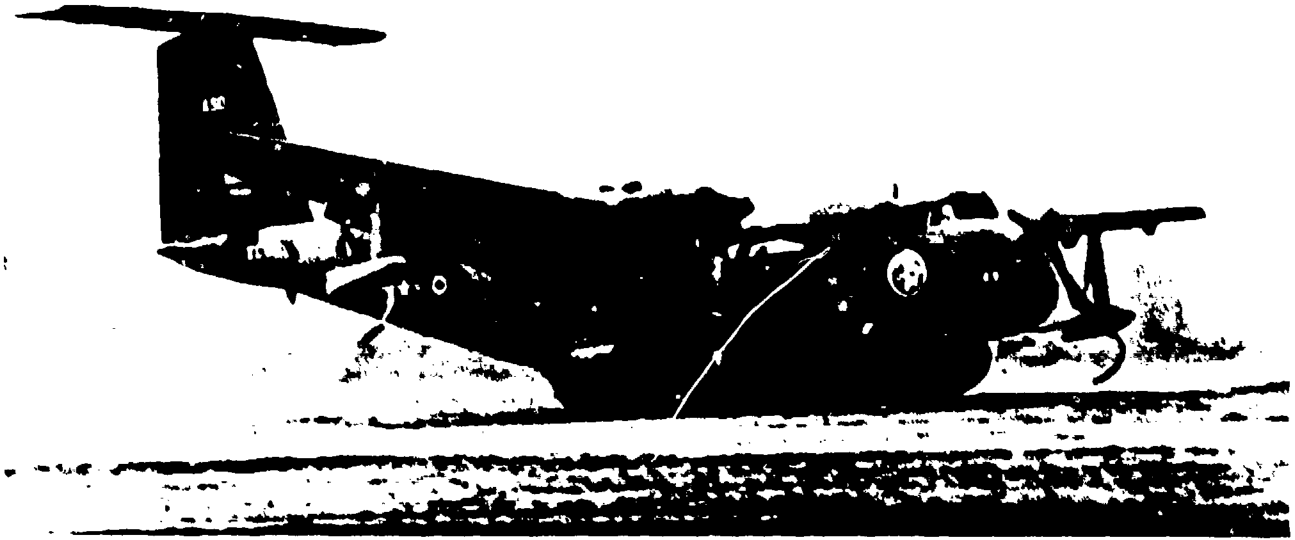
**Pioneer on Ice**

*The Voyageur ACV became an icebreaker by accident. A Canadian Coast Guard/Ministry of Transport crew was operating over ice in early 1974 when they discovered standing waves following the craft — the ice was rising up in "bumps" and shattering violently. Later trials added several additional icebreaking techniques, including river icejam breaking. In the spring of 1975, more than $3-million in property damage caused by annual flooding was avoided because a Voyageur cleared a 3½-mile icejam.*

FROM the beginning, the skill and dedication of its people have made Bell a pioneering leader. The men and women of Bell Aerospace have much to be proud of on this 40th anniversary. Bell possesses the technical knowhow, the management and the facilities to continue its record of achievement in the future.

W. G. Gisel

William G. Gisel
*President*



*April 11, 1975 — first cushion landing of XC-8A*

***Bell's pioneering history can be traced through its record of "firsts," including:***

**1937** first twin-engine escort fighter, the Airacuda.

**1938** first fighter to be designed around its armament, a 37mm cannon, the Airacobra.

**1938** first tricycle landing gear.

**1942** first U. S. jet airplane, the XP-59A Airacomet.

**1944** first modern all-wood fighter, the XP-77 Airabonita.

**1946** first helicopter to be commercially licensed, the Model 47.

**1947** first aircraft to fly faster than sound, the X-1.

**1954** first jet vertical takeoff airplane, the Air Test Vehicle.

**1955** first practical automatic all-weather aircraft landing system in the U.S.

**1961** first wingless back-pack flying system, the Rocket Belt.

**1965** first prepackaged liquid Propulsion System Rocket Engine (PSRE) begins development. The Bell PSRE provides a maneuverable fourth stage for the Minuteman III ICBM.

**1966** first astronauts to fly 851 miles from earth use the Bell Agena space booster engine (Gemini XI, September 13, 1966).

**1967** first Air Cushion Landing System (ACLS).

**1969** Bell Lunar Landing Training Vehicles, positive expulsion tanks, and other contributions to the Apollo program help make possible man's first moon explorations.

**1969** first jet-powered flying belt.

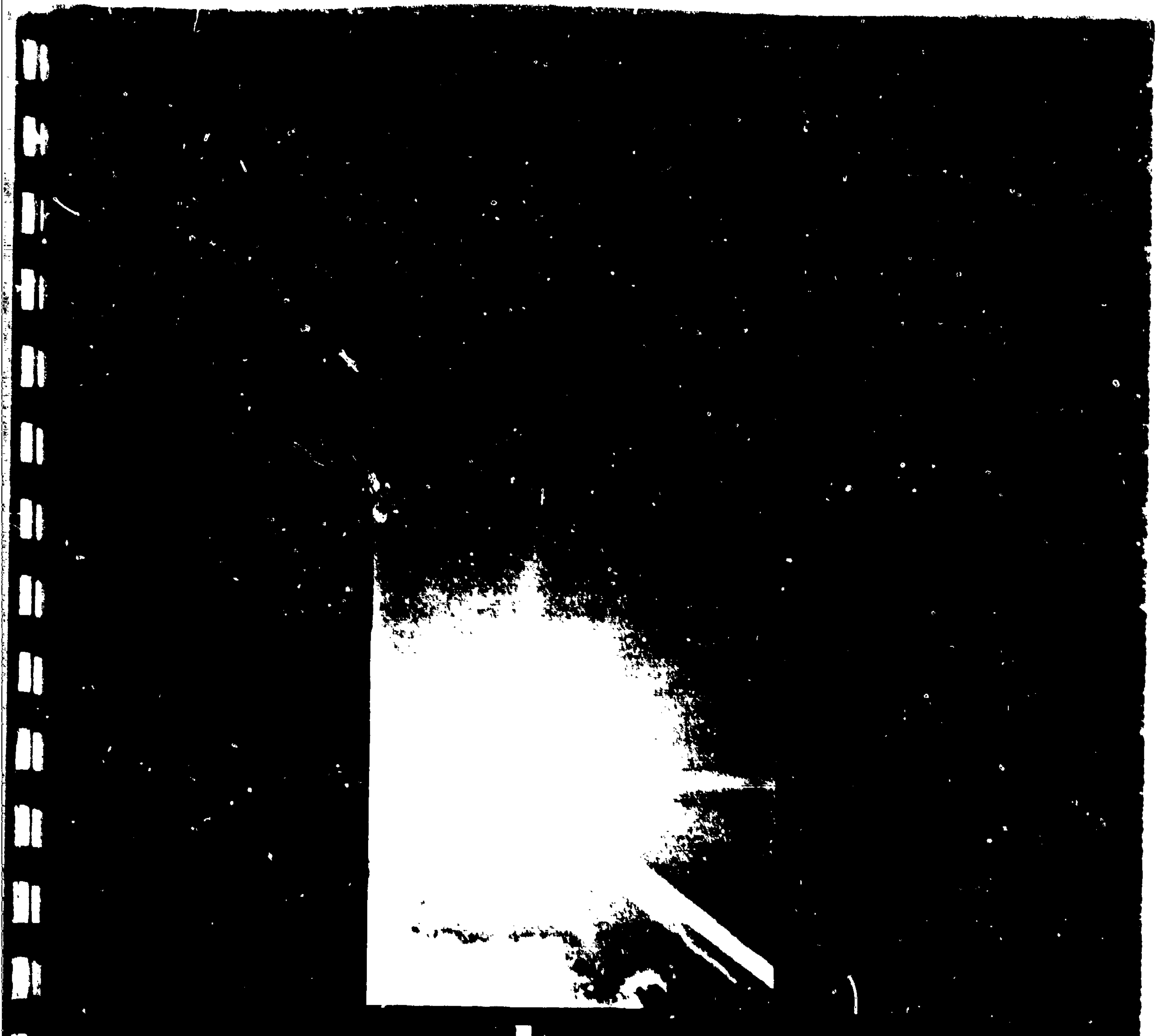
**1974** first self-propelled ACV icebreaker, the Bell Aerospace Canada Voyageur 002.

**1974** first SES to set a world record of more than 80 knots (92 miles per hour), the U. S. Navy/Bell SES-100B.

**1975** first application of ACLS aboard a large aircraft, the 20-ton XC-8A.

# APPENDIX B

## BELL AEROSPACE TEXTRON
## RENDEZVOUS - INTO THE 80's



# rendezvous

# People make it work

Bell's most valuable resource is its people. All other resources — capital, plant, tools — are much the same everywhere. It is the quality of its personnel that distinguishes Bell.

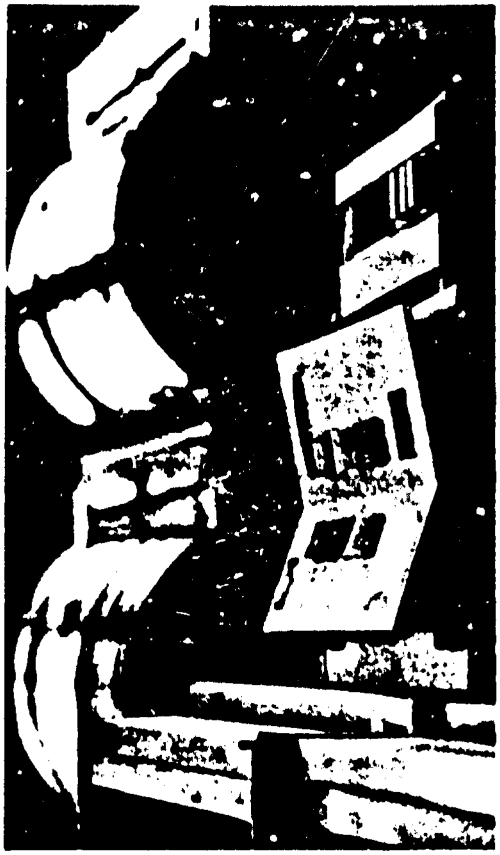
Most of the company's activities involve the extensive use of high technology, computer software applications and advanced management techniques. It requires a highly flexible risk-oriented organization. Bell's top management team provides entrepreneurial direction from headquarters at Buffalo, New York, and from the operating units at Buffalo, Belmont, California, and New Orleans, Louisiana. In addition there are two separate Textron subsidiaries, Bell Technical Operations, Tucson, Arizona, and Bell Aerospace Canada Textron, Grand Bend, Ontario, Canada, assigned to Bell for management purposes.

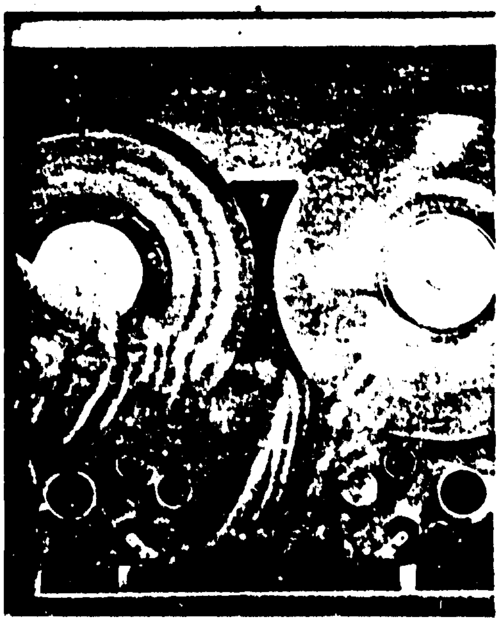
The people of Bell have a broad diversity of talent geared to focus on the problems of today and tomorrow.

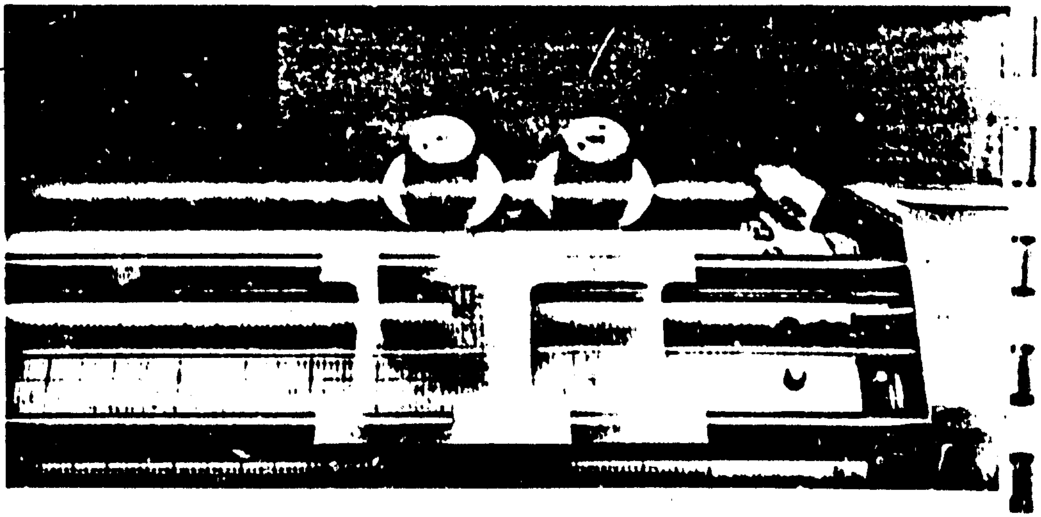
# Systems engineering

Activity in the areas of
ational defense, energy and
ansportation draws on many
echnical and management
isciplines. The synthesis,
imulation, analysis, engineering
nd management of systems
volve the integration of
omplex ideas and approaches.
irst, specialized technologies
re used to develop a useful,
liable system. Second, good
anagement assures the
ustomer that his needs will be
atisfied on time and on cost.

Bell uses digital and analog
omputer facilities to synthesize,
nalyze and simulate systems.
omputer-aided design,
omputer-aided manufacturing
echniques and computer-
ased management informa-
on systems are in everyday use.







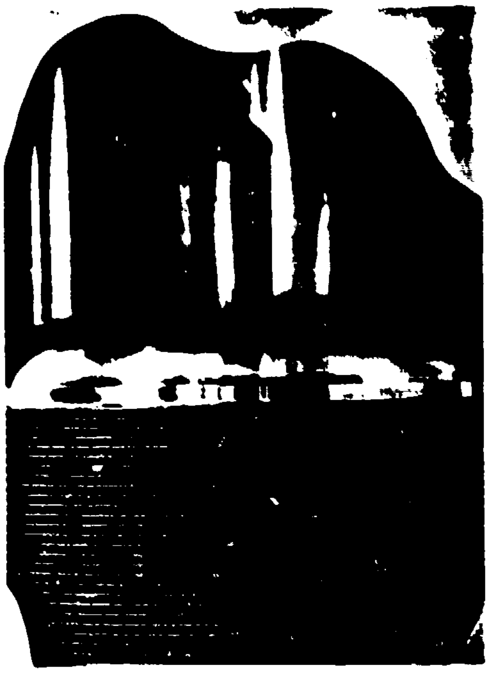
# Combustion uniquely Bell

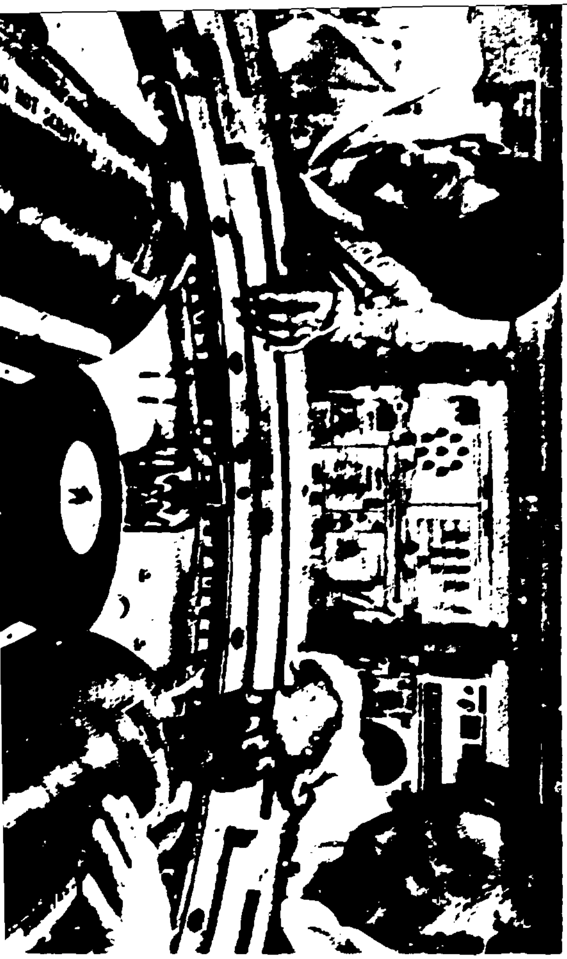
Liquid rocket propulsion involves the high technologies of heat transfer, fluid dynamics, high temperature materials and chemical kinetics as well as the techniques of handling and storing high energy fuels.

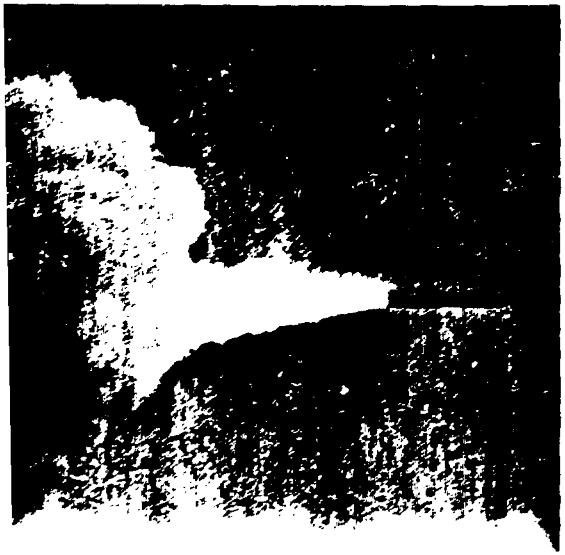
Bell holds a unique position in the field of prepackaged liquid rocket propulsion. In these systems rocket thrusters and fully-filled propellant tanks are sealed into a single unit integrated with other elements of a ballistic missile.

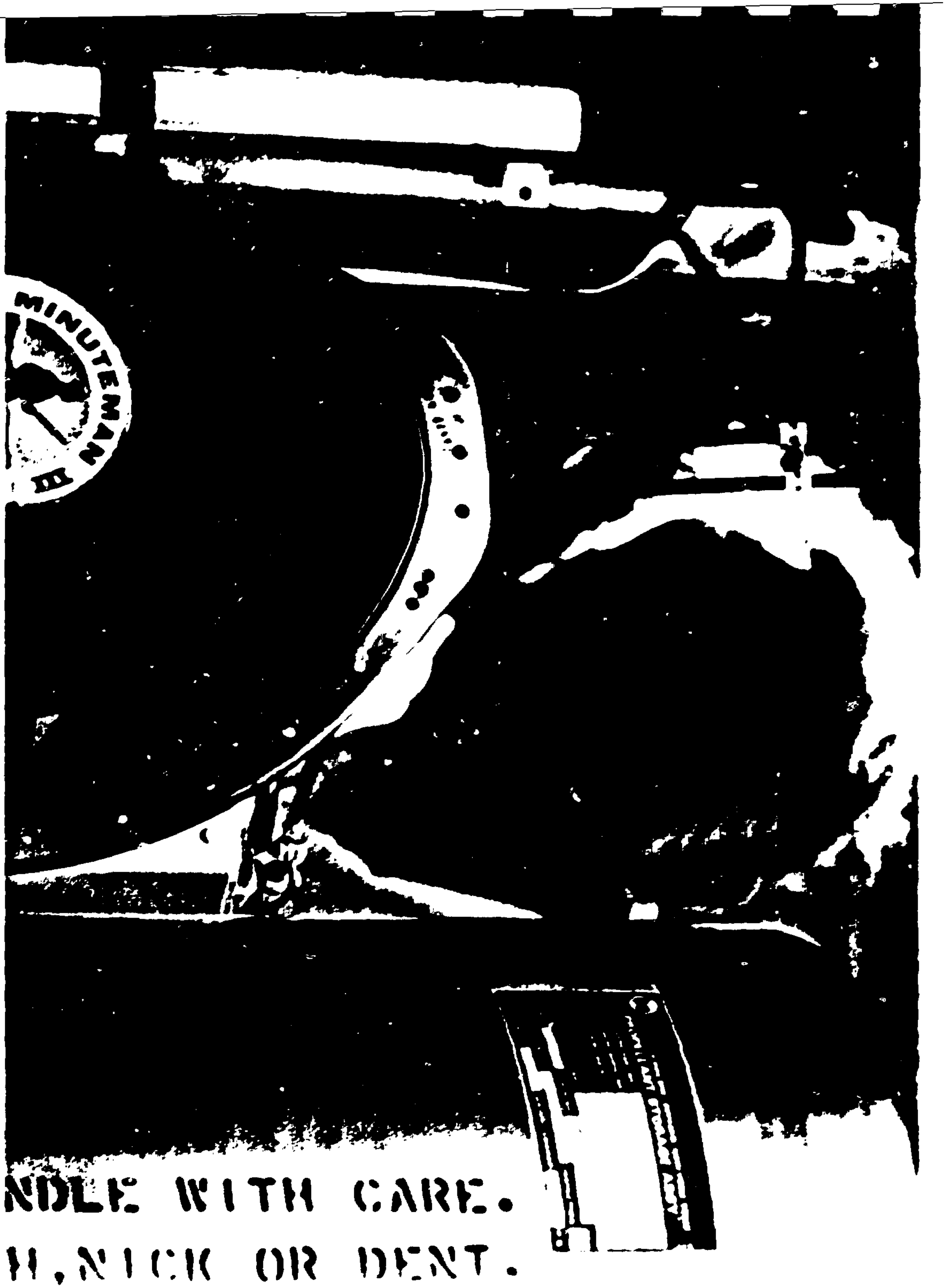
Ability to design and produce Post Boost Propulsion Systems (PBPS) at Bell is illustrated by a U.S. Air Force statement concerning the Minuteman program: "Seldom, if ever, in the history of military weapon systems has one been developed and used with such success as that enjoyed by the PBPS."

Success in that effort will be applied to similar U.S. Air Force programs in the future.





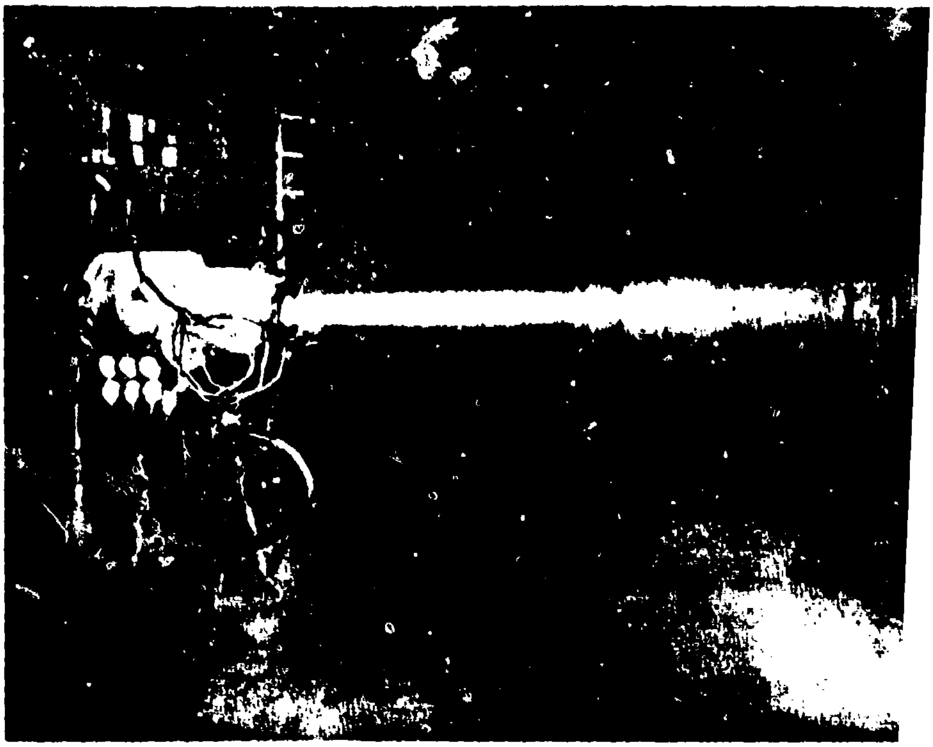


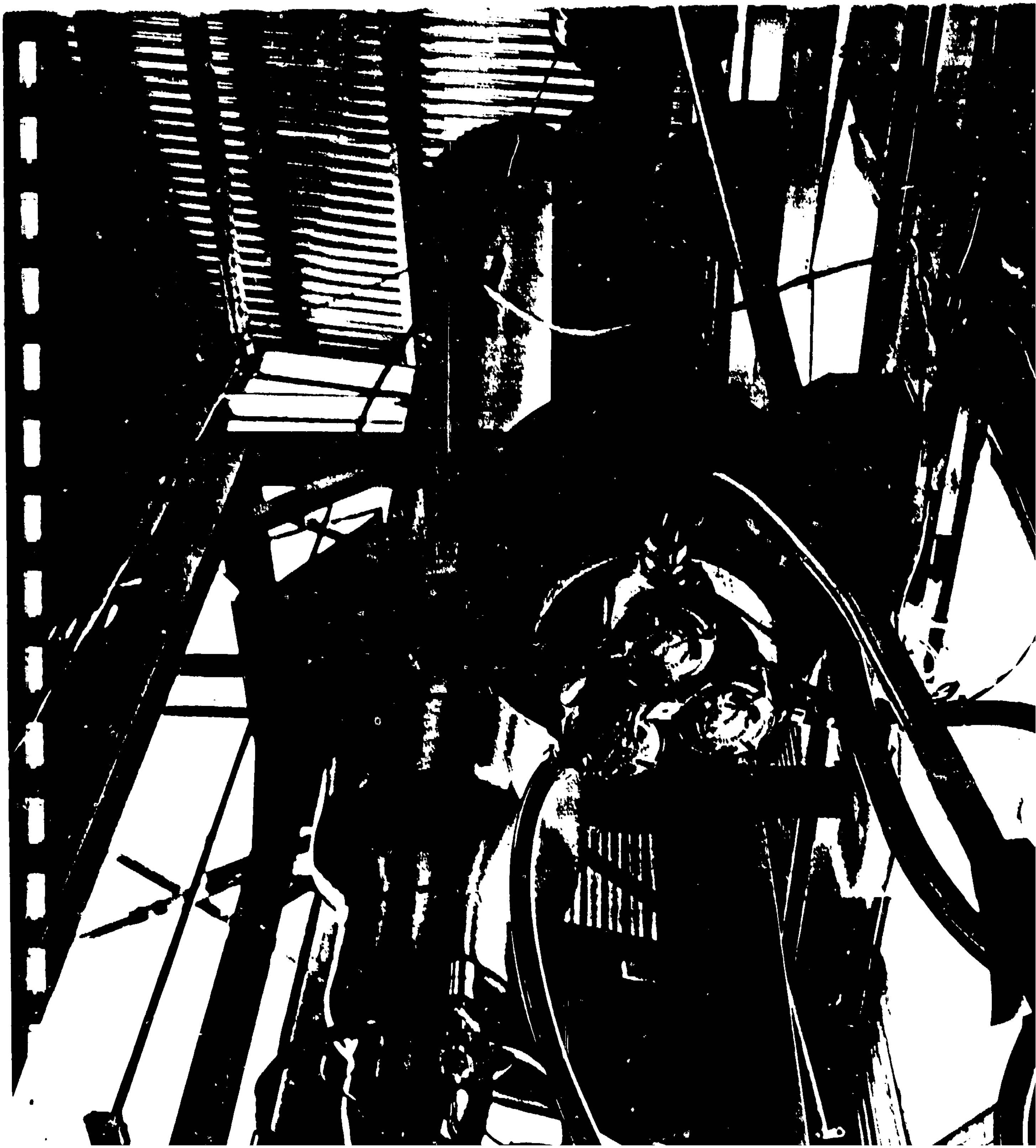

MINUTEMAN III
NDLE WITH CARE.
H,NICK OR DENT.

# Combustion for energy

Bell innovation is illustrated by the transfer of combustion technology to the critical area of energy. With the demand for energy increasing while oil and gas supplies are diminishing, there is increasing pressure to convert the nation's abundant supply of coal into a clean synthetic fuel.

Bell Aerospace engineers are applying rocket technology — injection and mixing of fuels; analysis and control of chemical reactions; design and fabrication of hardware, and conduct of test and evaluation programs - to develop high mass flux coal gasification systems. The gas produced is a low BTU fuel with potential for electric power, industrial and chemical use.





# Combustion for lasers

Another offshoot of the combustion and chemical sciences, which are part of liquid rocket engine work, is the high energy chemical laser. These lasers are devices which use the energies involved in chemical reactions to produce a laser beam which is many orders of magnitude more powerful than the small lasers being used today commercially.

Bell's capability to develop and use advanced fabrication techniques, such as electroforming and system synthesis, analysis and test has produced experimental lasers among the most powerful in the world. The effort will permit Bell to produce the operational systems of tomorrow.

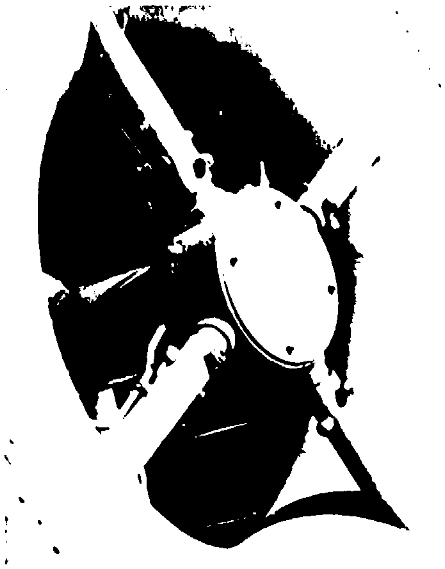
# Air cushion technology

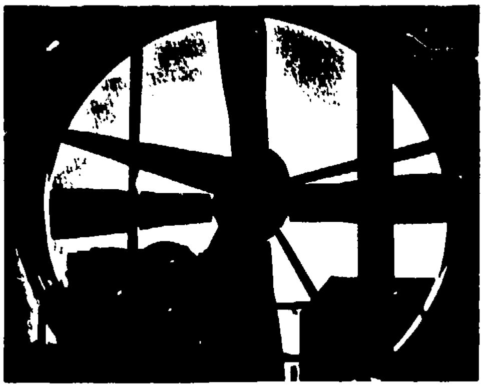
Bell's early development of V/STOL aircraft expanded to include the potential of supporting vehicles on a cushion of air. Company-funded facilities and research and development have given Bell engineers and management an opportunity to closely study this new product line.

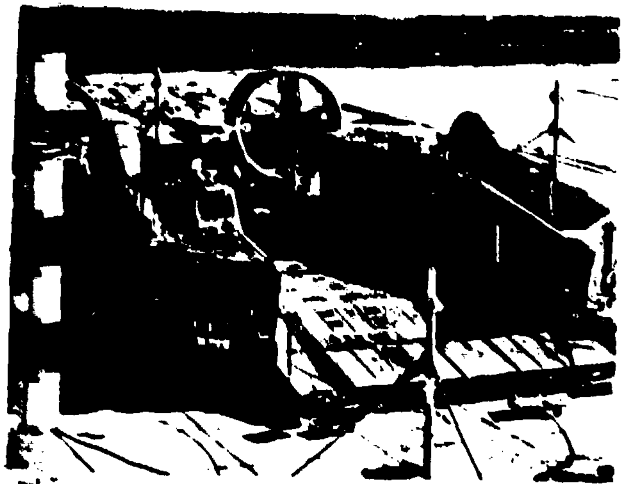
Air cushion technology produces amphibious and seagoing vehicles which at speeds up to 100 mph can skim over the surface of the land, water, ice, snow, marsh and/or mud — conditions which plague conventional vehicles. Rapidly advancing ACV technology requires extensive use of advanced test techniques in specialized facilities to confirm theoretical analysis of operating characteristics with valid test data.

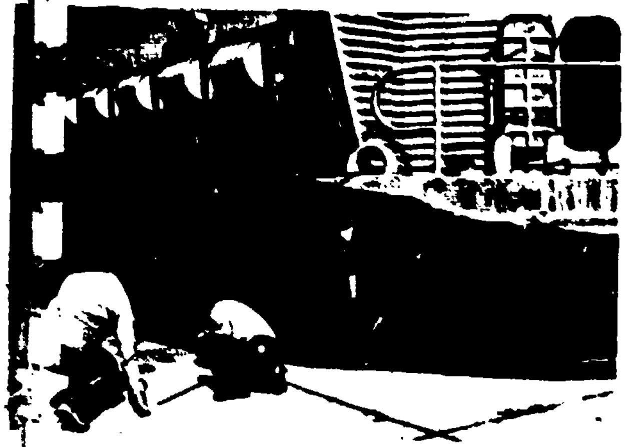
# Air cushion Navy

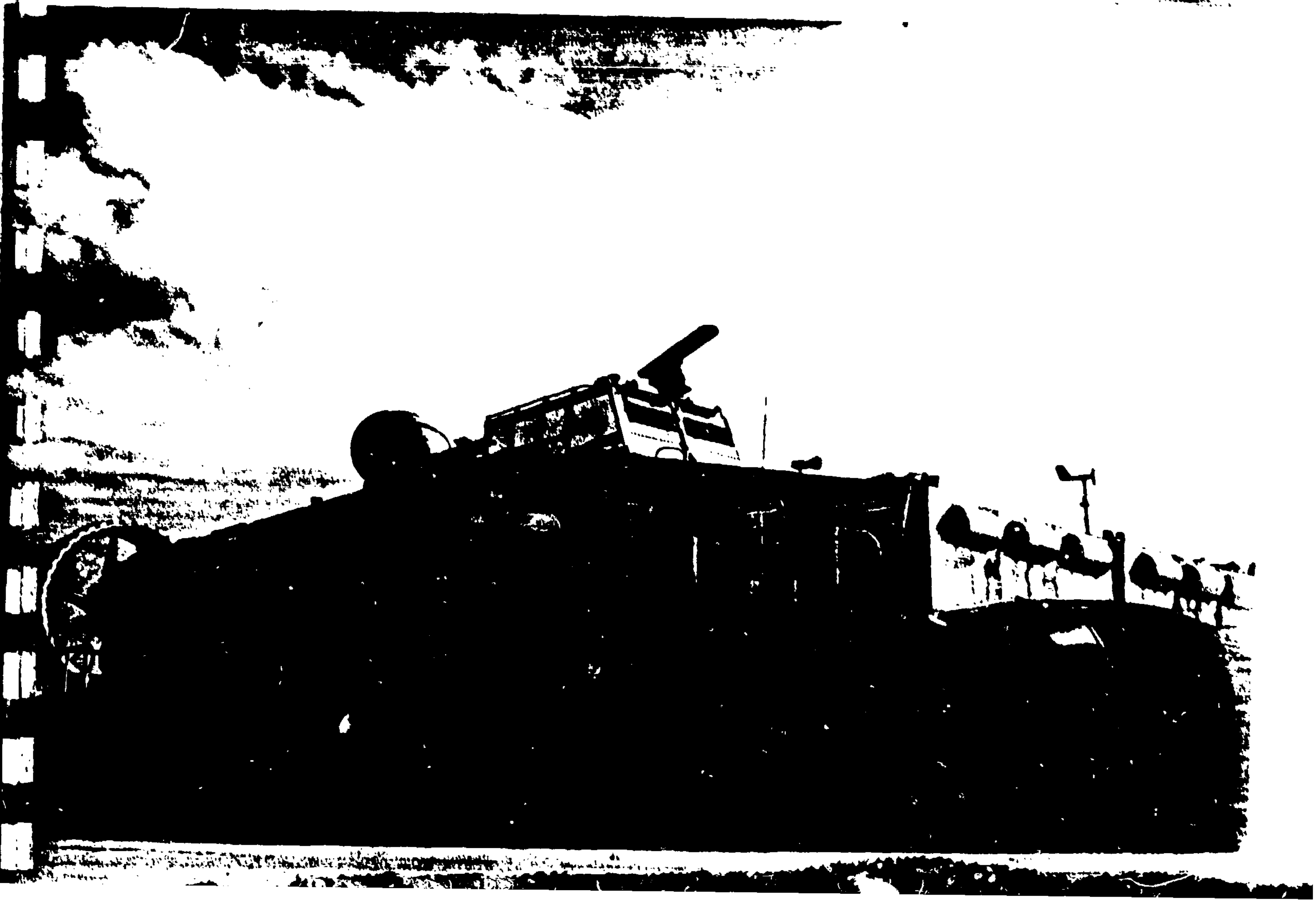
The U.S. Navy's Amphibious Assault Landing Craft illustrates the scope of Bell's involvement in systems engineering and management of air cushion technology. Known as the JEFF(B), its lightweight, high strength aluminum structure was produced by advanced welding techniques. High efficiency, lightweight lift fans combined with air distribution systems and a flexible structure air containment and control system comprise the core air cushion technology. The project also drew on Bell expertise in areas of marine gas turbines, transmission systems, high speed shafting, ducted propellers and integrated avionics systems. JEFF(B) demonstrates the complete capability to design and produce major air cushion systems.











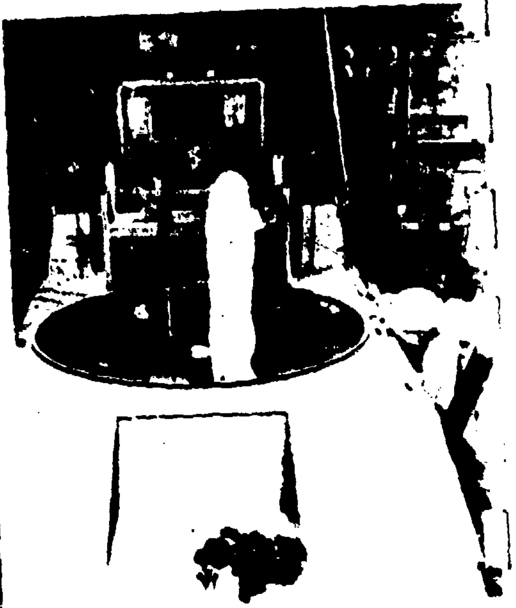
# Boats for the mission

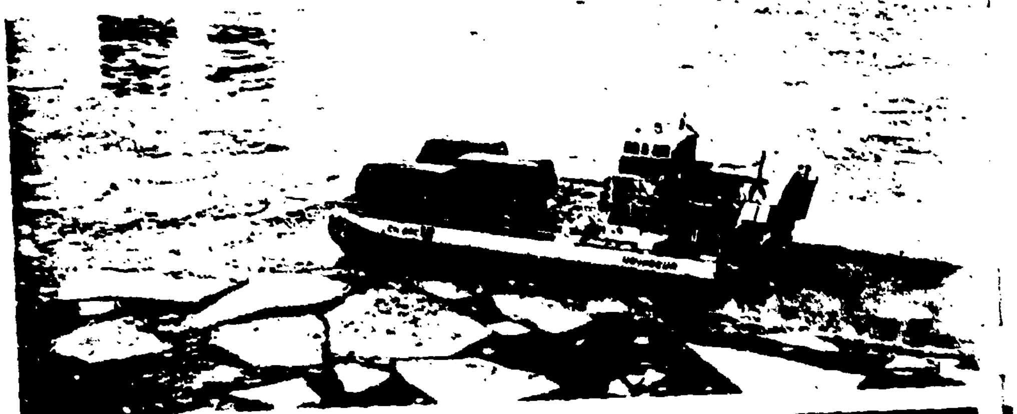
Each mission application of Bell's broadly based air cushion technology requires emphasis on different engineering disciplines.

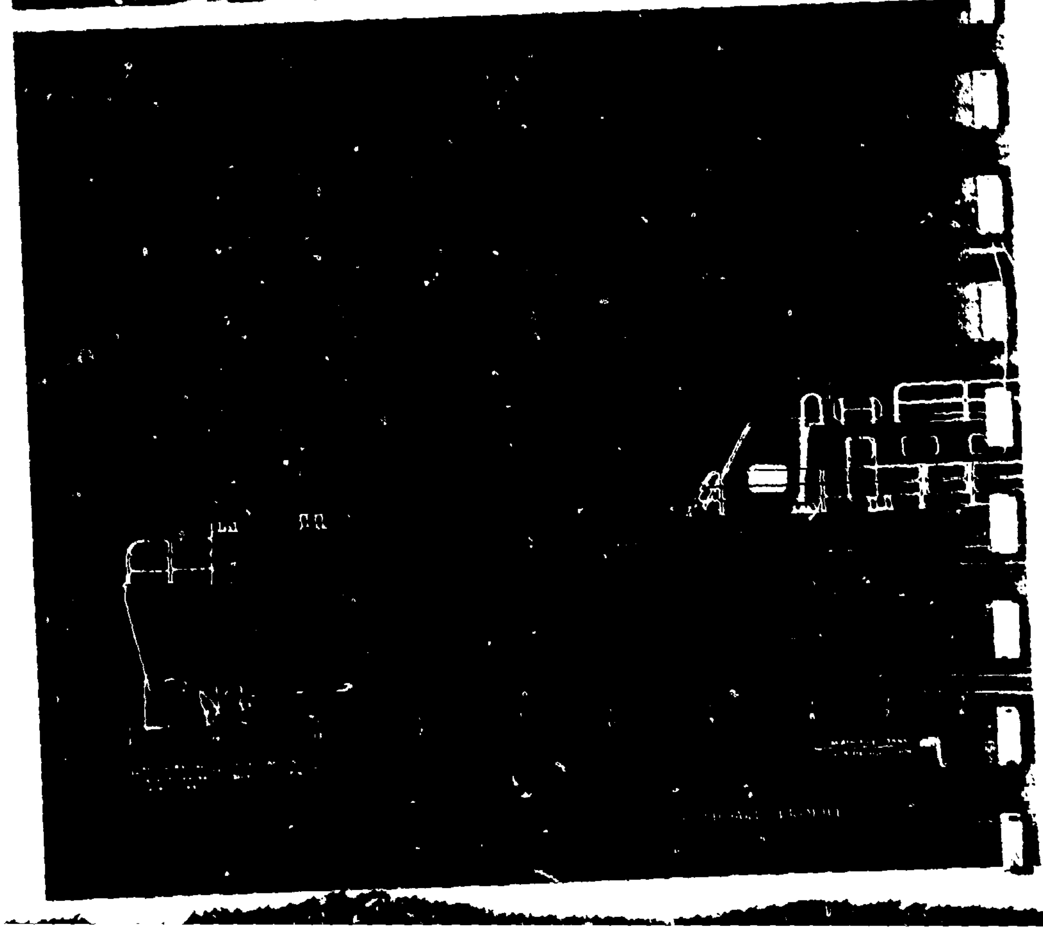
A surface effect ship type crew boat built by the Bell-Halter Joint Venture requires emphasis on human factors and habitability to assure comfort and acceptance by civilian passengers. Likewise, excellent hydrodynamic performance is required for efficient, cost-effective operation. Other variations are a ferry boat and a fast patrol boat.

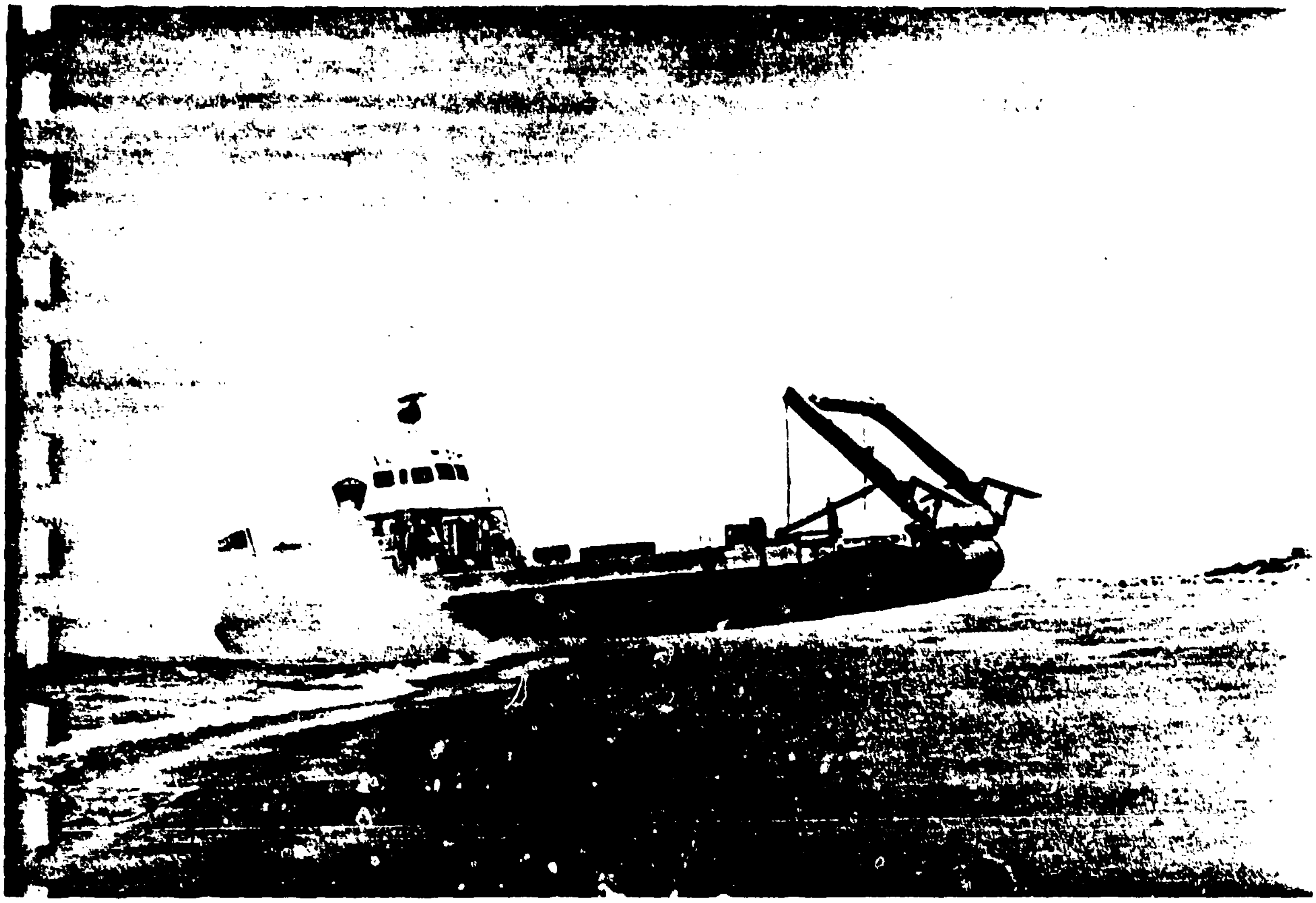
The Voyageur and its derivative LACV-30 were designed for fully amphibious, year-round mobility for logistics and icebreaking operations. Here the emphasis must be on rugged structural design and reliable protection from varied environments.

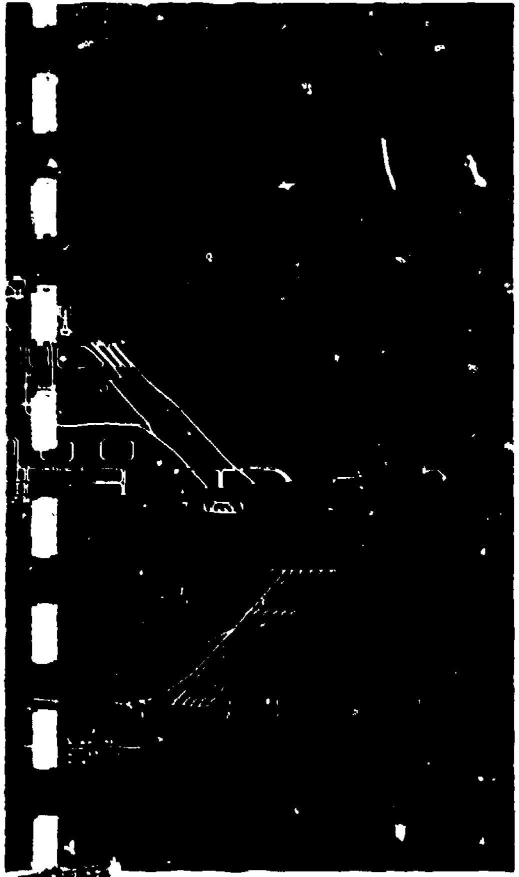
Bell's total systems capability enables the efficient combining of disciplines common to all craft, yet solving specific mission requirements for each vehicle.

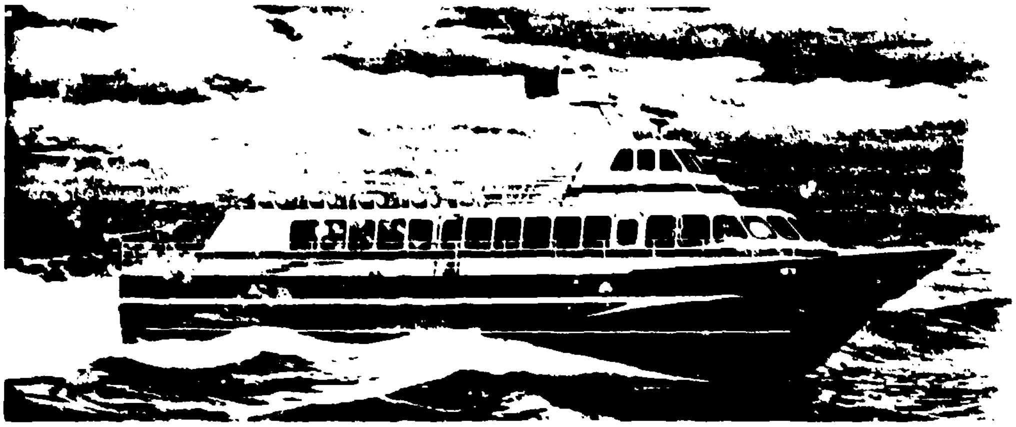


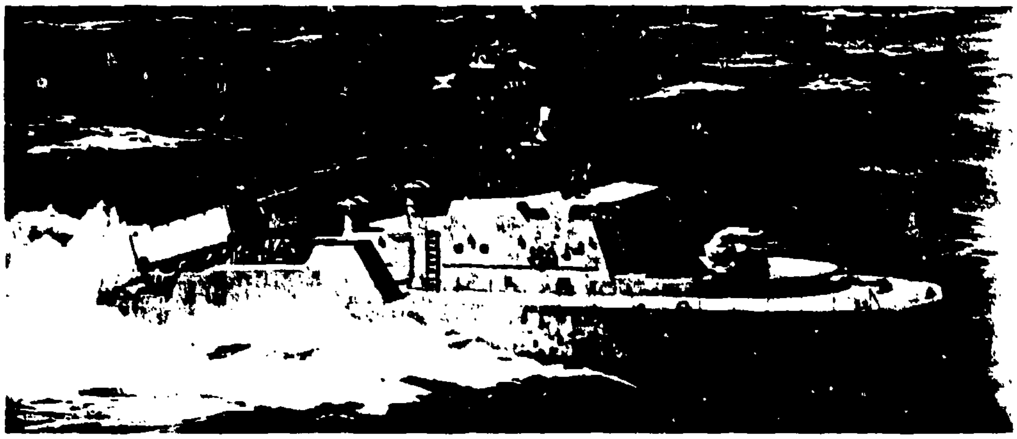








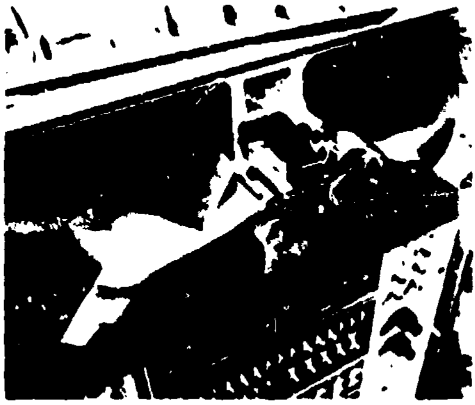


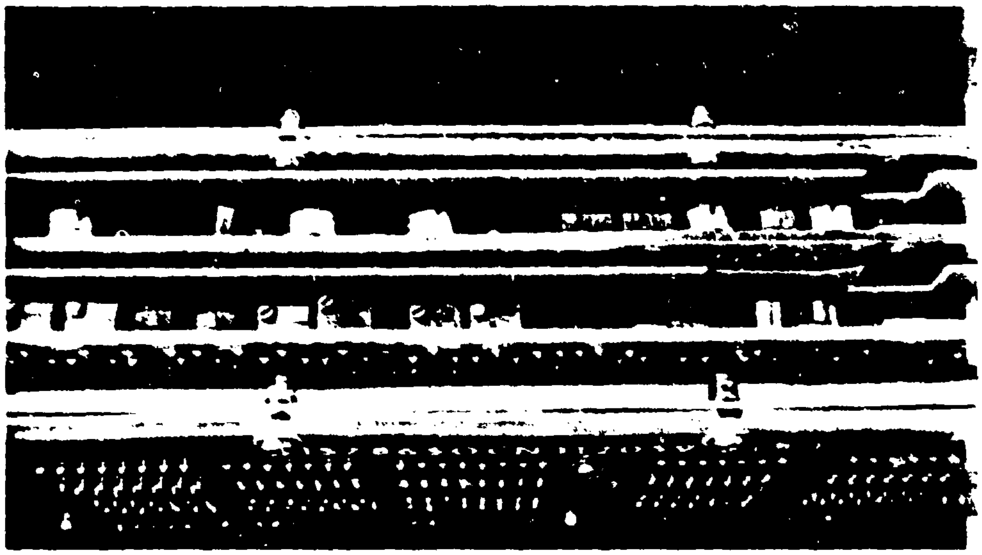


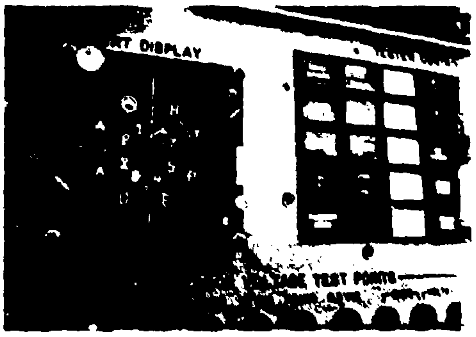
# EW for defense

Electronics is one of today's most dynamic technologies. Bell's on-going programs in automatic aircraft landing, electronic warfare (EW) and inertial systems have kept its people and management in the forefront of these areas.

Military pilots using Bell electronic warfare systems are protected by equipment capable of analyzing a large number of signals to detect threats. Bell is the nation's leader in designing and producing high speed, software programmable EW digital processors. Combined with its management capability to provide on time, on cost delivery, the company maintains an outstanding position in this area.



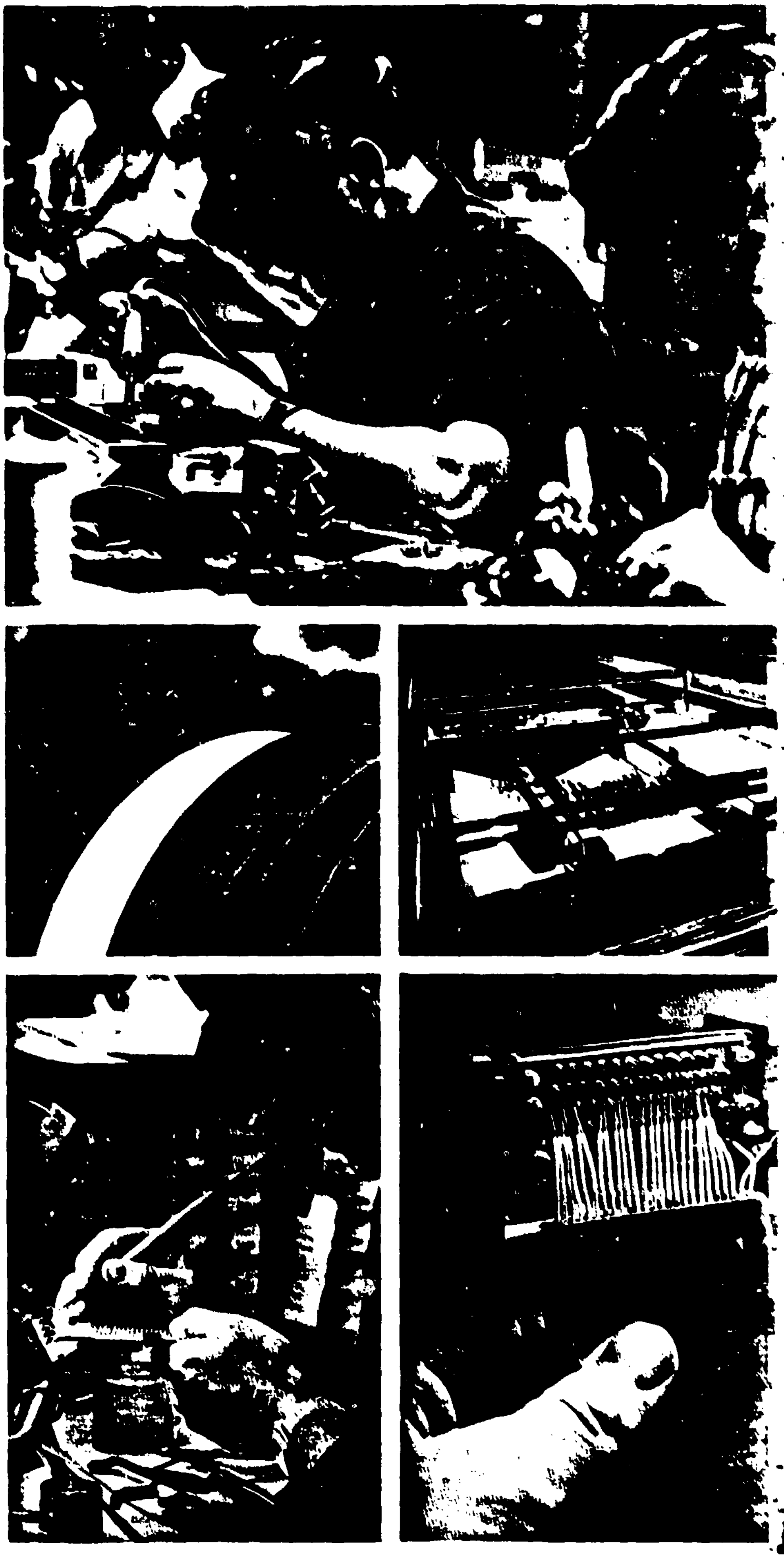


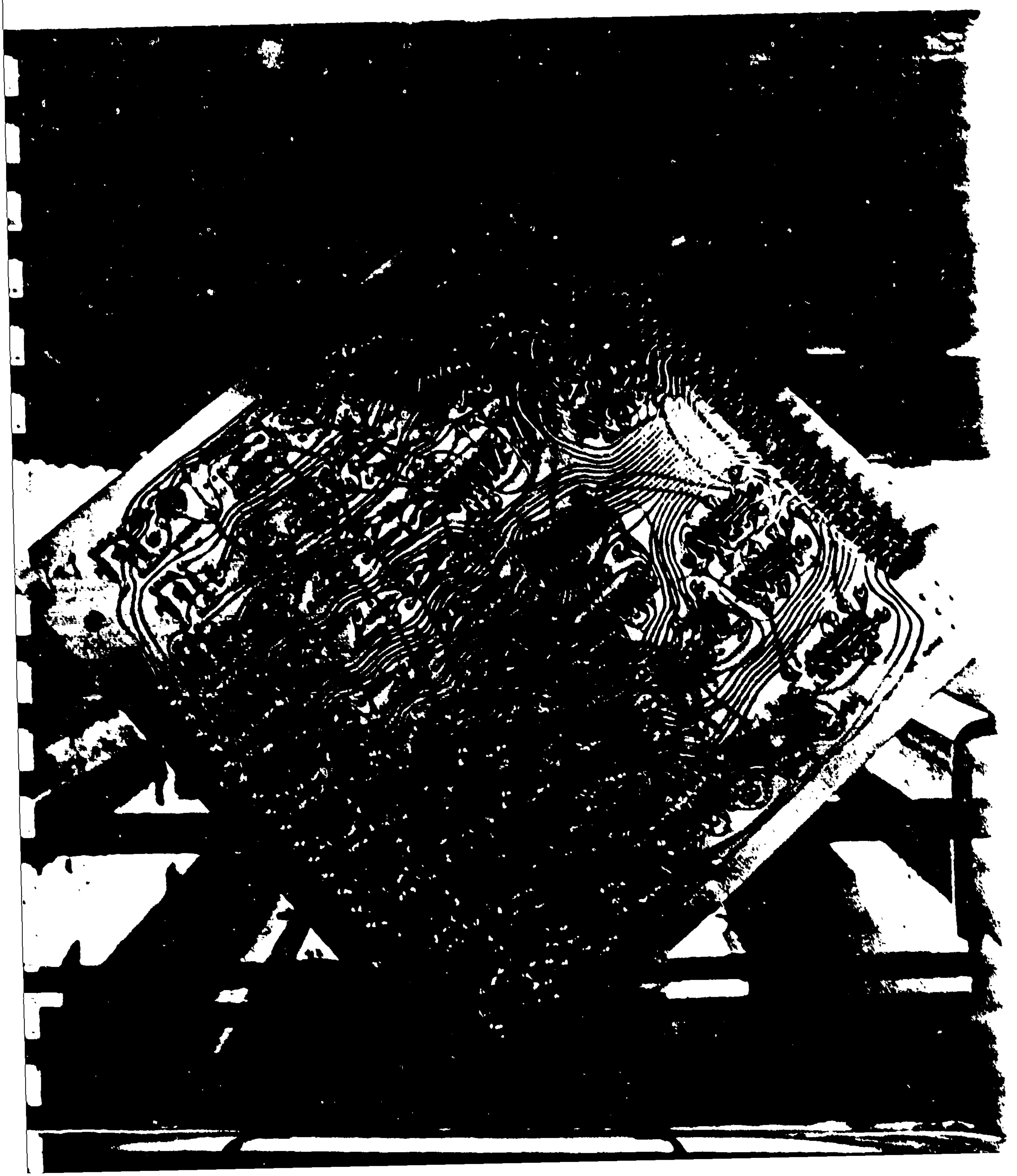


# For safe landings

Aircraft-oriented avionics systems such as Bell's Automatic Aircraft Landing System require a broad spectrum of engineering disciplines. Aerodynamic and control factors of the aircraft, hydrodynamics of the ship, and the environmental factors must all be faultlessly combined through precision electronics and mechanics to safely land the aircraft.

Bell has built automatic landing systems for more than 20 years and continues today in development of next generation systems.

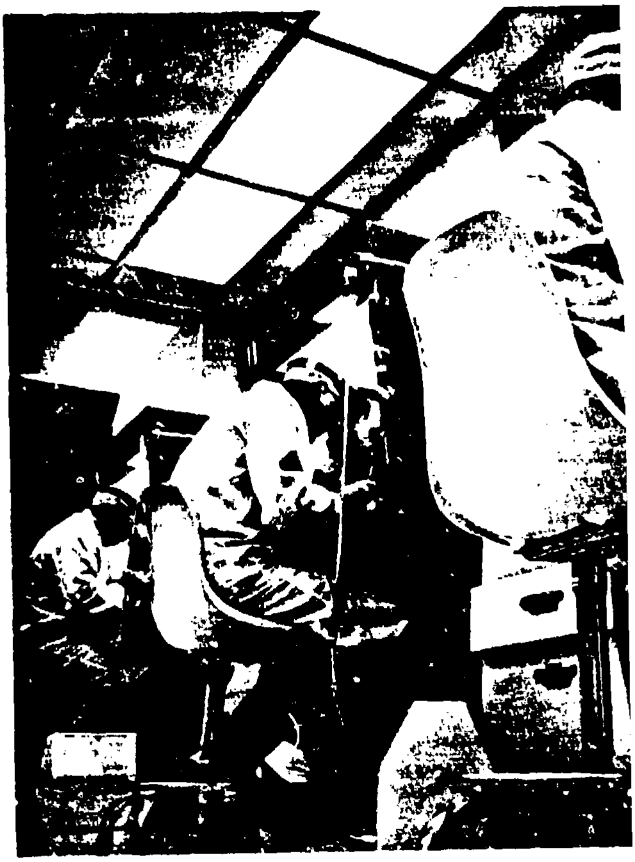


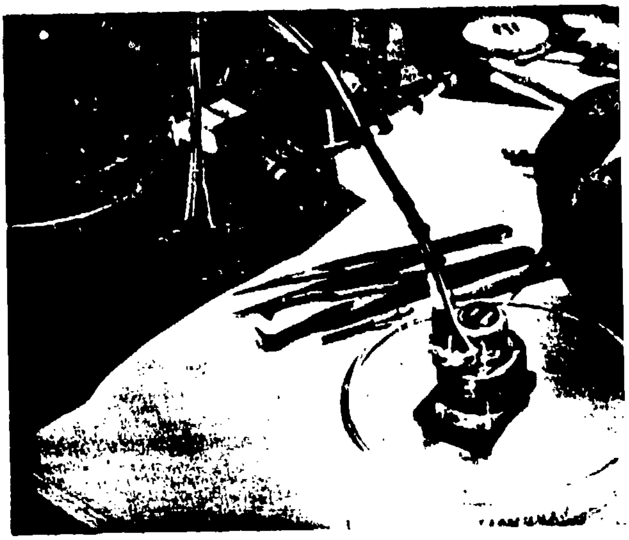


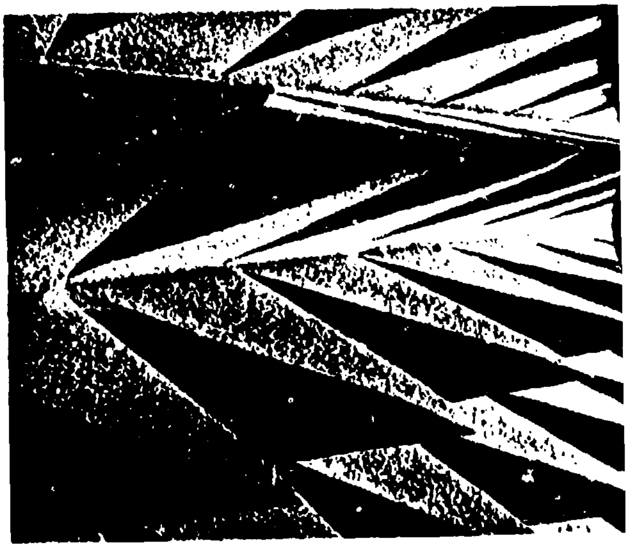
# Instruments that get around

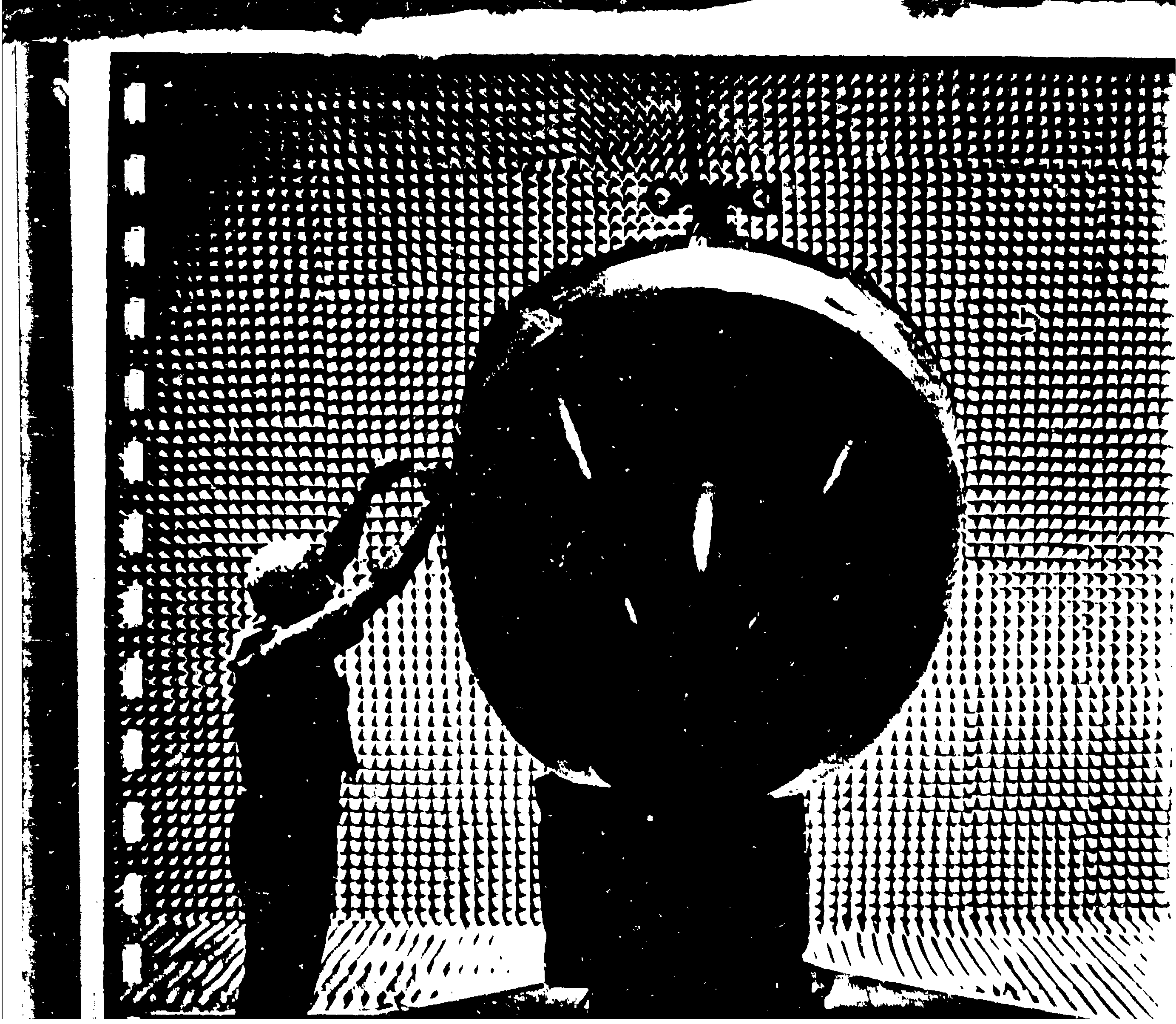
Past work on missile guidance systems has resulted in a capability to develop and build highly precise, low-cost inertial instruments for measuring velocity in space and the atmosphere. In addition this technology has resulted in a line of gravity meters used to provide gravity maps of the ocean floor. Several oil companies make use of these instruments to help detect oil deposits.

Bell has accepted the challenges and has developed the capability to design-to-cost and to total life-cycle cost. Engineers and management evaluate proven technologies against newer concepts to determine the most cost-effective, reliable and maintainable systems design to meet the customer's needs.



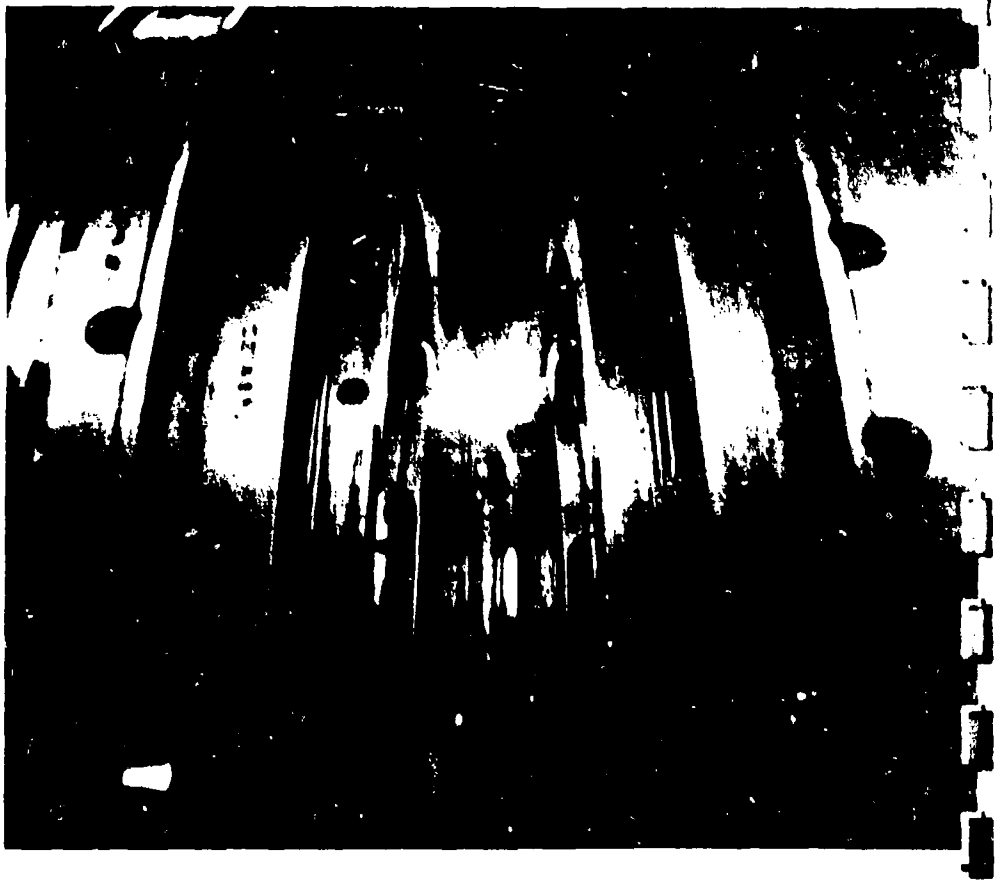


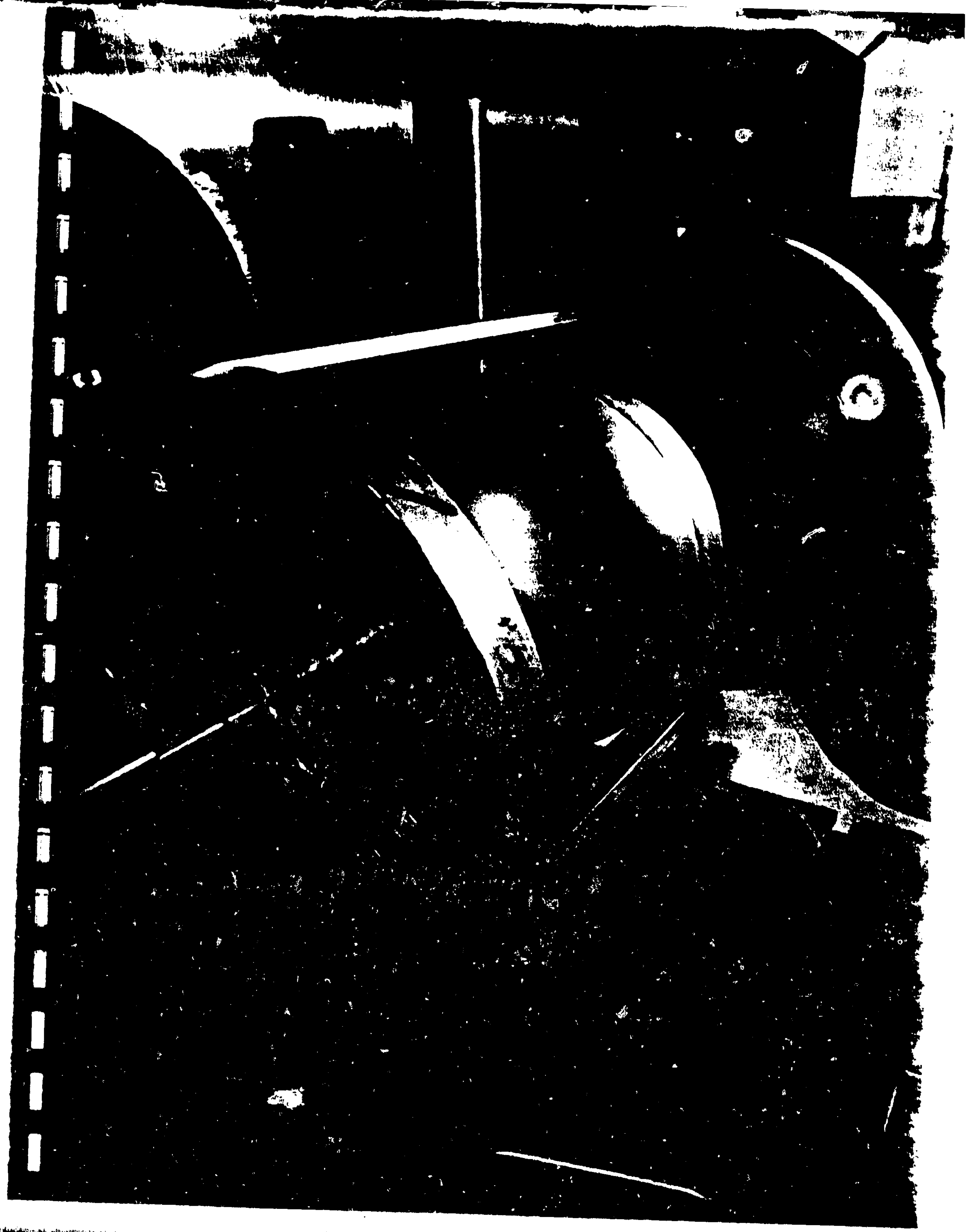




# The builders

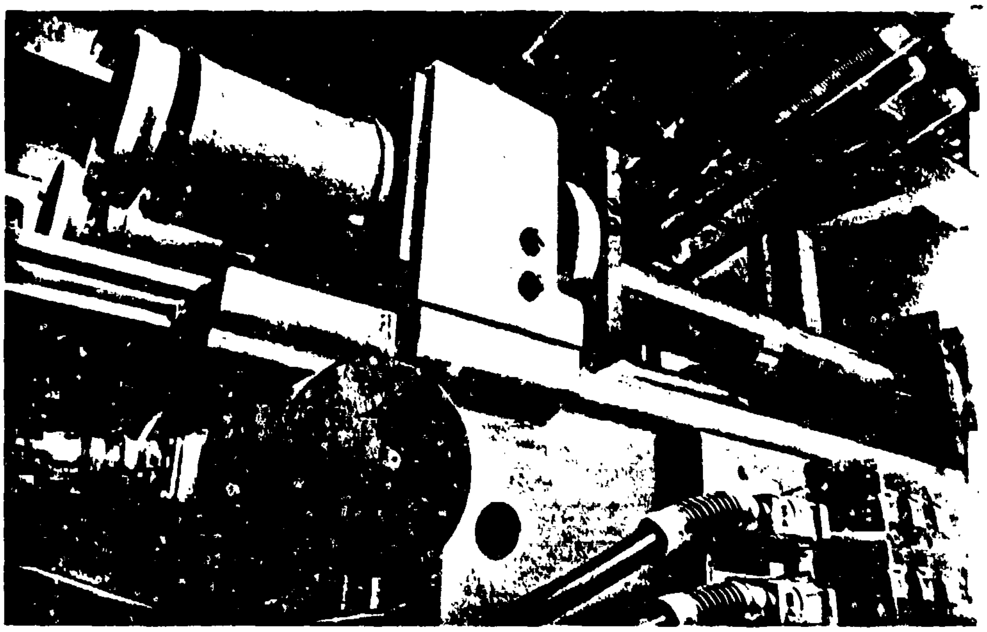
In addition to its other technologies, Bell maintains a continuing development effort in metal processing. This supports the need for high strength structures and minimum weight for such systems as air cushion vehicles, liquid rocket injectors and nozzles, high energy laser nozzles and propellant tanks. Techniques such as electron beam welding, plasma arc welding, laser welding, MIG and TIG welding are constantly being improved and expanded to new and novel applications by Bell manufacturing personnel.



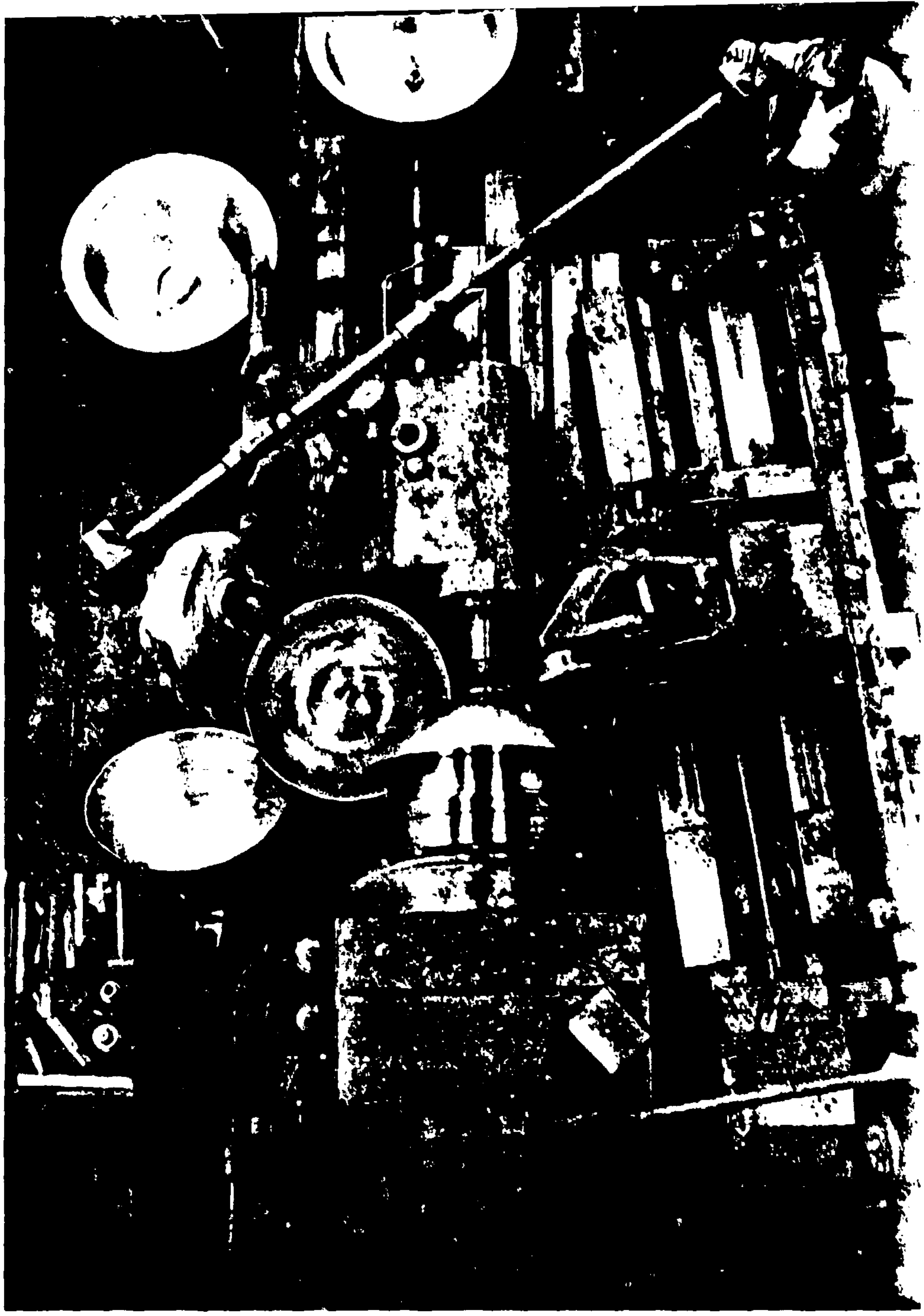


# Cutting, forming, spinning

Fabrication of the many products of Bell Aerospace Textron requires capabilities ranging from straightforward metal cutting and forming to precision machining and forming of exotic metals such as columbium and tantalum. Knowledgeable operators use the best available equipment for electric discharge machining and shear spinning of multi-curved shapes. New and unique equipment, also, has been developed to work on the flexible, rubberized materials of the high strength and stretchability required for air cushion systems.

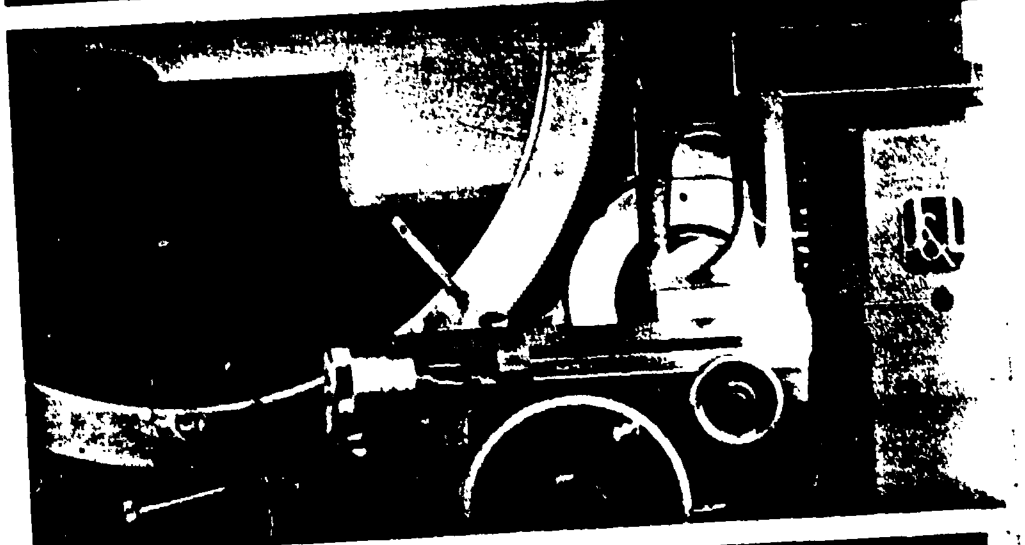


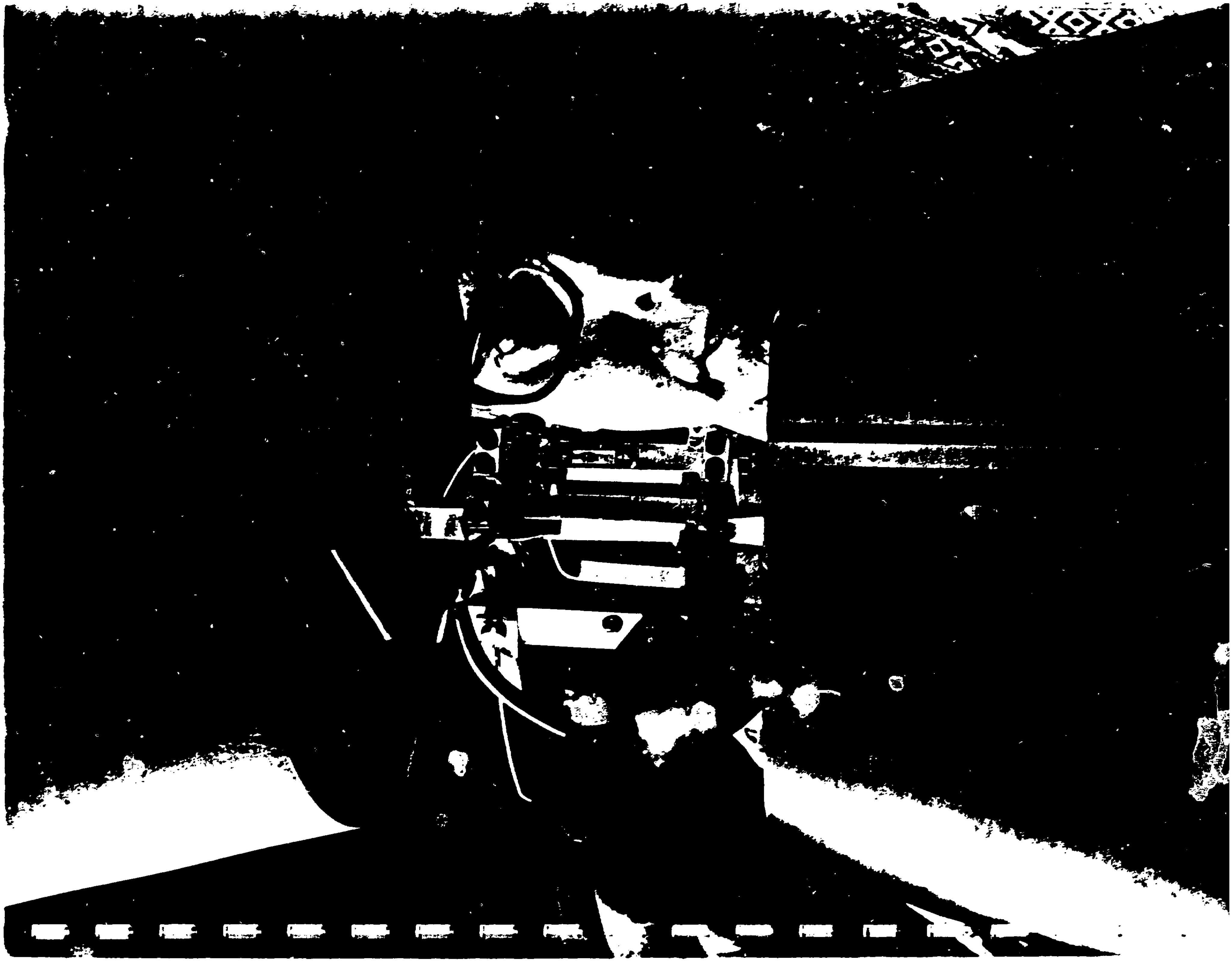
BELL



# Quality's the key

The company's engineering and manufacturing capabilities are supported by research laboratories in a wide range of fields, from chemicals and metals to fabrics and electronics. All Bell products are backed by the company's product assurance organization. Supported by an extensive and advanced computer facility, Bell has the capability to evaluate,test and assure compliance with every customer's needs and design requirements.





Technology is a land unknown. No one can tell where each new path will lead. Bell began with standard aircraft design. What has been shown on these pages is a partial picture of the company's capability today in widely diverse technologies. The best measure of Bell's success in mastering and applying these technologies is its accomplishment. A partial list includes:

First U.S. jet airplane • First supersonic airplane • First licensed helicopter • First U.S. swept wing and variable sweep airplanes • First jet V/STOL • Largest U.S. air cushion vehicle • First automatic all weather landing system • First air cushion landing system • First digital electronic warfare system • First liquid post boost propulsion system.

# APPENDIX C

## BELL HELICOPTERS

Lawrence Bell began his career as a mechanic in 1912 and was soon promoted to superintendent for one of the early airplane builders. In 1935, Bell formed his own company. By the time the United States entered World War II, Bell Aircraft Corp. had won worldwide recognition as the manufacturer of the P-39 Airacobra.

In 1941, Bell was selected to build the first American-built jet-propelled airplane — the XP-59. Within 13 months the P-59 made its inaugural flight at Muroc Dry Lake in California.

After WWII, Bell developed and manufactured the X-1, the world's first supersonic airplane.

Other Bell "firsts" include — first twin-engine escort fighter (Airacuda); first tricycle landing gear on modern military aircraft (Airacobra); the first airplane to vary the sweep-back of its wings in flight (X-5); first airplane to fly two and one-half times the speed of sound (X-1A).

Bell's venture into rotary-wing aircraft started in 1941, with the hiring of a youthful inventor named Arthur Young. Young had devoted 13 years to assembling his own set of helicopter design principles. He and about 30 other employees, bolstered by an apprentice named Bartram Kelley, began a helicopter development program.

Young had brought to Bell an almost perfectly stable flying helicopter model, which could be ground-controlled for forward and lateral flight, and for vertical climbs and descent. The conceptional model soon became a reality — the Model 30 helicopter. It was a one-place, open-cockpit machine powered by a 165-horsepower Franklin engine enabling it to reach speeds of 100 mph in level flight.

In rapid succession improved versions of flying models were built, each new machine incorporating refinements drawn from the previous years of hard-earned knowledge. On March 8, 1946, Bell was awarded the world's first commercial helicopter license. That year also marked the start of production, when 10 Model 47's were built. During the ensuing years, Bell has set the pace for all other commercial and military helicopter manufacturers. It has built and marketed more helicopters than all other manufacturers combined. These versatile machines are being used by the farmer, rancher, oilman, miner, constructor, forester and just about everyone else who grows or manufactures a product or provides a service.

Bell Aircraft Corporation, the predecessor of Bell Helicopter Textron, was founded July 10, 1935, in Buffalo, New York, by Lawrence D. Bell, a man referred to as "America's most seasoned dreamer."

Bell Aircraft Corporation created a Helicopter Division which moved to Fort Worth, Texas in 1951 and became Bell Helicopter Corporation, a wholly owned subsidiary of Bell Aircraft Corporation.

In 1960, Textron Inc. of Providence, Rhode Island, bought various Bell Aircraft properties including the helicopter operation. Textron changed the name of the helicopter operation to Bell Helicopter Company. Within a few years Bell Helicopter Company established itself as Textron's largest division. In January, 1976, the name was changed to Bell Helicopter Textron.

# *Historical Highlights*

*1941* Birth of Bell helicopter—control line model.

*1943* First flight of experimental Bell Model 30 helicopter.
*1944* Aviation history is made when Bell helicopter is flown inside 65th Regiment Armory, Buffalo, New York, marking the first U.S. indoor flight.
*1945* A Bell helicopter performs the first emergency rescue for this type craft by flying a doctor to an injured pilot snowbound in western New York.

*1946* A Bell Model 47B helicopter is granted the world s first commercial helicopter license.

Bell receives Helicopter Type Certificate No. 1, the first granted by the Civil Aeronautics Administration (predecessor of FAA).

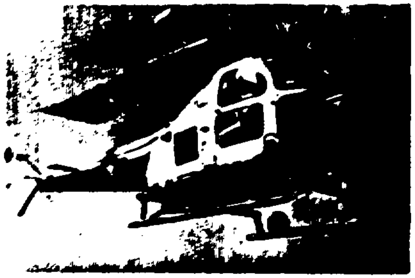
Bell establishes the first Flight Training School for commercial helicopter pilots.

*1947* Delivery of Bell's first military helicopter.

*1949* A Bell helicopter sets an altitude record of 18,550 feet.

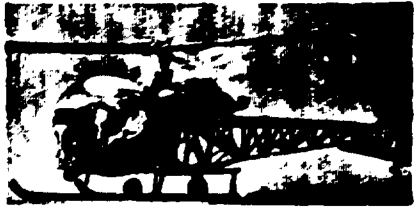
A Bell helicopter sets a speed record of 133.9 mph.

First helicopter air mail service started in Chicago.



*1950* Model 47D-1 becomes first helicopter to fly over Alps.

*1951* The U.S. Army announces that Bell's Model 47D-1 has broken all records for speedy evacuation of wounded troops in Korea.
*1952* The non-stop flight of a Bell Model 47D-1 helicopter from Fort Worth, Texas to Buffalo, N. Y., sets a world record of 1,217 miles.
*1953* Autorotation record of 16,000 feet is made by XH-15.



*1954* The first flight of a turbine-powered Bell Model XH-13F helicopter is made.

*1955* Bell wins industry competition for Army turbine-powered utility helicopter (Army HU-1/Bell 204 model). Marks first all-Texas design and developed model.

XV-3 convertiplane is first flown.

*1956* Army pilots set helicopter endurance record at National Air Show (Oklahoma City) by flying H-13H for 57 hours 50 minutes without landing.

*1958* The XV-3 convertiplane makes aviation history with the first 100 per cent conversion of tilting rotor fixed-wing aircraft.

*1959* XV-3 convertiplane is first VTOL craft to shift gears in flight.

*1960* Three Army pilots fly Bell HU-1 to six world and one national rotary-wing record in categories of speed, distance and time to climb to altitude.

*1961* Bell commercial Model 47's established eight new world records.

Bell HTL-6 sets unofficial world record for helicopter flight endurance of 72 hours at Navy's Ellyson Field, Pensacola, Florida.

*1962* Bell announces development of Microwave Remote Area Instrument Landing Sensor which makes it possible for helicopters to be flown in zero visibility conditions.

Army piloted Bell YUH-1D claims three world records.

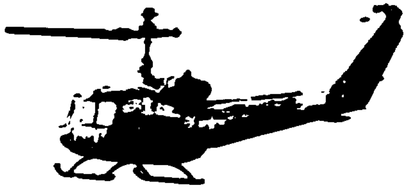
*1963* Bell Model 47G-3B-1 claims altitude record in Australia.

Bell Model 204B certified by FAA.

*1964* Bell becomes first company to fly a rotorcraft at a speed in excess of 200 knots per hour.

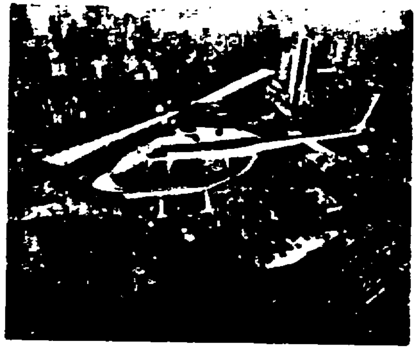
Eleven more world records claimed by UH-1D making a total of 21 for the Iroquois model and a total of 27 records held by Bell helicopters.

*1965* Bell YUH-1B compound helicopter flies 250 miles per hour — fastest speed ever attained by a rotorcraft.

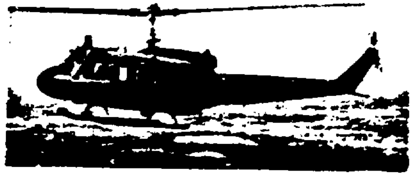


Bell announces development and first flight of helicopter with twin-turbine power plant, Bell Model 208.

Bell announces development of HueyCobra.



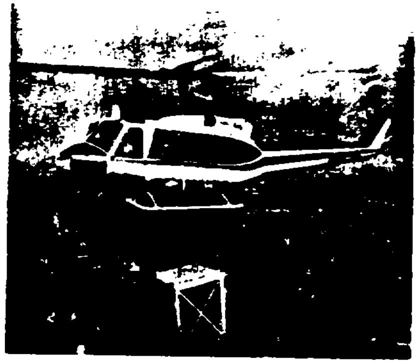
*1966* Roll-out of new five-place JetRanger.



Bell receives largest contract ever awarded by U. S. Army Aviation Materiel Command for 2,115 UH-1 Iroquois helicopters.

A unique radar antenna built into the blade of a helicopter is successfully tested.

*1967* Los Angeles County Fire Department becomes first municipality to purchase 204B.



Bell announces a new 15-place commercial model, the 205A, to be available in 1968. It is the largest commercial model ever manufactured by Bell.

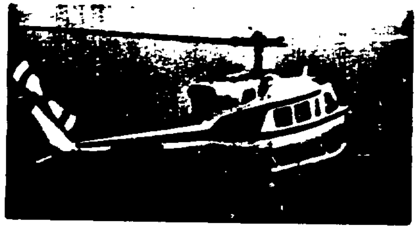
*1968* JetRanger named winner of the U. S. Army's light observation helicopter competition.

Bell delivers its 10,000th helicopter, a JetRanger to Petroleum Helicopters, Inc., world's largest operator.

Bell announces that its Model 212, nation's first twin-engine, medium size commercial helicopter, will be ready for delivery early in 1970.

*1969* Bell compound research helicopter attains speed of 316 mph in level flight — highest ever for a rotorcraft.

Canadian Government orders 50 twin-engine Bell helicopters, designated CUH-1N, for its armed forces.



*1970* Bell's 212 Twin gets FAA type certificate.

*1971* First production model of Bell's JetRanger-II delivered to Okanagan Helicopters Ltd. of Canada.

*1972* Commercial and International Marketing break all-time records with firm orders for 105 helicopters.

# *The Military application and development of Bell helicopters*

In 1946 the military forces, being interested in vertical takeoff and landing capabilities, purchased their first Bell helicopters. U.S. involvement in the Korean conflict became the proving ground for helicopter application concepts. Helicopters proved most valuable as medevacs in Korea, where Bell's early Model 47 rescued an estimated 25,000 wounded, and is credited with advancing the acceptance of the helicopter by 10 years.

The advent of the more reliable light turbine power plants enabled the helicopter to be exploited in terms of potential applications, and it soon became an integral part of all airmobile forces. The Vietnam conflict vividly demonstrated its value, resulting in new and even broader applications of the helicopter's role in U.S. military forces. Through the years Bell has continued to produce military aircraft in quantity for the Armed Forces of the United States and many foreign countries.

***Model UH-1H***

The UH-1H is the latest single engine model in the famous multi-mission Huey series, the most proven aircraft in active military service. This series has accumulated millions of hours of flight time, and literally rewritten the history book on Army aviation.

Free world nations the world over rely on the dependable UH-1H capability for a number of civil and military missions: personnel transport, medical evacuation, rescue, cargo transport, reconnaissance, or weapons platform.

***Model TH-57A SeaRanger***

The Navy found yet another vital mission for the world's most popular turbine-powered helicopter. As a primary helicopter trainer the SeaRanger is an ideal way to begin flying rotary-wing aircraft. It has excellent flight stability, fast control response, yet it is highly maneuverable at any speed. Helicopter flight principles and controls are simple to teach and easy to learn in the TH-57A.

***Model OH-58A***

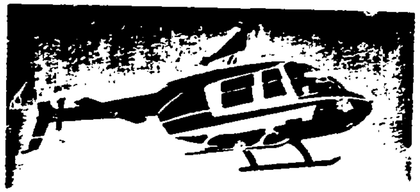
With its particular design and performance characteristics, the Model 206 was the logical choice for the Army's light observation helicopter. Designated OH-58A Kiowa by the Army, it represents the second-largest military purchase in Bell's history.

When not performing observation missions, the five-place OH-58A can be used for a variety of light utility requirements.

***Model AH-1G HueyCobra***

The first attack helicopter in U.S. military combat history was a HueyCobra. The AH-1G's primary mission was to provide fire support for ground operations, but as experience has shown, this high speed gunship is one of the most versatile weapon systems in the tactical arsenal.

Bell announces breakthrough in elimination of helicopter vibration by suspending fuselage from "nodalized" beam.



*1973* 1,000th JetRanger delivered.

Development of new model seven-place, light-turbine 206L LongRanger announced.

*1974* Model 222, the first U.S.-built commercial light twin helicopter, receives a total development go-ahead.

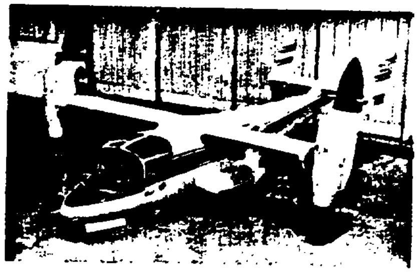
Bell commemorates the delivery of the 20,000th Bell helicopter.

Bell's new Model 206L LongRanger makes its initial flight.

*1975* Bell's Model 206L LongRanger, the new seven-place, light-turbine helicopter, receives FAA certification.

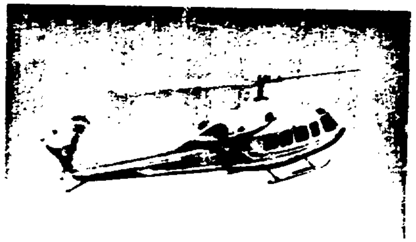
An Iranian Model 214A helicopter sets five world records in altitude and time-to-climb categories.

A major technological breakthrough is achieved by Bell when the main transmission of a Model 214A helicopter runs for one and one-half hours without oil.



*1976* Bell's first XV-15 tilt-rotor research aircraft prior to flight test.

Bell and Collins Radio Group announce the development [illegible] an IFR system for the LongRanger.



*1978* The 19-place 214ST super transport, a longer, twin turbine version of the powerful 214, goes into a rigorous flight test program.

In the decades of the 80's and 90's, Bell Helicopter Textron will continue to refine and develop its products to meet the needs of constantly expanding markets.

### Model UH-1N

The 15-place military version of the Two-Twelve Twin has all the characteristics and flight experience of the renowned Huey, with the added performance and safety features of redundant systems. The UH-1N has basically the same seating and litter capabilities as the Huey, but the twin-turbine power plant assures greater overall reliability in marginal weather, on hot days and at high altitudes. Bell's Automatic Flight Control System (AFCS) provides a fly-through capability in all flight modes, increasing system safety while easing pilot work load.

### Model AH-1J

This twin turbine-powered version of the HueyCobra results in improved performance characteristics, and greater payload capabilities. The twin-turbine package featured in the AH-1J offers increased safety and dependability for over the water armed escort and fire support.

### Model OH-58C

The OH-58C is a modified version of the OH-58A incorporating a more powerful engine, an uprated transmission, and an anti-glint flat glass canopy. These modifications and improvements will enable the OH-58C to carry out its observation missions with improved survivability characteristics, while offering a significant increase in aircraft performance.

### Model 214A

The 16-place 214A is Bell's most powerful single turbine-powered helicopter. Utilizing the long proven Huey airframe and incorporating advanced systems technology, the 214A was designed to accomplish similar missions as the Huey, but is far more capable of performing heavy lift operations at high altitudes under extreme weather conditions.

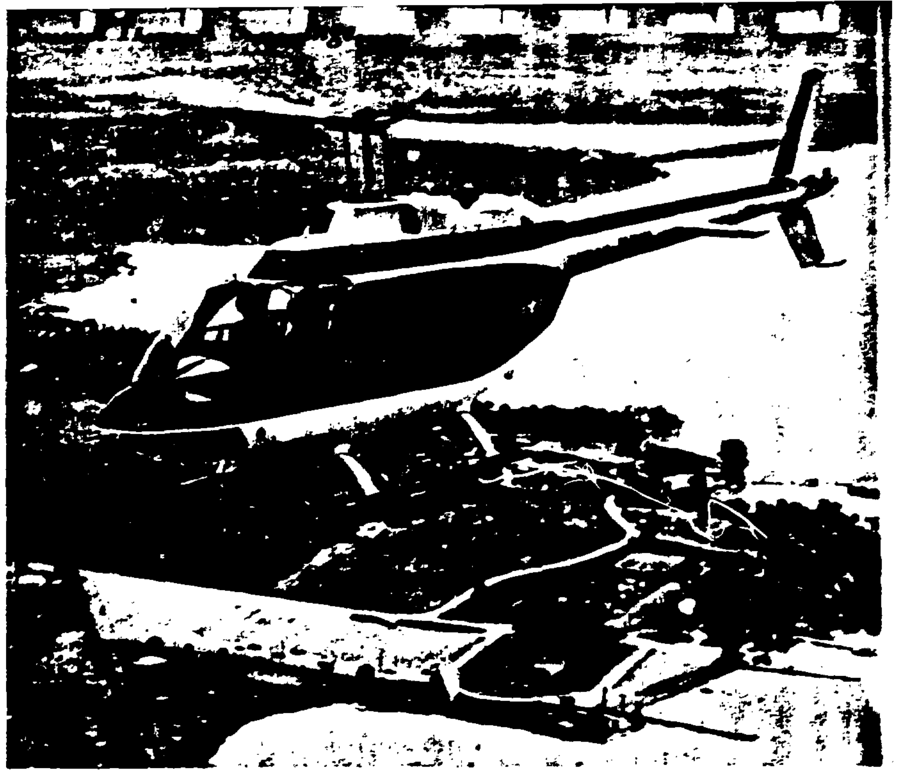
### Model AH-1T

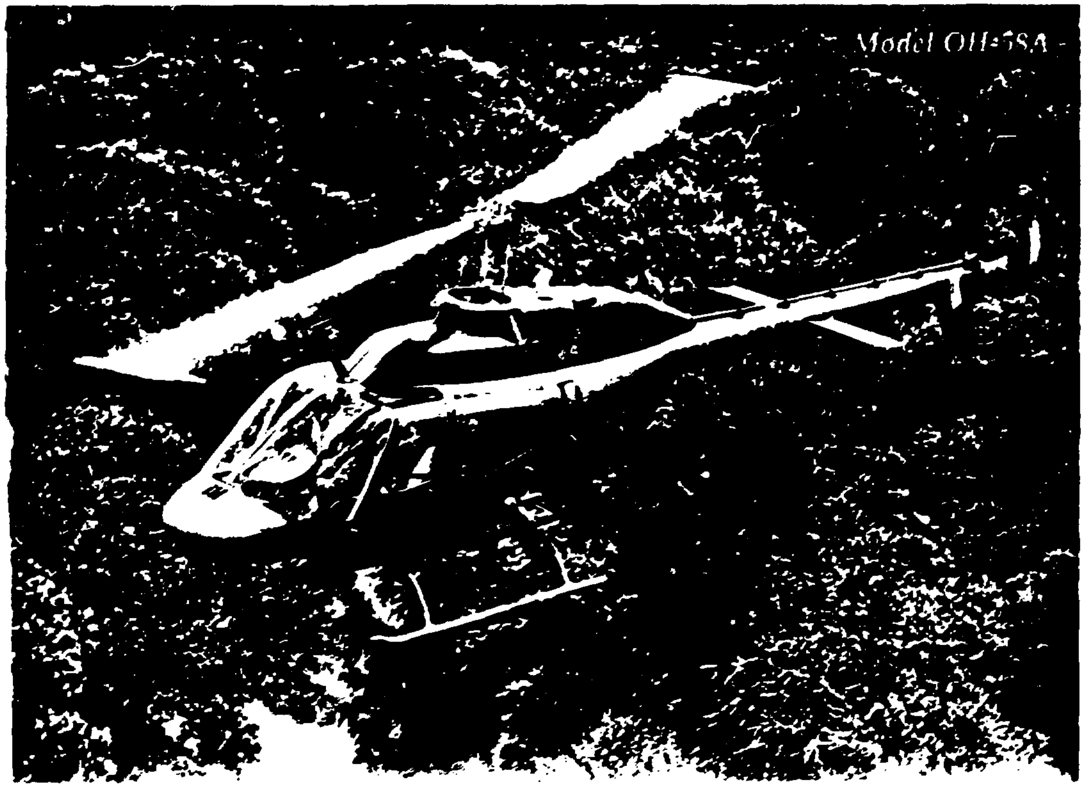
A growth version of the AH-1J, the U.S. Marine AH-1T has four times the payload capability of its predecessor. Using Model 214 dynamics and an upgraded engine, the longer AH-1T provides the Corps with responsive close-in fire support during amphibious and helicopterborne operations. Part of the highly reliable and easily maintained Improved Sea Cobra fleet is equipped with the TOW missile system for destruction of point targets.

### Model AH-1S

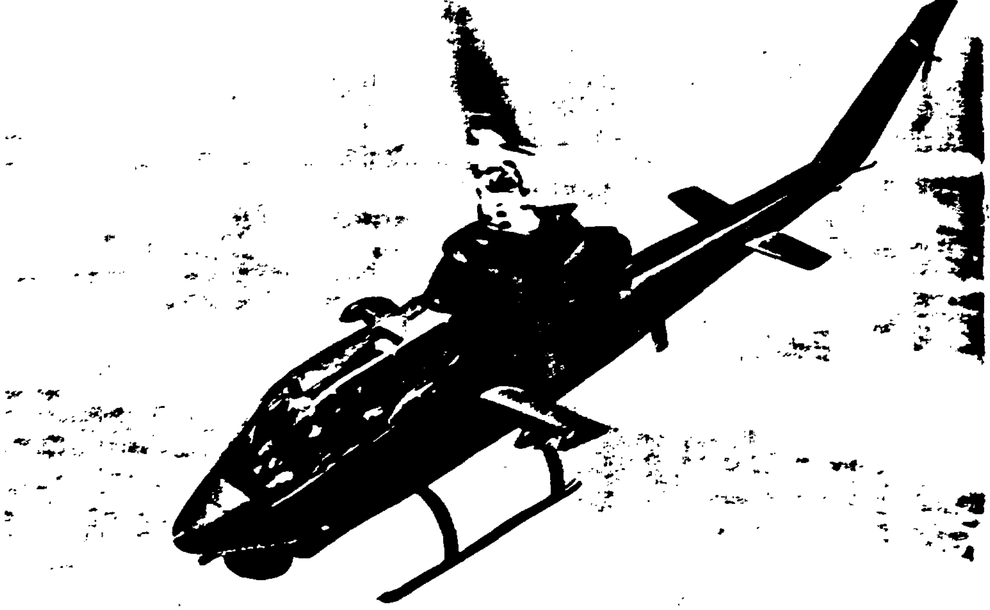
The AH-1S is an improved version of the AH-1G, designed specifically to meet the U. S. Army's nap-of-the-earth flight requirements. These improvements include a more powerful engine, an uprated transmission, and the antitank TOW missile system. With the emphasis on agility and maneuverability, the AH-1S incorporates all the essentials necessary for successful nap-of-the-earth operations.

Model UH-1H




Model OH-58A

Model AH-1G HueyCobra



## *The Commercial application and development of Bell helicopters*

When two out of three helicopters at work in the world today are Bells, there has to be a reason. The reason is that Bell offers the widest range of models, all backed by the world's largest and most advanced helicopter support system.

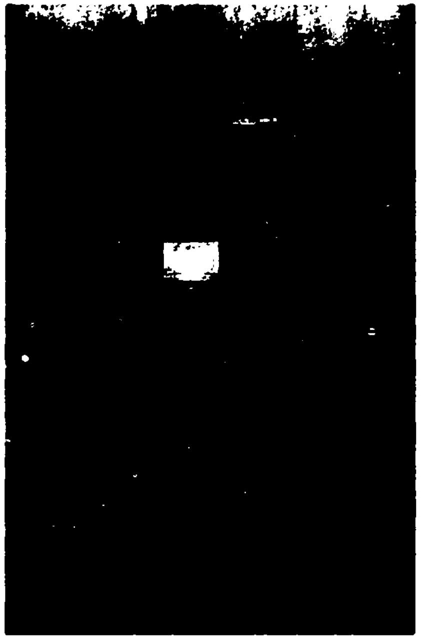
These reliable and versatile machines are being used by individuals, manufacturing industries, utility companies, oil firms, farmers and ranchers, the lumber and paper industries, mining companies, law enforcement agencies, and the heads of state of scores of nations all over the globe.

### *Model 205A-1*

Bell's 15-place Model 205A-1 is a design offspring of the remarkable "Huey" military helicopter — a design that has proved its reliability on thousands of jobs covering millions of flight hours. For transporting people, hauling cargo, or as a two ton aerial crane, it's the ruggedly dependable 205A-1, the "do-everything" helicopter.

### *Model 206 B JetRanger III*

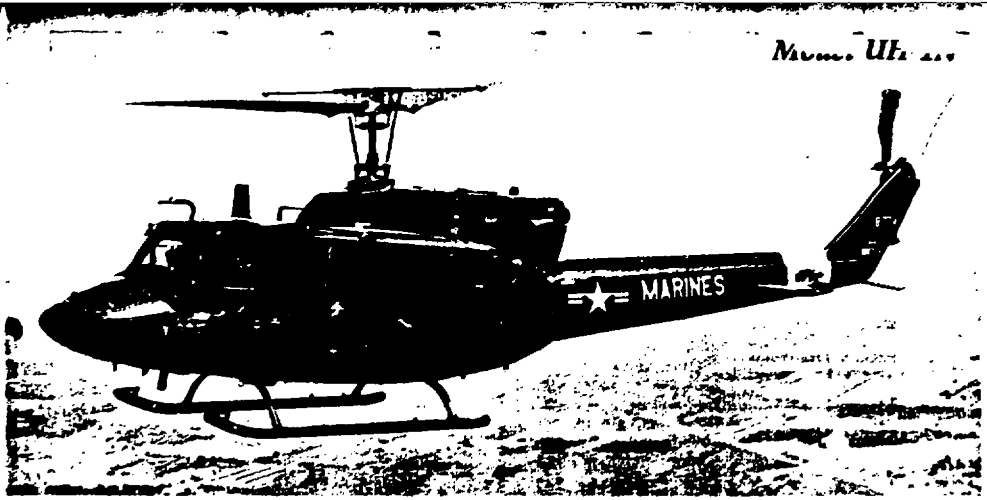
The JetRanger is the world's most popular, most widely used five-place turbine helicopter. It is unexcelled as a speedy air taxi, executive transport, police aircraft, aerial crane, medevac, or all-around utility vehicle. It can whisk busy businessmen from doorstep to doorstep faster than any combination of air and ground transportation within a 350-mile range. The 130 mph JetRanger combines versatility and cost effectiveness with custom cabin interiors in a variety of fabrics and colors to help make it the most wanted helicopter in the world. And now, the JetRanger is available with additional features like an auto-pilot and single-pilot IFR.

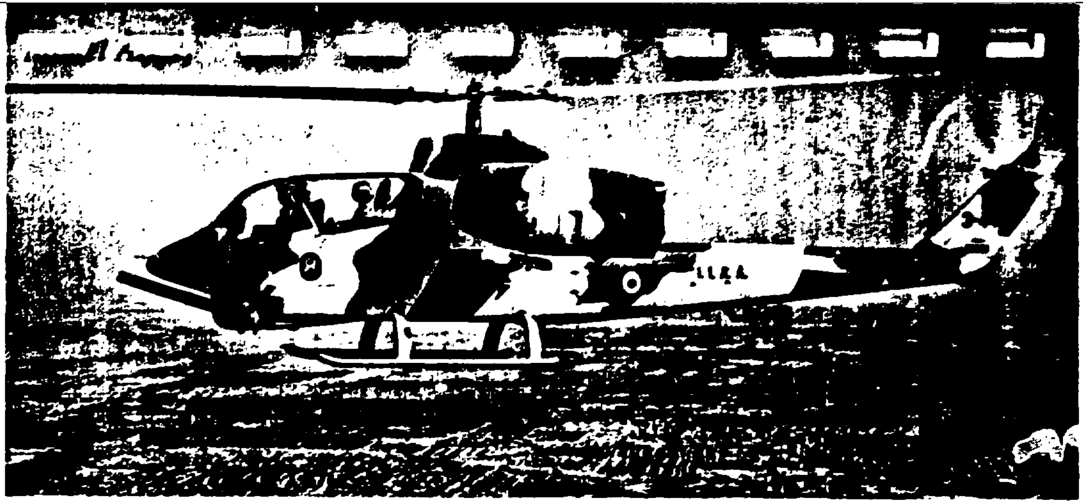


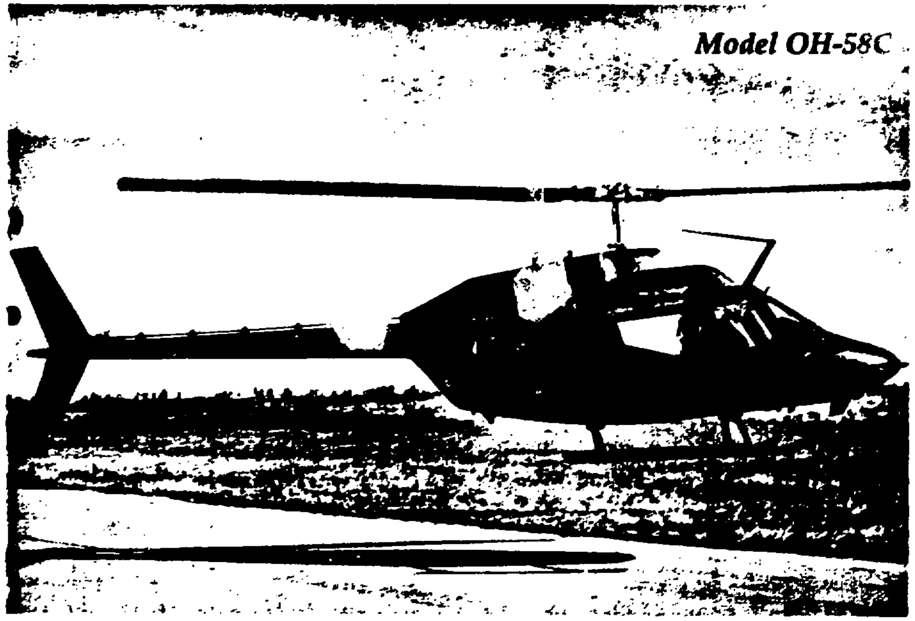
### *Model 212*

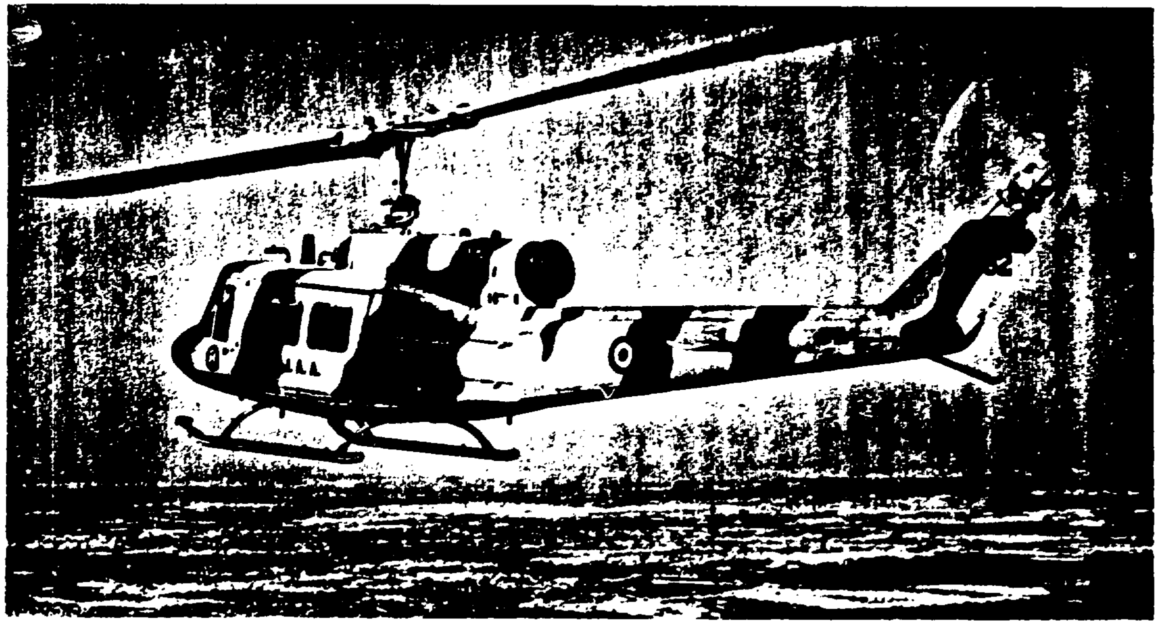
The Two-Twelve was designed with twin power plants, twin hydraulic systems, twin electrical systems, twin fuel systems. Even twin fire detectors and extinguishing systems. And it's IFR certified to fly at night or in adverse weather.

The Two-Twelve Twin has proven itself to be an outstanding performer in the petroleum industry, serving crew transportation and equipment replacements at distant offshore and remote onshore drilling sites. And it is serving these needs, with day-in, day-out dependability, in construction, power utility, forestry and mining industries — worldwide.

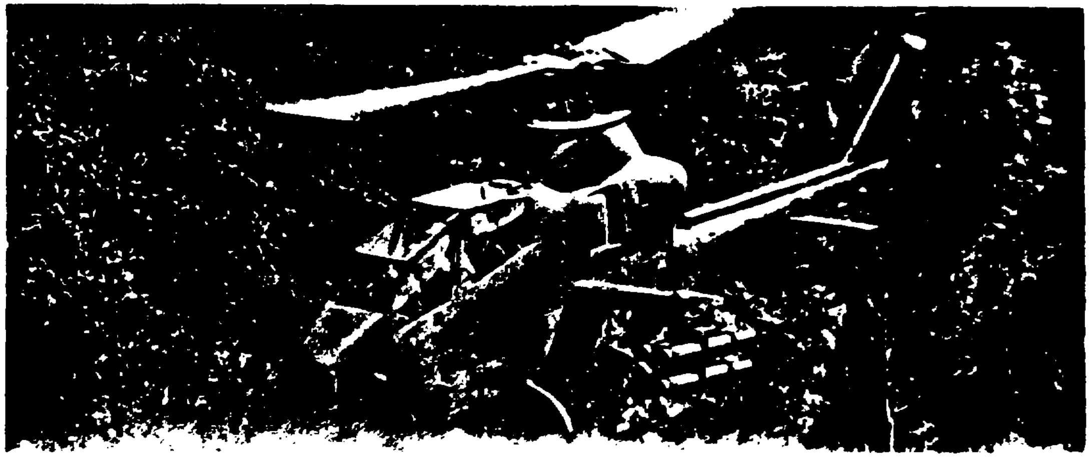

Model UH-[illegible]




Model OH-58C



Model AH-1T



### *Model 206L LongRanger II*

The seven-place, 140 mph turbine-powered LongRanger, with executive comfort interior styling and a smooth, vibration-free nodalized suspension system ride, is a worthy extension of the popular JetRanger, capable of filling a wide variety of single engine helicopter requirements. In corporate transportation configuration, or stripped for hard working action as a utility craft, the dependable LongRanger can take on any job that other light helicopters can handle. And with the addition of an auto-pilot and single-pilot IFR it can handle assignments others can't.

### *Model 214B*

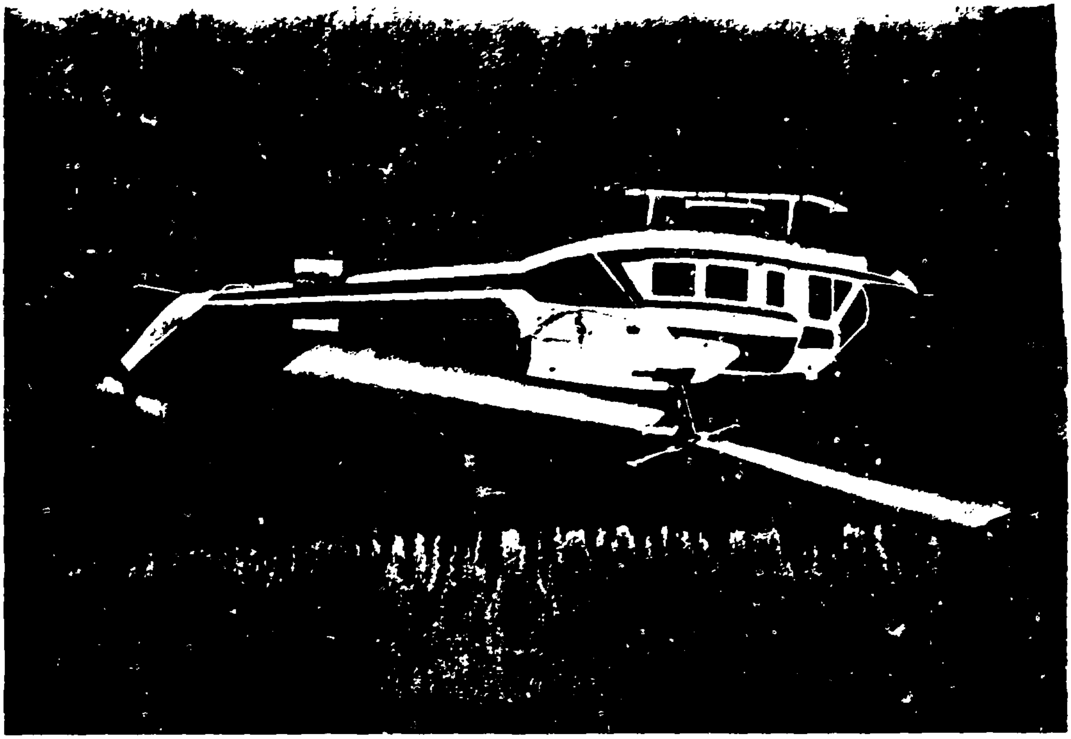
The 16-place 214B is Bell's most powerful single turbine-powered aircraft, providing more lift and speed capabilities than any other Bell utility helicopter ever manufactured. Externally, with quick release cargo hook, the 214B can lift over 7000 pounds at sea level and move it at 120 mph.

It can carry 15 passenger work crews causing less fatigue due to the vibration-free nodalized suspension system, or lift helicopter transportable oil rigs and power transmission towers into remote areas. It can move pipe, structural parts, power equipment, and bulky components over rugged terrain in all kinds of weather. And the 214B can do it all with greater efficiency and more cost-effectiveness than any other medium lift helicopter.

### *Model 222*

Seating as many as 10 in unprecedented quiet and comfort, Bell's Model 222 light twin turbine, fully nodalized and IFR equipped will revolutionize corporate air travel. It will afford more speed and almost double the range of most single engine helicopters, with an optional climate control system, and a wide selection of executive-styled interiors and seating configurations.

Comfort, styling, smooth and quiet flight, and an all-weather capability make the feature filled 222 the most exciting new, efficiently practical executive helicopter yet. The 222 is now in development to serve the increased needs of the corporate and commercial markets.



HELICOL

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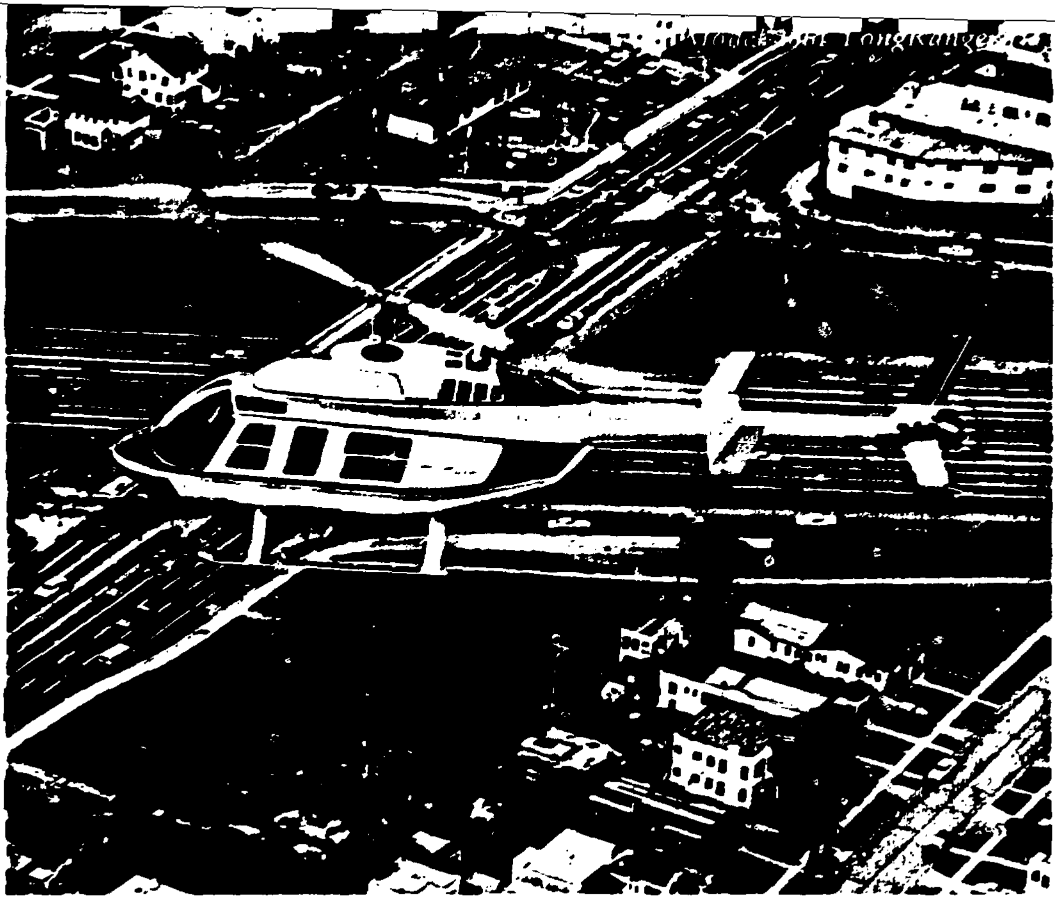
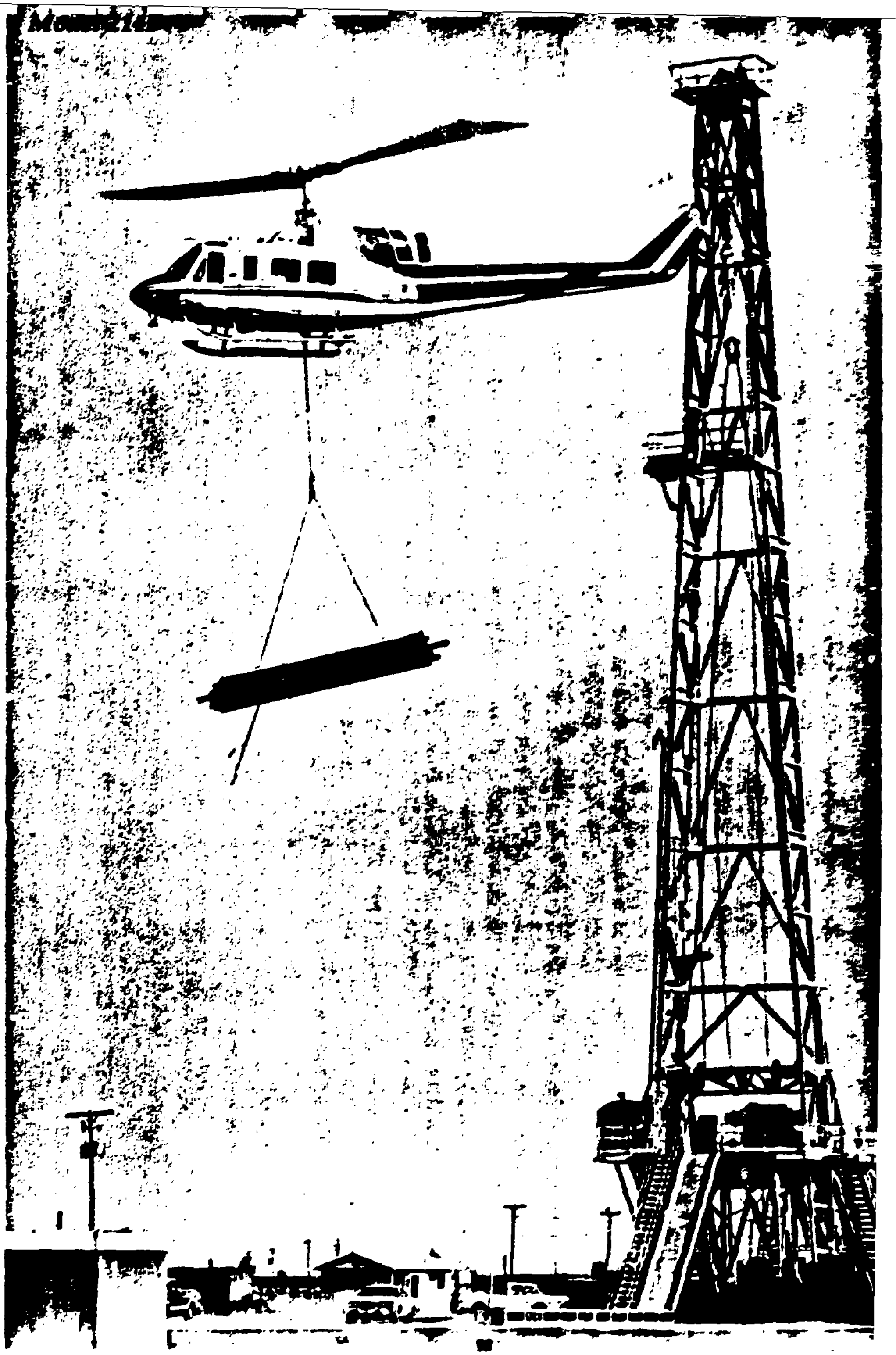
## *120 acres of aircraft design and manufacture*

At Bell Helicopter Textron, located in the heart of the Fort Worth/Dallas metroplex, you will find the world's largest and most comprehensive facilities devoted exclusively to the manufacture of rotary-wing aircraft. The extensive network of plants has more than 2,300,000 sq. ft. of floor space. Bell has unexcelled in-house capabilities for engineering design, laboratory testing, exotic metals machining, fabricating, gear-train manufacturing and assembling, metal processing and bonding.

Three complete tower-controlled heliports are maintained for in-flight functional and performance checks.

Main Plant and International headquarters.


Model [illegible] LongRanger


Model 212

Model 222

# *Engineering and Research…*
# *where advanced technology maintains Bell's leadership*

*Engineering*

At Bell, you will find the most knowledgeable and experienced helicopter-oriented engineering staff ever assembled.

Personnel are divided into two basic operating sections; Project Groups that are concerned with the development of individual models, and Technology Groups that are responsible for the performance of all ships. Advanced concepts, aerodynamics, avionic applications, exploratory projects, and new material applications developed by the Technology Groups are used to refine current Bell ships and create new models.

Bell's engineering design and development activities are conducted primarily at the main facility. Three separate buildings totaling over 75,000 square feet provide for additional testing, including fatigue, ballistic, environmental and reliability studies.

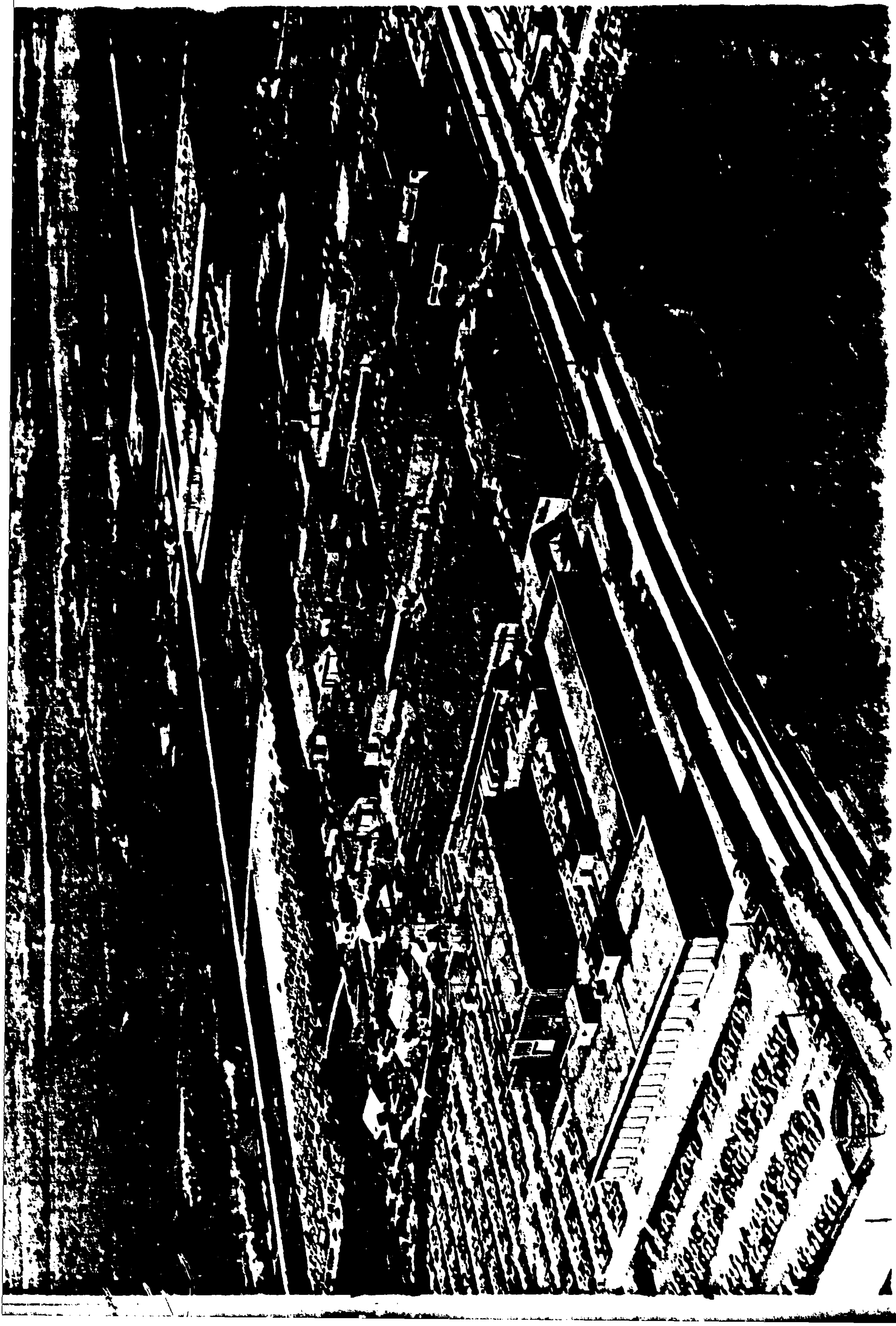
*Research and Development*

Sensitive to the importance of an aggressive research and development program, Bell management enthusiastically supports an imaginative staff of R & D engineers, specialists and technicians.

Current research is directed towards developing hardware for experimental ships with VTOL capabilities. A prime example is the Model XV-15, a tilt-rotor VTOL transport . . . capable of vertical lift and descent, and approaching jet speeds in horizontal flight . . . now in cooperative development with NASA/Army. Continuous development work takes new products and services and systematically evaluates them for new helicopter applications. Special emphasis is now being centered on noise abatement through extensive design and testing of new rotor configurations.

Through such programs, Bell has maintained an enviable position of leadership in helping to solve the problems of vertical flight. Because of this, the future is exciting with great challenges to be met and resolved.

1. Design engineers are responsible for the detailed design of airframes, transmissions, rotors, controls, electronics, and other systems for all helicopters.
2. Computer tapes provide complex analysis for greater confidence in designs and less risk in building new aircraft.
3. Many hours of analyzing and testing are required to determine exact component requirements.
4. Wind tunnel testing of future tilting proprotor aircraft.



## In-house capability... a combination of designing, engineering, tooling, building and testing that is unique in aircraft manufacturing

*Manufacturing*

In-house capability means having the facilities and technical skills necessary to *design, engineer, tool, build* and *test* everything that makes a helicopter a Bell helicopter. Bell's requirements are of such exacting standards that in-house capability becomes an imperative.

Separate buildings house facilities for research, manufacturing, assembly and testing of Bell transmissions and Bell rotor blades. Here, exact tolerances, precise manufacturing and step-by-step quality control methods are maintained that are unequalled by any other helicopter manufacturer.

Bell's vast background of flight experience, testing and experimental rotor data is fed into each new helicopter model to establish the right configuration for smoother, longer, and quieter rotor blade operation.

Each part is tested. Every part is numbered, and its history, from raw material to replacement is recorded. Analyzing such data, Bell engineers are constantly extending the capabilities of transmissions, the gears they incorporate, and the design and performance of Bell rotor blades. From such exacting standards and extensive research has come a revolutionary new gear box which can operate for extended periods of time after the loss of all lubricant; a highly dependable, all-elastomeric bearing rotor hub that needs no lubrication, yet will last four or five times longer than conventional hubs; new rotor blade composite materials with environmentally tested adhesives, permitting lighter construction; self-lubricating Teflon bearings; and a nodalized cabin suspension system that virtually eliminates vibration, greatly extending parts and sub-systems life as well as reducing crew fatigue.

*Assembly*

Subassemblies are built in Bell-designed fixtures. They are inspected for quality, tested and stocked along with other components in stations strategically located along the final assembly line. As the airframe advances down the line, highly trained Bell personnel install cabins, transmissions and gear trains, rotor assemblies and engines. Special packages, containing electrical systems, avionics and instrumentation, are also fed into the assembly line through stations manned by specialists.

A computerized circuit analyzer is used to verify the integrity of wiring assemblies. This piece of equipment is one of the most advanced quality control systems in the aircraft industry.

1. With one of the most modern gear manufacturing facilities in the U. S., Bell has the in-house capability to harden, carburize, nitride and precision grind both internal and external spur gears, as well as helical and spiral bevel gears.

2. Fatigue testing of Advanced Attack Helicopter prototype.

3. Computer circuit analyzers are used to inspect the electrical circuits in each subassembly.

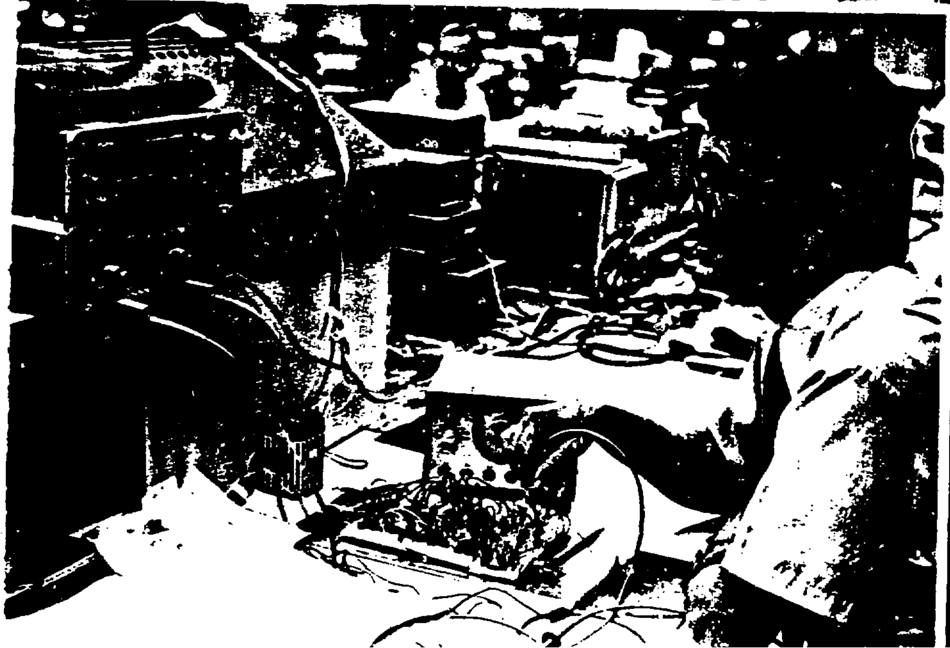
4. Blade materials are vacuum sealed and placed in autoclaves for curing under elevated temperature and pressure.

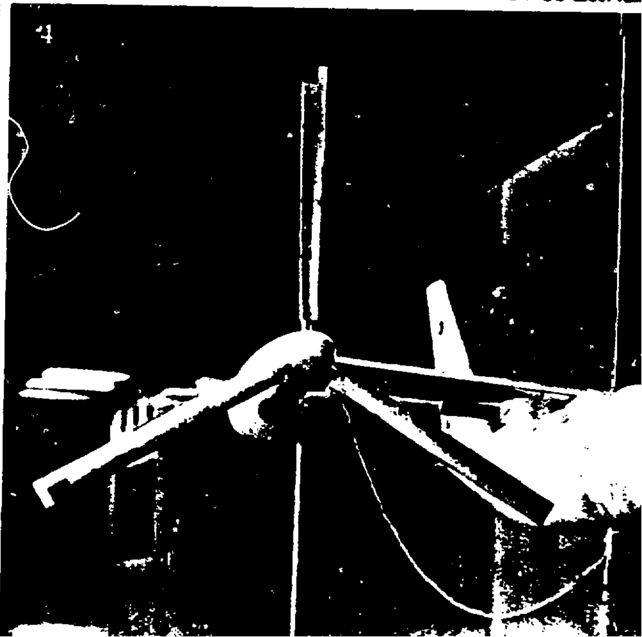
5. Main assembly line.

6. A complete Plexiglas forming area is maintained that includes blowing bubbles, forming shapes and laminating assemblies.

1

2

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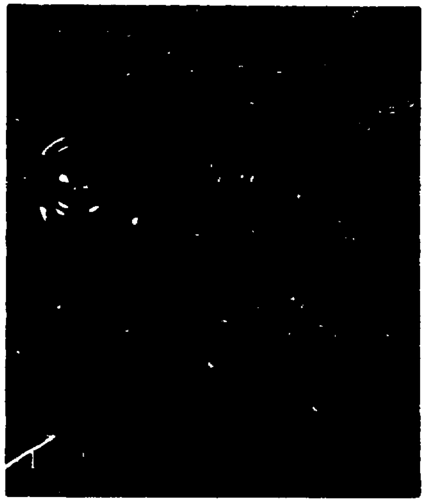
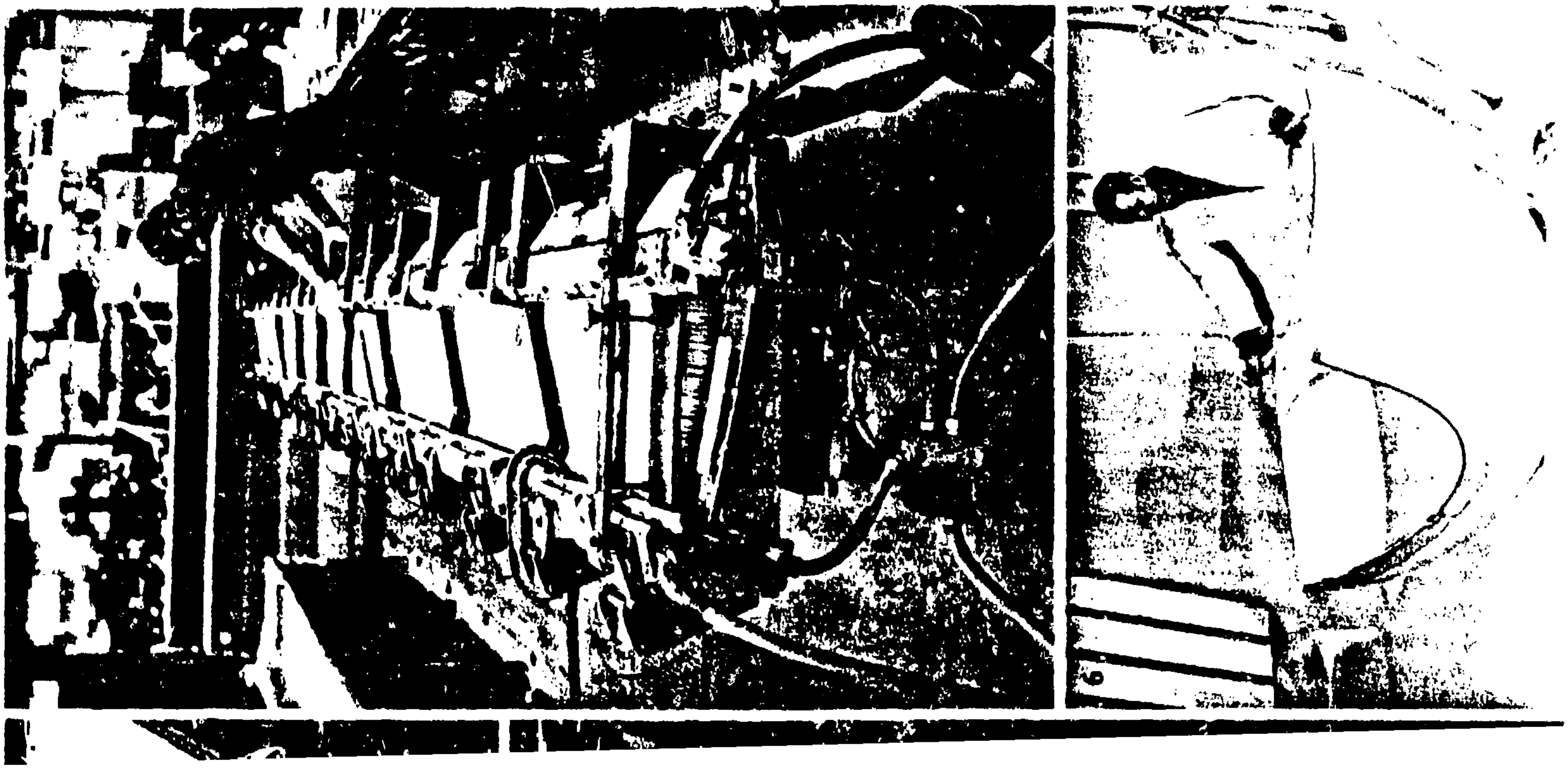


## *Bell quality… thoroughly tested and proved in every product prior to delivery*

Bell has established a single standard of quality with such high priority that the Director of Product Assurance reports to the company Sr.Vice President. Bell's quality equals or exceeds all applicable FAA, military, national and international regulations. Every ship and replacement part or kit must achieve this criterion for all customers. Staffs of engineers, helicopter pilots and experienced quality technicians are stationed in key positions throughout Bell plants. They have the responsibility to confirm that all manufacturing and testing meet Bell's standards of product assurance.

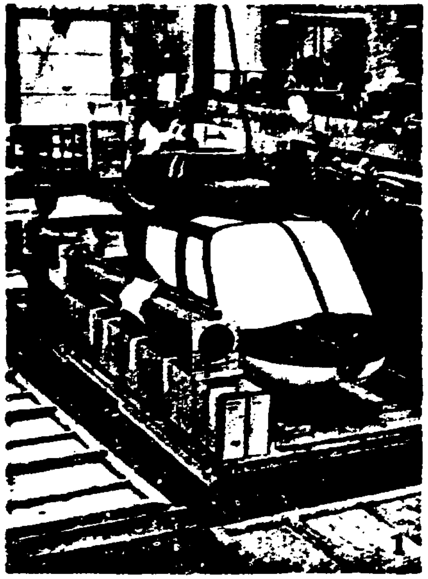
Bell's engineering test pilots are the most demanding pilots in the world. When they're satisfied, you know you have a ship of exceptional performance. These pilots, operating out of Bell's three FAA licensed, tower-controlled heliports, put each Bell through its paces. Power packages, control response, electronic gear, avionic packages, instrumentation and other operating parts of the ship are matched against Bell's "Single Standard of Quality."

1. To guarantee accuracy of helicopter inspection tools and instruments, which must be calibrated to a precision within ten millionths of an inch, Bell Helicopter employs such sophisticated techniques as the Laser Beam Measuring system.
2. Each gear utilized in the helicopter drive system is inspected for tooth-to-tooth spacing and tooth form on the Maag gear measuring machine. This instrument provides both visual and print-out test results which are permanently retained by Bell.
3. A completed transmission is installed and inspected during assembly line operation.
4. All purchased products and materials are evaluated in this environmentally-controlled area to insure exacting standards. This measuring device is used to read minute component contours.



## *Regardless of who buys a Bell, we always think of it as one of ours*

Bell owners can rely on a worldwide service and support system of foreign dealers, representatives and spare parts warehoused all over the world, plus Bell's own field representatives and maintenance instructors. And backing them are dedicated people whose full-time job is to handle requests for parts and service, by way of Bell's round-the clock telephone hot line, and the more than 600 people in Bell's logistics operations who store, package and ship from the multi-million dollar inventory of parts on hand.



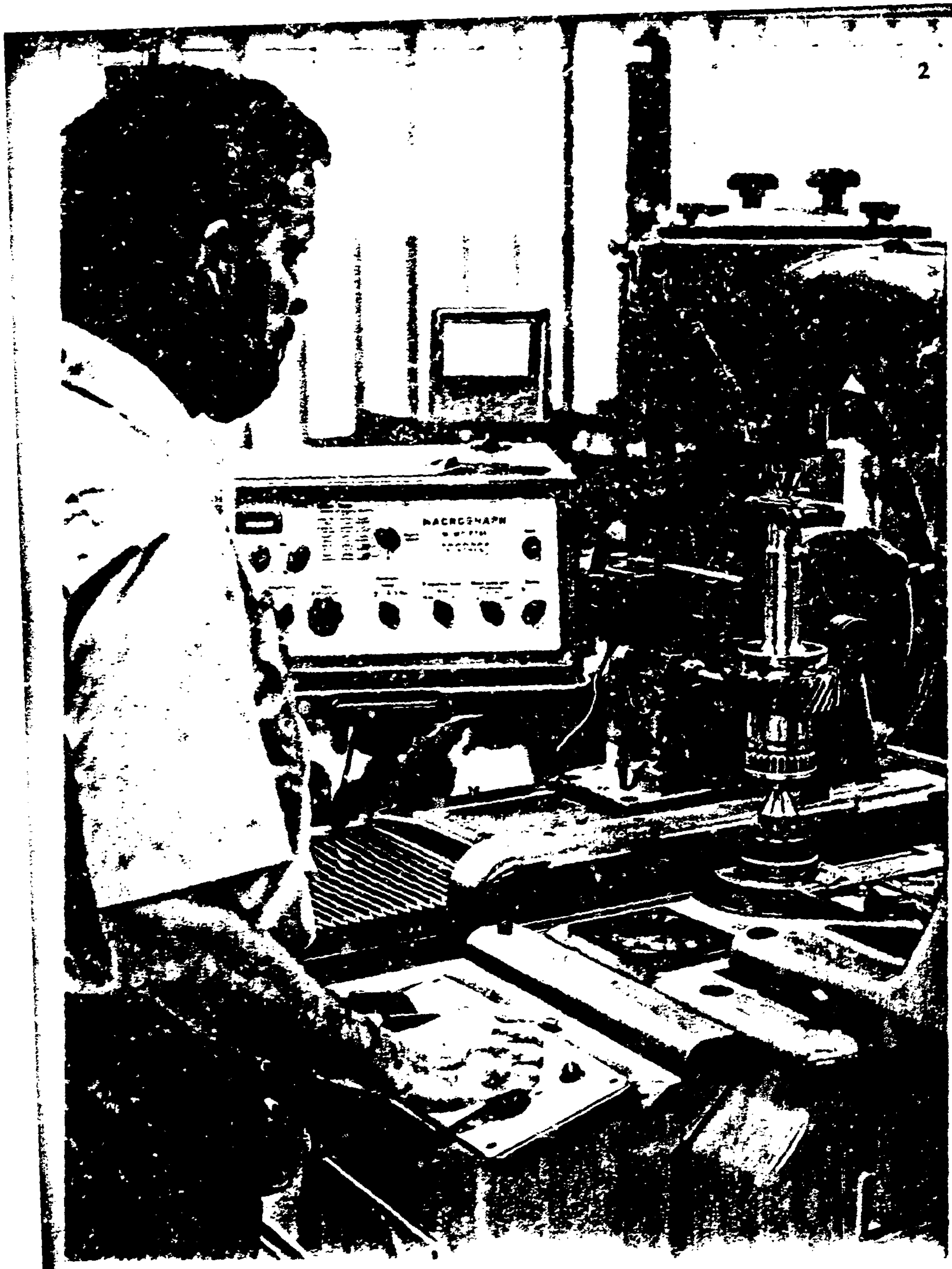
*Bell owners have priority.*

If your aircraft is grounded for need of a part and Bell doesn't have the part in inventory, they will take one away from production.

And, they will get the part on its way in less than 24 hours. Much less usually, because Bell's inventory is 100 per cent computer controlled.

Bell Helicopter Textron knows its customers and the jobs they do. This is the key to providing the kind of effective service support desired by both Bell and its customers.

1. Typical boxing and crating of helicopter for shipment by motor freight.
2. Modern warehousing methods and computer control, aid in meeting customer's urgent and routine demand for spare parts.
3. Overseas shipments are boxed and crated to withstand heavy handling en route.
4. 24 hour telephone service to handle requests for parts and field support.



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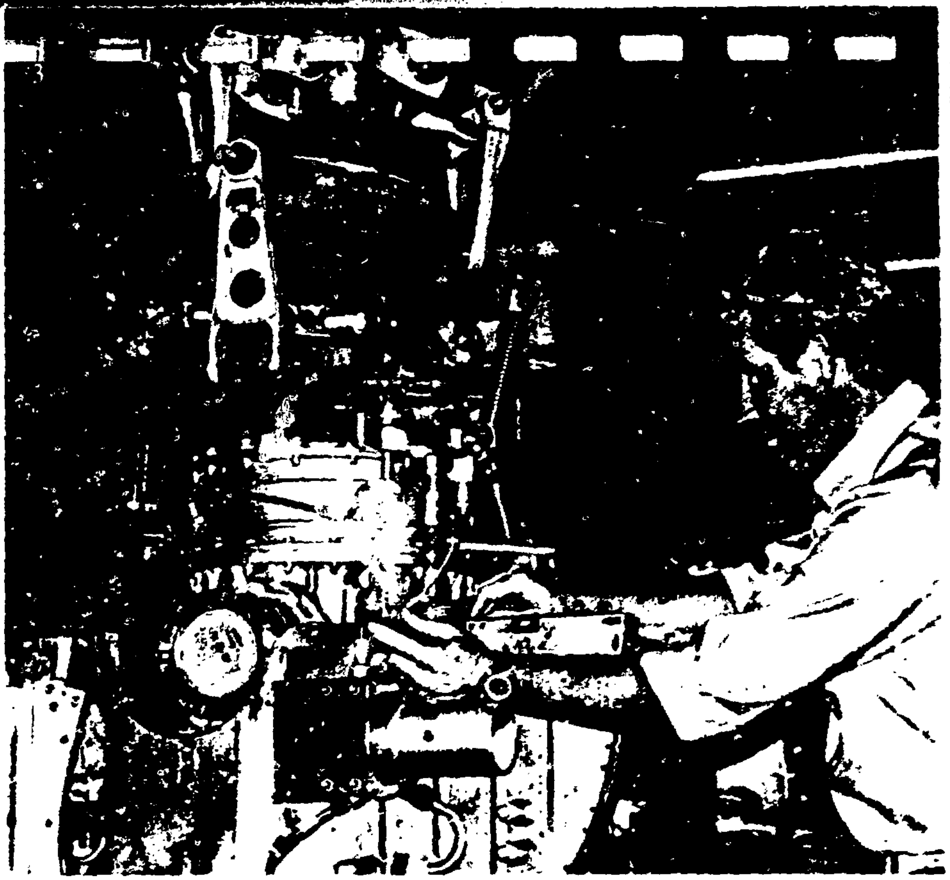

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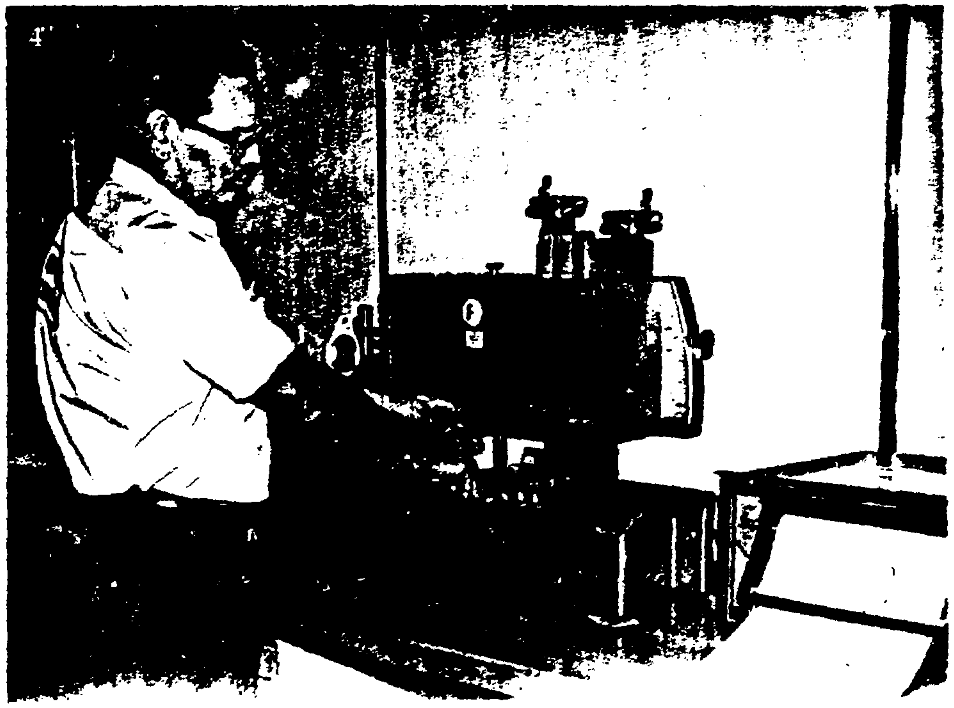


4

## *Professional consideration is evident in every step from flight transition training to delivery check-out*

Bell's Training School and Delivery Center facilities offer the most complete training and customer service available. The facilities include an instruction building housing nine classrooms, a library, training school and pilot office space, new aircraft delivery offices and a customer lounge.

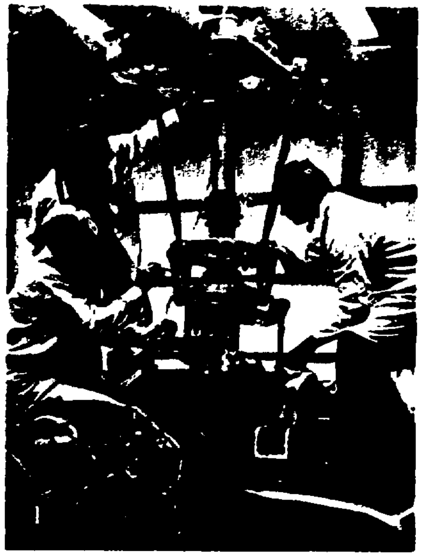
And two hangars. One is utilized by the school to teach complete maintenance and overhaul capabilities on all Bell models. The second hangar stores new aircraft awaiting delivery and serves as a showroom floor for customers.

For the individual seeking training in his Bell helicopter, a wide range of instruction is available.

The Bell Training School is an FAA-certified flight school. Under this program the student may obtain primary, advanced or additional rating courses. He may train either in his own aircraft or utilize one of the company's.

Bell also offers transition flight training, proficiency training and instructor pilot qualification training.

Transition instruction is given when the pilot is taking delivery of an aircraft that is a new model to him. He receives 12 to 16 hours of ground school and up to five hours of flight familiarization.



In the proficiency program the pilot comes to Bell for a refresher course designed to update him on new techniques and to study new manuals. Safety is strongly emphasized in the instruction.

Instructor pilot qualification is aimed primarily at fleet operators with chief pilots. Such pilots receive ground school as in the transition course plus another five hours of flight time in order to obtain an instructor's rating. The new instructor is then given a complete set of Bell-produced instructor guides and teaching aids to conduct his own courses.

The Delivery Center expedites the final steps in the turnover of each new Bell helicopter from the factory to the customer. All paperwork is handled here: the transfer of title, bill of sale, aircraft registration forms, miscellaneous invoices.

All equipment is completely checked out: the engine and airframe manuals, the ground handling equipment.

Between the School and the Delivery Center, everything is done to prepare each Bell helicopter for immediate operation.

1. & 6. Student groups are kept small and work on full-size aircraft equipment.
2. New aircraft awaiting pickup and delivery.
3. At Bell's Training School, students can learn about helicopters in a variety of languages through multi-lingual capabilities.
4. Student pilot receiving flight training.
5. Specialized classrooms utilize motion pictures, slide presentations, overhead projectors, models, cutaways and other visual aids.

3

4

## *Bell management philosophy... a professionally engineered balance of product performance and dependability*

*Design*

Products are designed for overall excellence of performance balanced with dependability, maintainability, survivability. This concept assures cost effective, mission oriented helicopters.

*Quality*

Bell products are quality controlled from concept to completed manufacture. Designs, fabrications, testing, specifications, and final assemblies are closely inspected by highly trained, responsible quality specialists.

*Production*

Bell designs and produces its own rotor blades, transmission gears, drive trains, flight controls, avionics, airframes, tools, and landing gears to exacting, self-imposed standards. Precision gear grinding to a micron tolerance is commonplace. Modern bonding and composite material structures manufacturing techniques are originated, refined, and proven at Bell's uniquely integrated facility, the world's most advanced in the helicopter industry.

*Test*

Bell's test flight heliport complex is the most active in the world. A modern Flight Research Center complete with Quantovac remote flight telemetering data system verifies product integrity. All phases of rotary-wing testing are accomplished with nearly 40 full-time experimental flight vehicles. The Center's foundation is furnished by engineering technical labs: Mechanical, Chemical, Metallurgical, Test Operations, Process, Instrumentation, Methods and Materials, X-Ray, Data Processing, Standards and Calibration.

*Support*

After-sales support is paramount. Through a worldwide logistics network, Bell has established a thorough maintenance, training and spares support system.

For all these reasons . . . from design and production excellence to global service support, more Bell helicopters are flying throughout the world today than all other makes combined.

4

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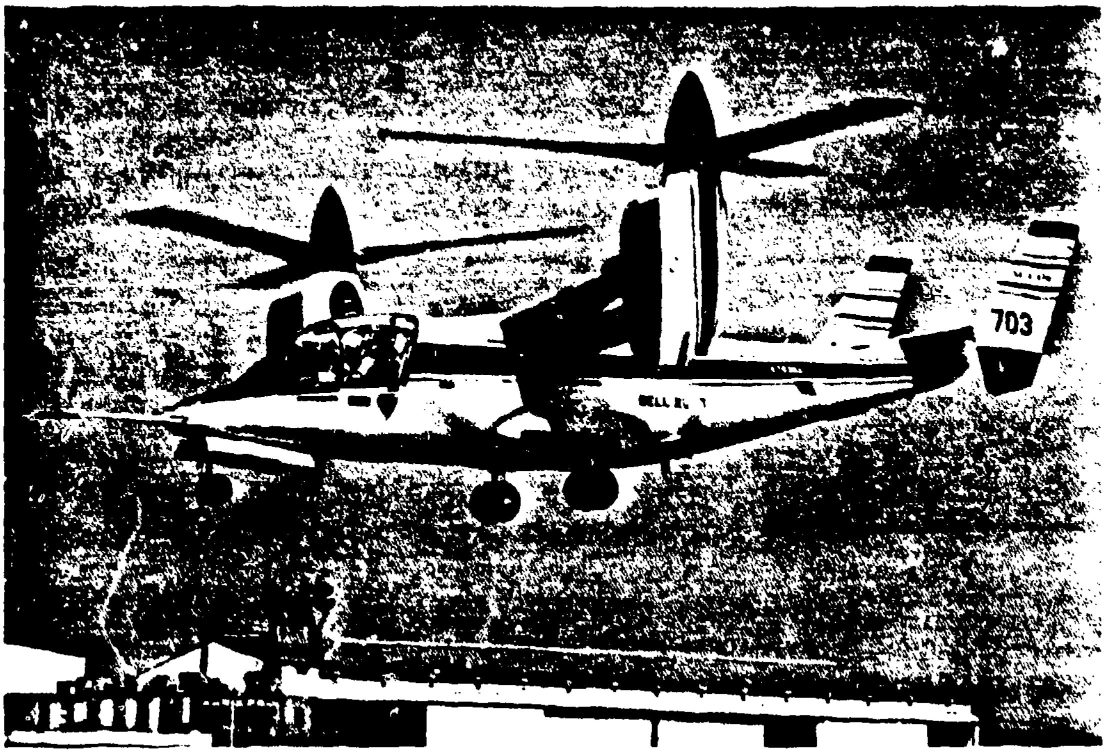
# APPENDIX D

## BELL HELICOPTER TEXTRON
## MODEL 301 TILT-ROTOR AIRCRAFT

# XV-15

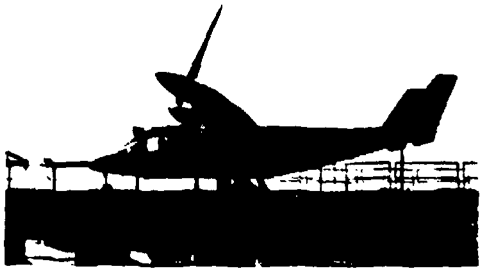
# TILTROTOR PROGRAM

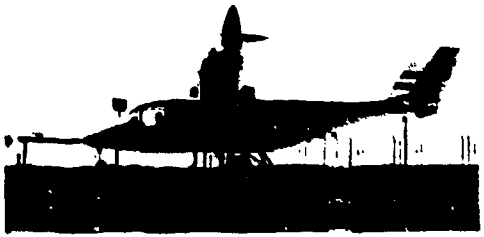


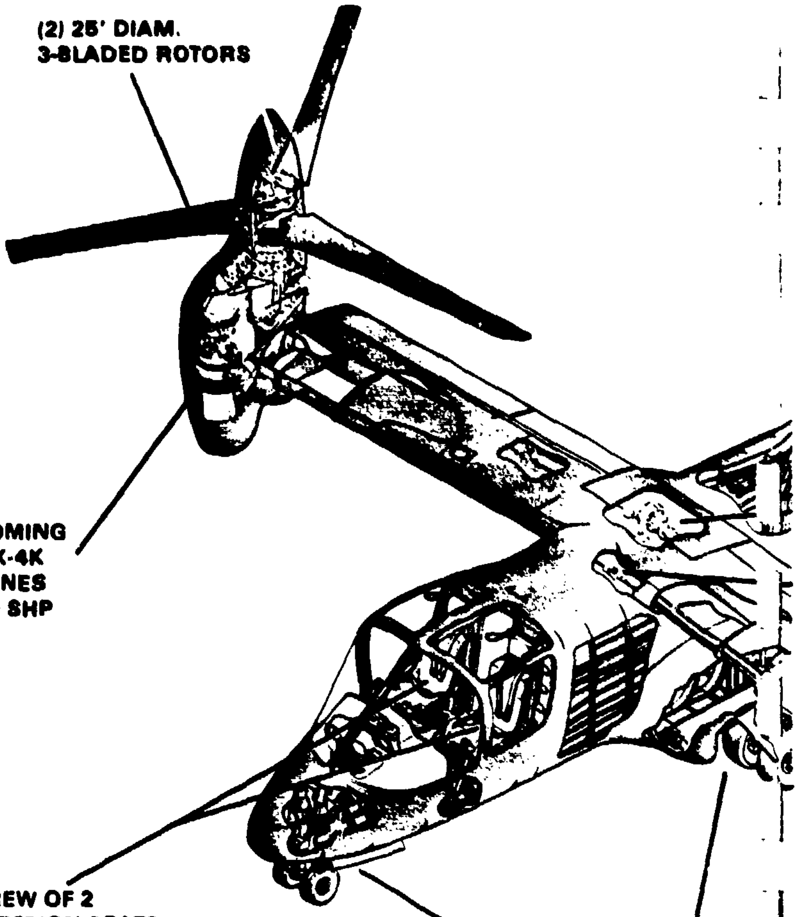
Bell Helicopter TEXTRON

Division of Textron Inc

# BELL TILT ROTOR

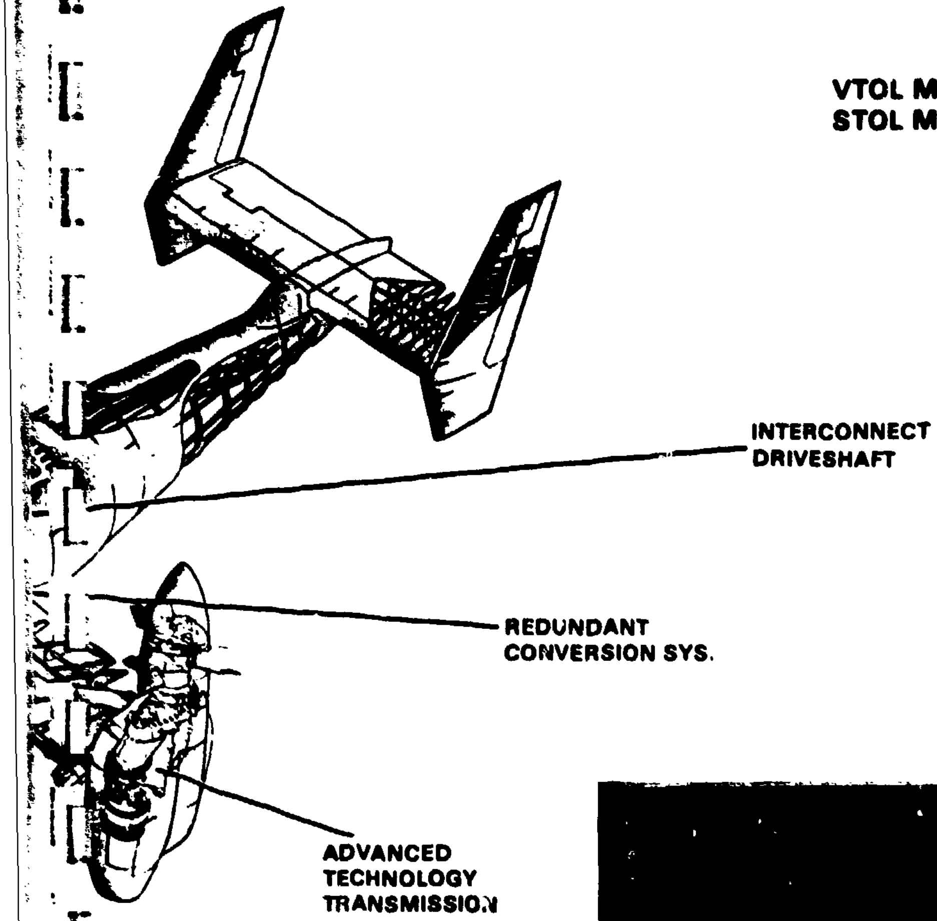


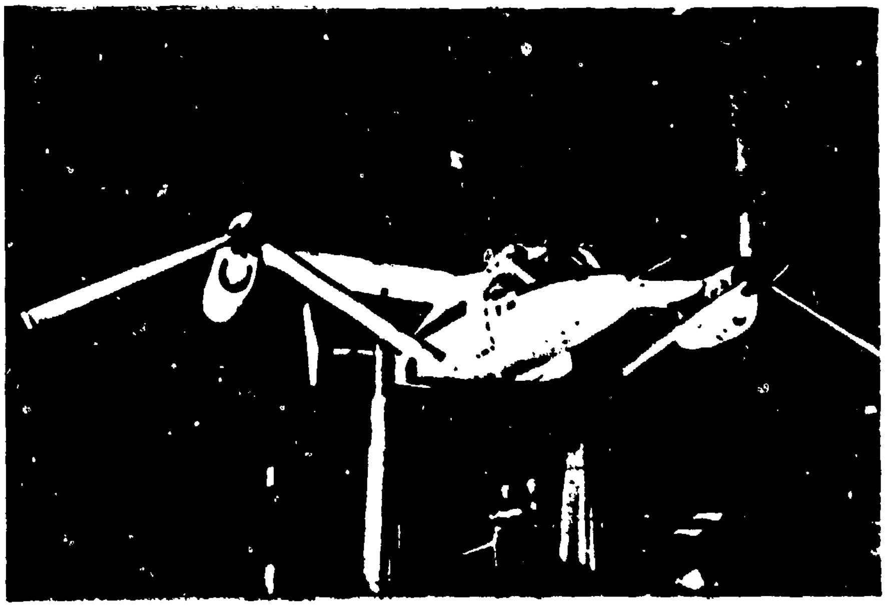



(2) 25' DIAM.
3-BLADED ROTORS
LYCOMING
LTCIK-4K
ENGINES
1550 SHP
CREW OF 2
EJECTION SEATS
RETRACTABLE
LANDING GEA

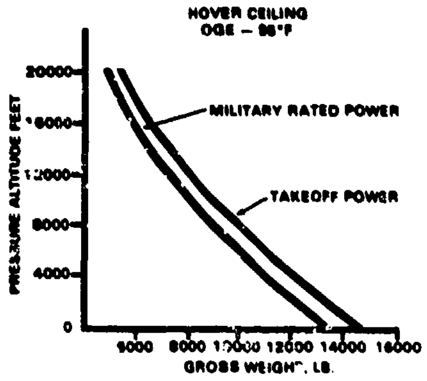
|  |  |
|---|---|
| LONG RANGE CRUISE: | 265 KTAS |
| MAX. SPEED: | 335 KTAS |
| ALTITUDE CEILING: | 30,000 FT. |

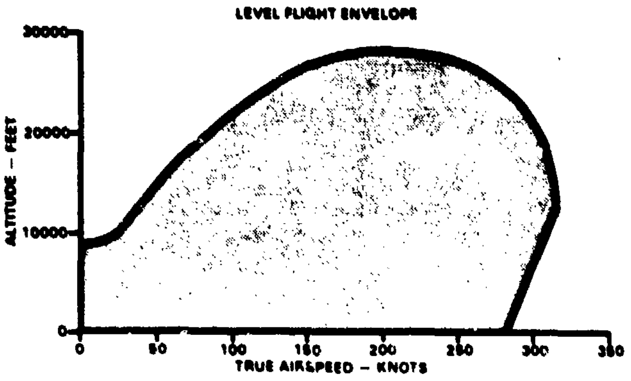
|  |  |
|---|---|
| VTOL MAX G.W. | 13000 LB. |
| STOL MAX G.W. | 1500 LB. |

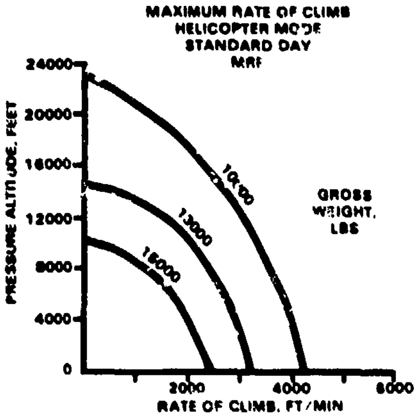

INTERCONNECT DRIVESHAFT
REDUNDANT CONVERSION SYS.
ADVANCED TECHNOLOGY TRANSMISSION

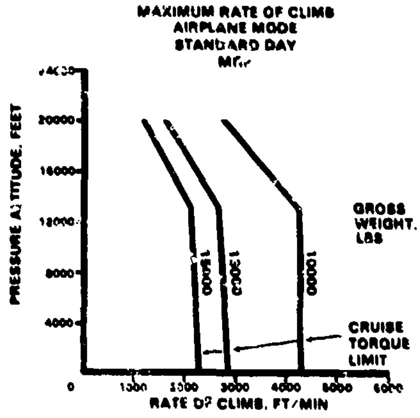


# PERFORMANCE


HOVER CEILING
OGE – 95°F

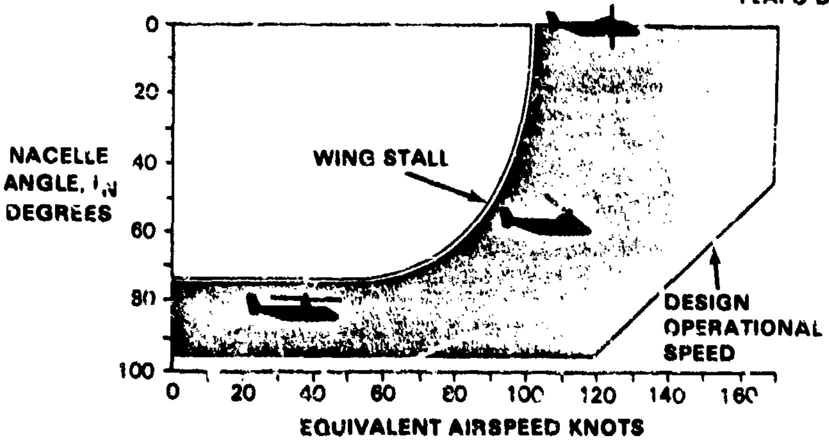

LEVEL FLIGHT ENVELOPE

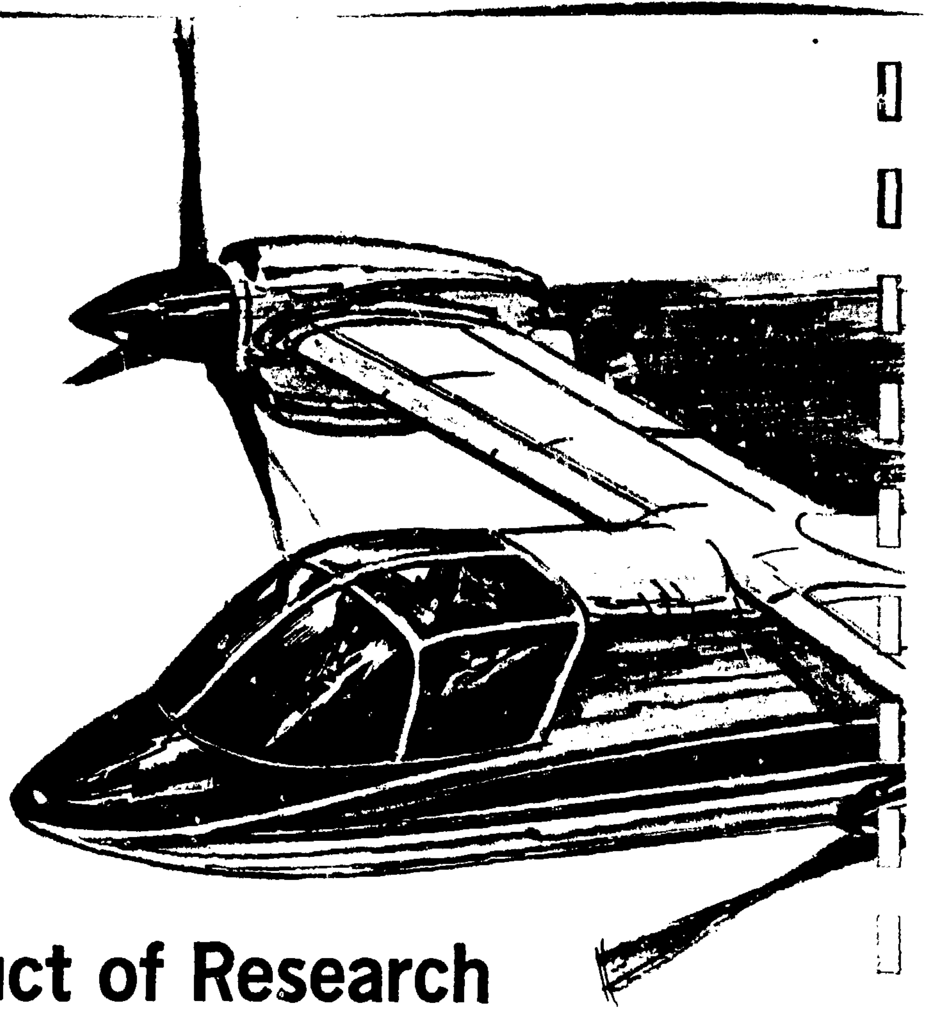

MAXIMUM RATE OF CLIMB
HELICOPTER MODE
STANDARD DAY
MRP


MAXIMUM RATE OF CLIMB
AIRPLANE MODE
STANDARD DAY
MRP

# XV-15 CONVERSION CORRIDOR

LEVEL FLIGHT
GROSS WEIGHT = 13,00
FLAPS DOWN 40°





# Model 301 Tilt Rotor Aircraft...

## ...A Product of Research

In **April 1973**, the National Aeronautics and Space Administration and the United States Army announced that Bell Helicopter Company was selected to design and manufacture two tilt-rotor research aircraft. The vehicle Bell will build, designated the **Model 301**, is designed to explore, through flight research, the state of tilt rotor technology and its potential in civil and military missions.

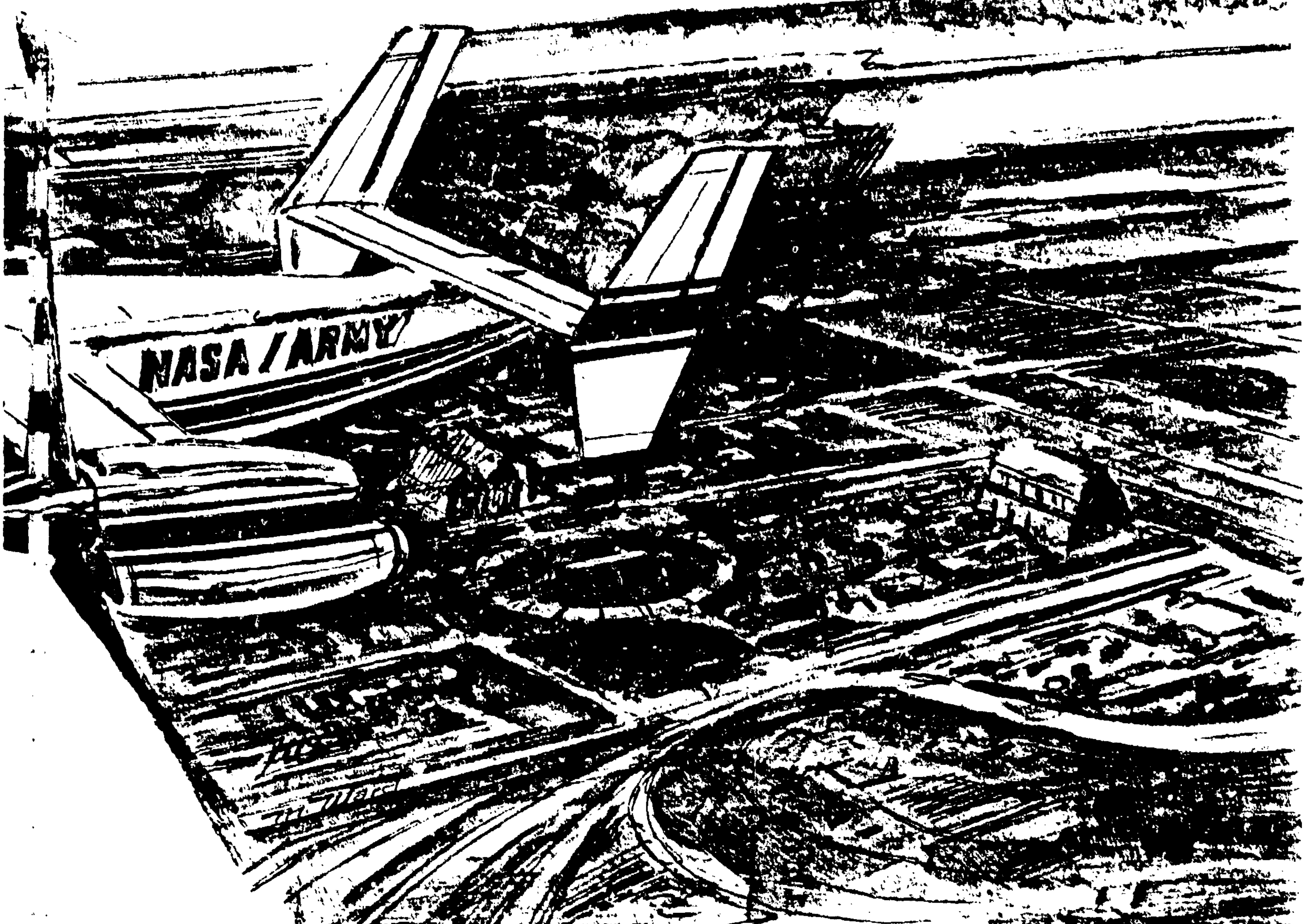
Primary research objectives for the NASA/Army program are contained in a series of **proof-of-concept** tests designed to investigate the technical value of the tilt rotor concept. **Dynamic stability** and **aircraft performance** over the entire operational envelope will be evaluated to verify the prediction methods used in analyses.

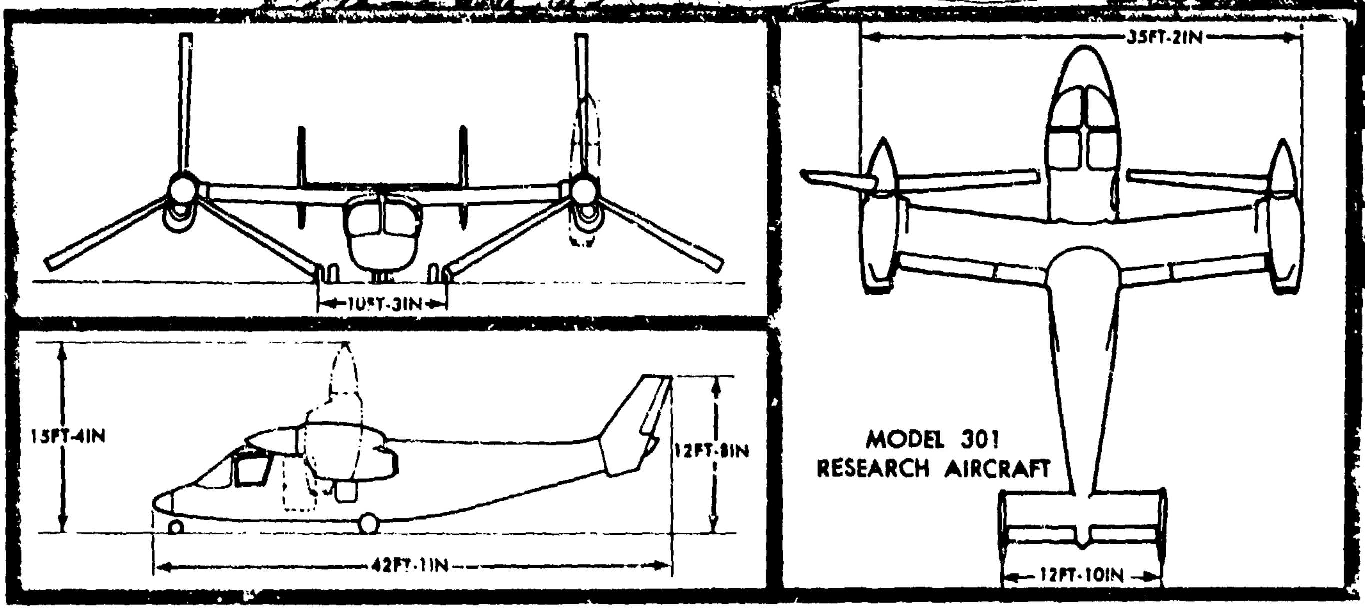
A **safe operating envelope** will be established and assessment of **handling qualities** will be conducted for advanced flight research. Noise, gust sensitivity, and maintenance characteristics will be explored.

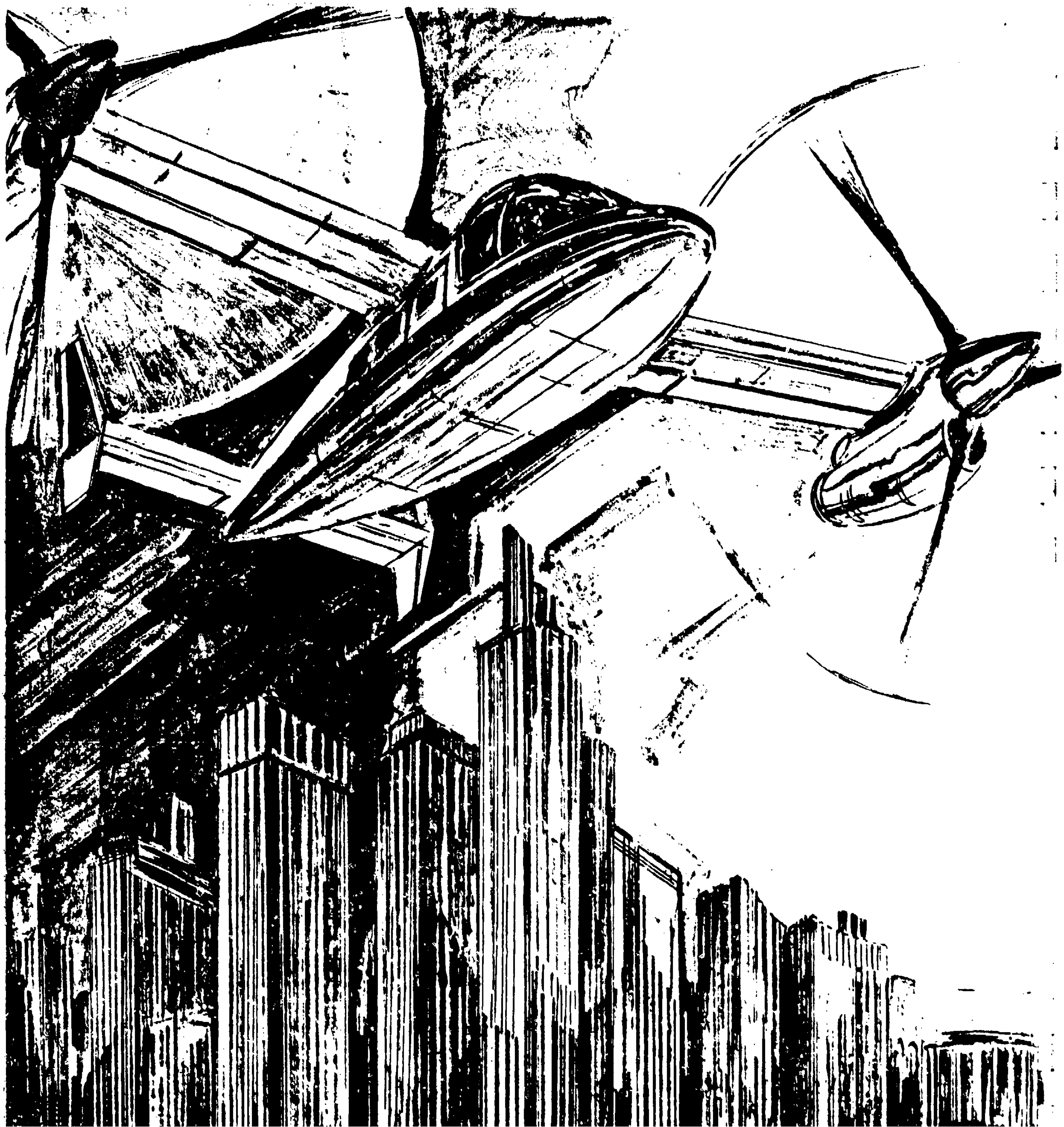
The Model 301 Tilt Rotor Aircraft has a **design gross weight of 13,000 pounds** and a maximum gross weight of 15,000 pounds. It can hover out-of-ground effect at 7700 feet with both engines or on a single engine at sea level. Cruise **speeds will exceed 300 knots** in level flight and 360 knots in a shallow dive.

Each wing tip nacelle contains a Lycoming LTC1K-4K engine. This engine, designed to permit vertical operation, has a normal rating of 1290 SHP and a takeoff rating of 1550 SHP. A 2 minute rating at 1760 SHP will permit a range of testing under single engine conditions.

The model 301 utilizes a rotor and transmission system designed and fabricated under a Bell IR&D program. Design characteristics include a forward-swept high wing, a clean fuselage with retractable landing gear, and a large volume H-tail. For the research phase, crew ejection seats are incorporated.


NASA / ARMY


10FT-3IN
15FT-4IN
12FT-8IN
42FT-11IN
35FT-2IN
MODEL 301
RESEARCH AIRCRAFT
12FT-10IN



# TILT ROTOR AIRCRAFT . . .

## The Optimum In VTOL Mission Effectiveness

A Tilt Rotor Aircraft combines the helicopter's hovering advantages with good forward flight performance. It uses large, slow-turning rotors, which give excellent efficiency in both flight regimes. **Low disc loading** is the characteristic that makes a tilt rotor the optimum VTOL design. Lower disc loading means higher hovering efficiency — more lift per horsepower. For this reason, the helicopter is the most efficient vertical lift aircraft. Second in efficiency is the tilt rotor which trades a small amount of hover capability for more than twice the helicopter's cruise speed.

Many VTOL aircraft have been developed using high disc loading which favors achieving high speed flight at a sacrifice in hover capability. As noted on the chart below, fan-in-wing, tilt-wing and direct jet thrust aircraft require considerably more power to hover than the tilt rotor. In order to obtain high cruise speeds, these aircraft accept severe limitations in true VTOL mission versatility due to inefficient hovering and low speed performance.

Ground operations under a hovering VTOL are more practical when the downwash velocity is low. High disc loading creates extremely high downwash velocities, thereby reducing visibility in unprepared areas and making ground operation hazardous. The low downwash velocity of the tilt rotor allows helicopter-like operation in unprepared areas.

Low speed maneuverability is similar to that of a helicopter. Pilot workload is low, permitting attention to be directed to accomplishment of the mission.

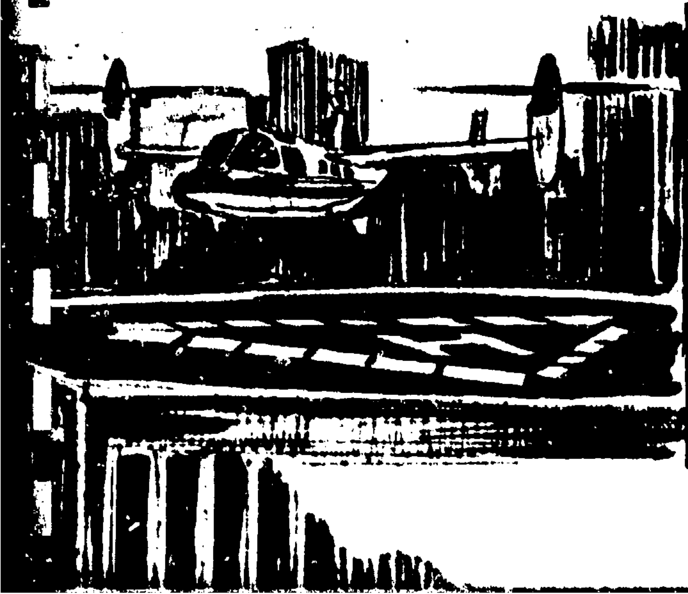
An important safety aspect of the tilt rotor is its autorotation capability. This power-off landing maneuver is a safety feature unique to low disc loading aircraft.

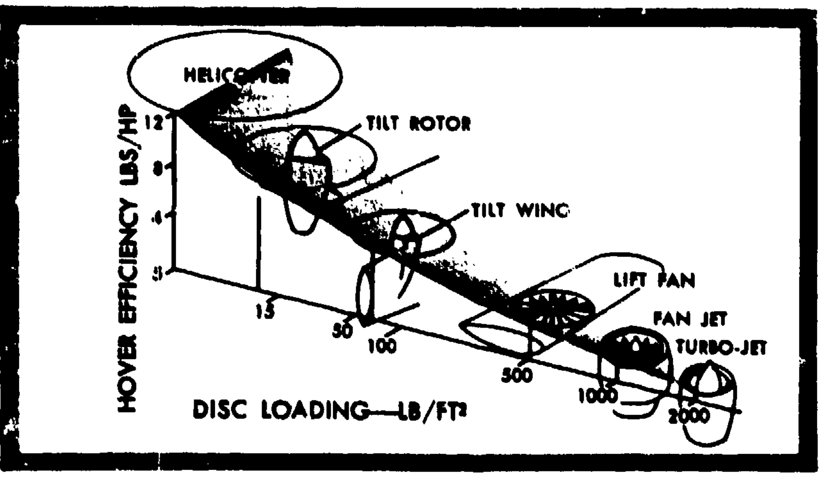
### Lifts Like A Helicopter . . .

Low disc loading permits the tilt rotor to **hover at low power**, with resultant lower fuel consumption, than any other type VTOL except the helicopter. This high hovering efficiency means more payload and increases the tilt rotor's usefulness as a cargo or personnel carrier.

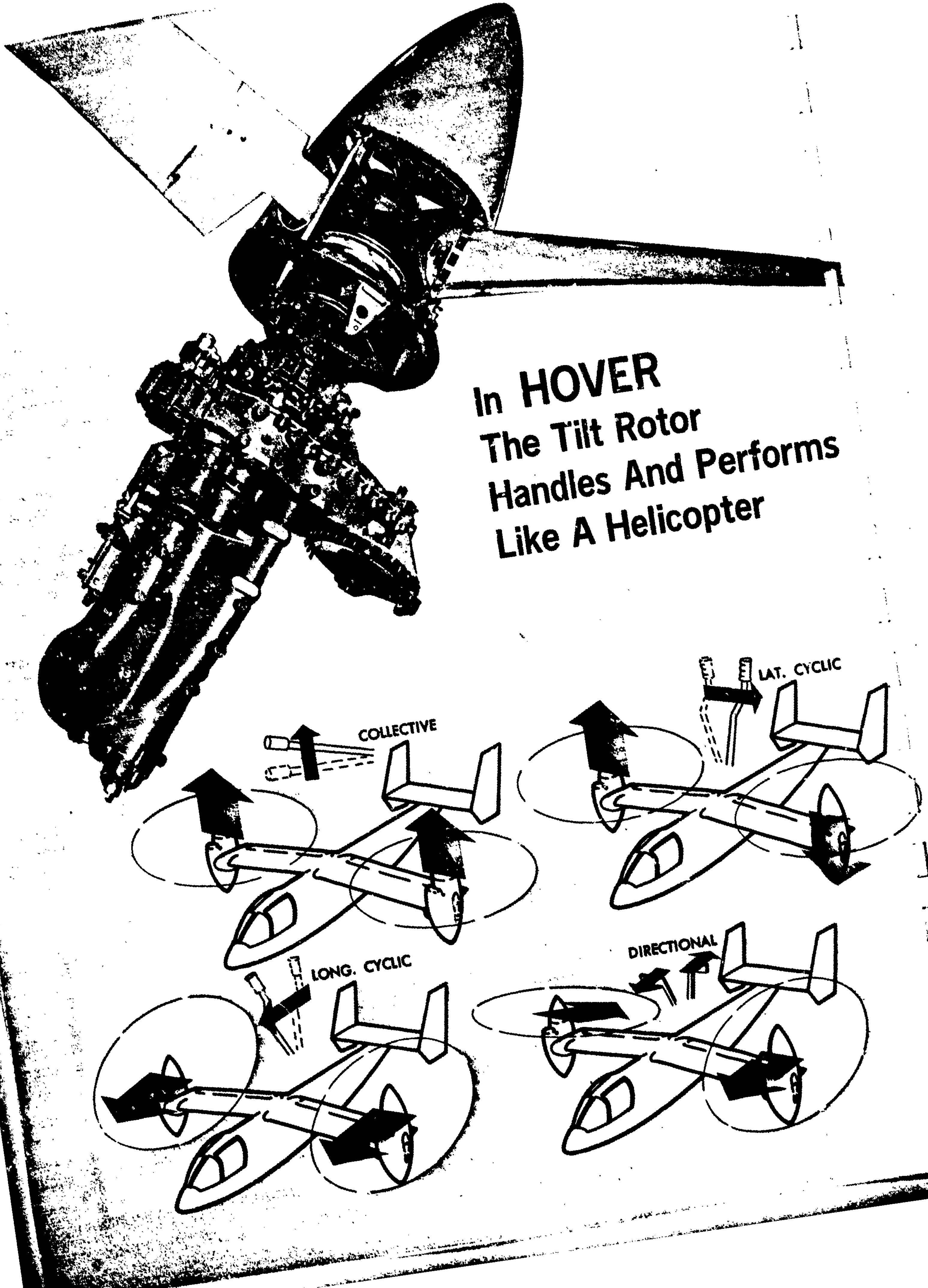
### And Flies Like An Airplane . . .

In forward flight, with the rotors in the airplane mode, high propulsive efficiency provides cruise speeds in the range of conventional turboprop aircraft. The tilt rotor will fly at any speed from 35 knots sideward or rearward to over 300 knots forward. Model wind tunnel testing has confirmed performance estimates throughout this speed range.





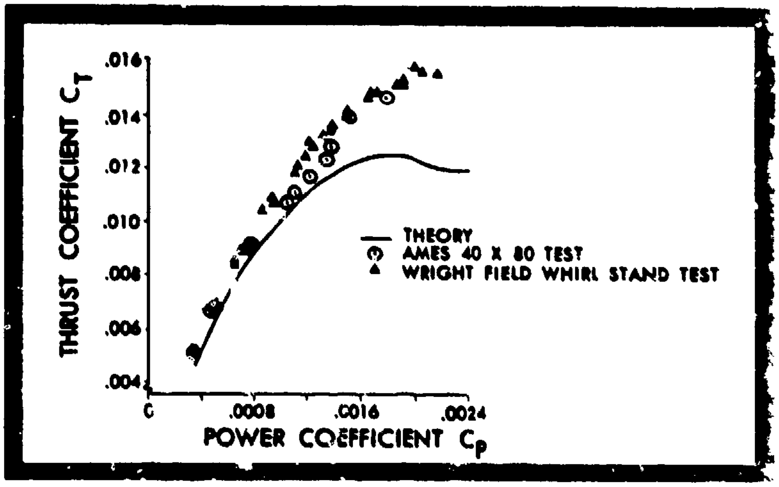
# In HOVER The Tilt Rotor Handles And Performs Like A Helicopter


COLLECTIVE
LAT. CYCLIC
LONG. CYCLIC
DIRECTIONAL

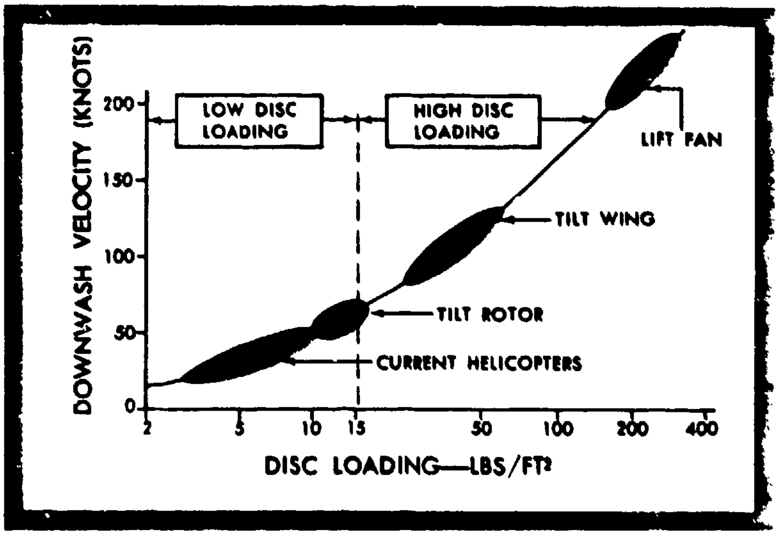
**Conventional cyclic and collective controls** provide helicopter-type handling qualities in hover and low speed forward flight. Lift is controlled by varying collective pitch and longitudinal control is effected through fore-and-aft cyclic as in a conventional helicopter. Lateral control is obtained by differential collective and yaw by differential cyclic. No auxiliary thrust/control devices are required.

A stability and control augmentation system provides enhanced handling qualities for IFR and confined area operations.

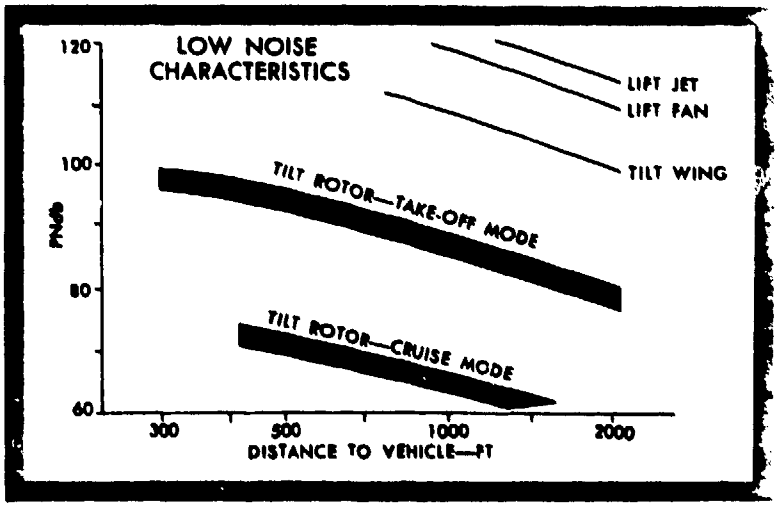
Pilots with helicopter experience will transition easily to the tilt rotor aircraft. Forward flight to conversion speeds as well as sideward and rearward flight are identical to helicopter operations. Conversion requires about the same amount of attention as management of flaps and landing gear.



Recent hover performance tests have shown the highly twisted rotor to have 7% greater thrust efficiency than predicted. Hover performance and low speed maneuverability will exceed theoretical estimates.

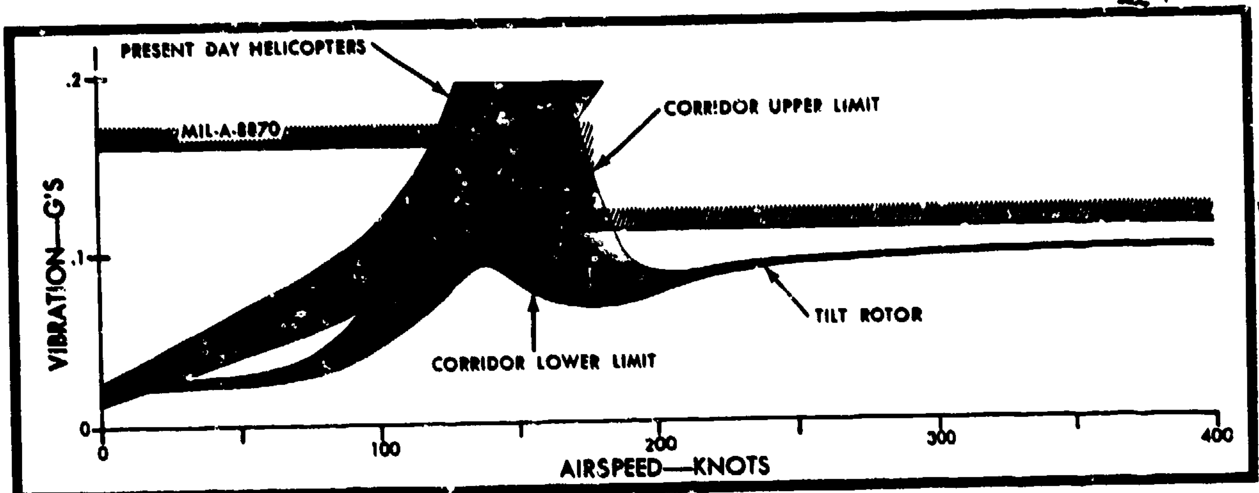


Disc loadings less than 15 psf generate low downwash velocities. Thus, the tilt rotor can operate from unprepared areas the same way as a helicopter. VTOL types with higher disc loadings generate increasingly higher wake velocities with resultant surface erosion, recirculation of debris and hazard to ground personnel.

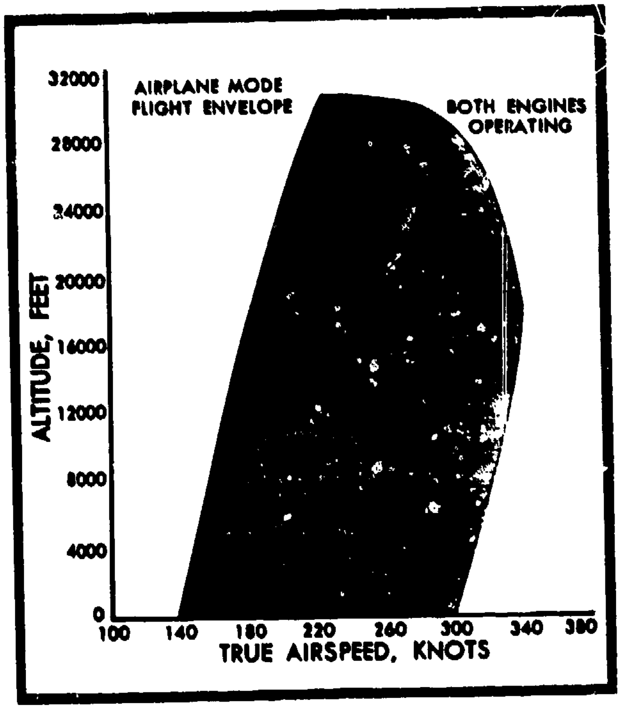


Its low tip speed will make the tilt rotor the quietest of the high speed VTOL's. With low downwash and low noise level, the tilt rotor will be found acceptable for terminal operations in noise sensitive areas.

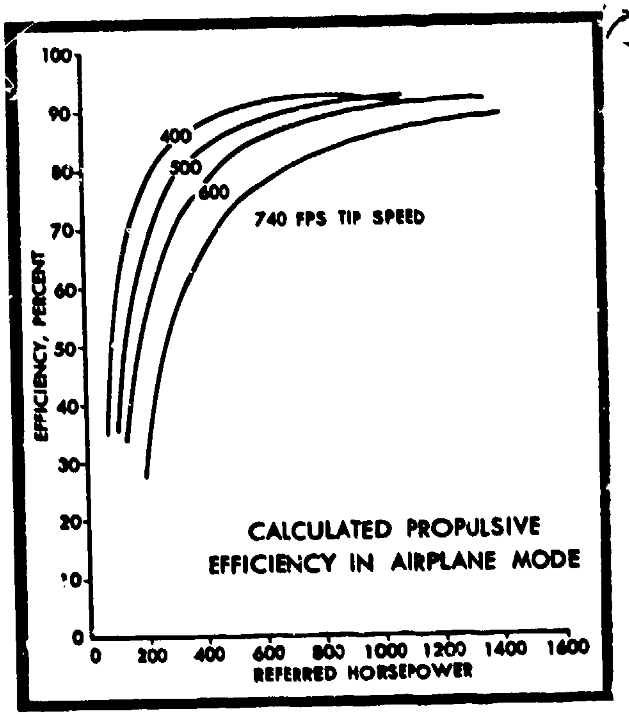
# In FORWARD FLIGHT
## Ride Qualities, Speed And Safety Are Like A Turboprop Airplane



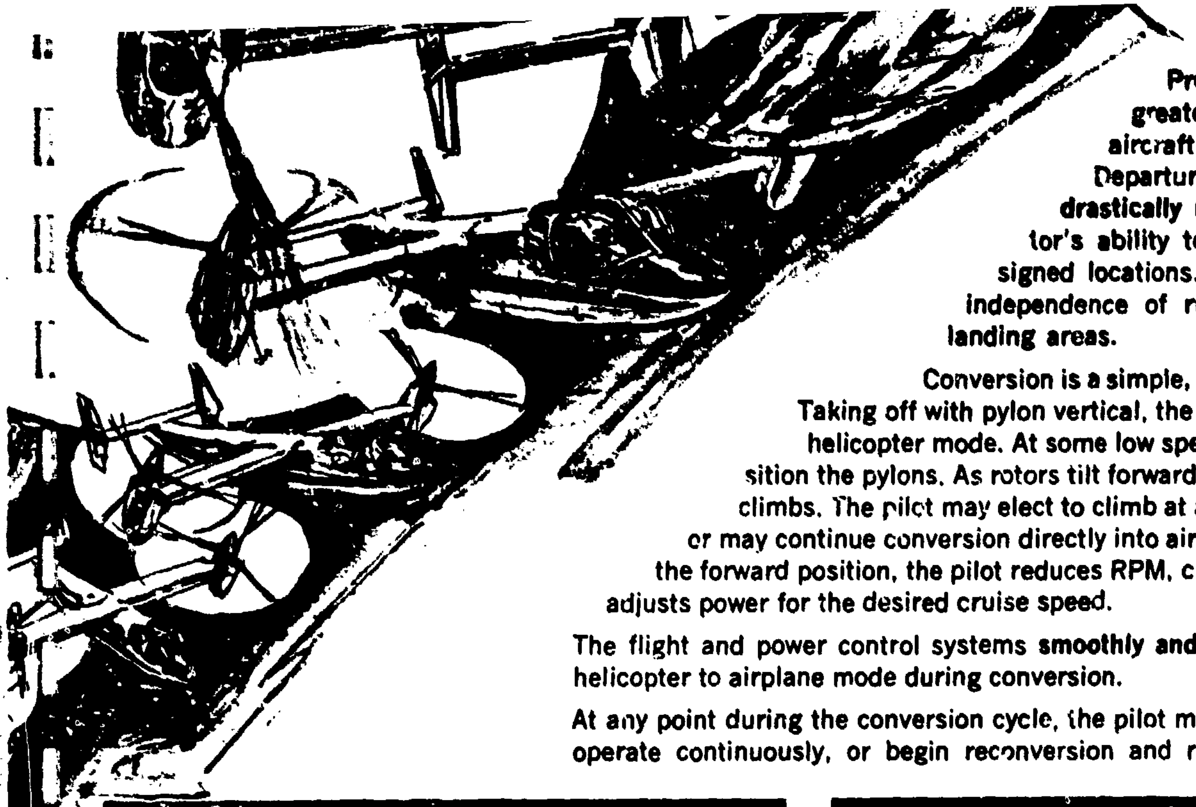
Since the wing is not required for take-off and landing, the tilt rotor design incorporates higher wing loading (smaller wing) than that of a comparable sized airplane. This reduces high speed drag, thereby increasing cruise performance. Higher wing loading also decreases gust sensitivity. With the rotors, engine and transmission isolated at the tip of the wing, negligible vibration is transmitted into the fuselage. Ride qualities are comparable to executive turboprop aircraft and superior to present day helicopters.



A typical tilt rotor flight envelope shows cruise speeds of up to 300 knots at cruise altitude. With one engine out, over 220 knots can be sustained. These speeds are in the same range as executive turboprop aircraft.



Propulsive efficiency of the large diameter rotors in forward flight is greater than for jets and is comparable to a well-designed propeller. Peak efficiencies above 90% have been measured with normal cruise efficiencies in the range of 75-80%. This means both higher cruise speeds and increased range.

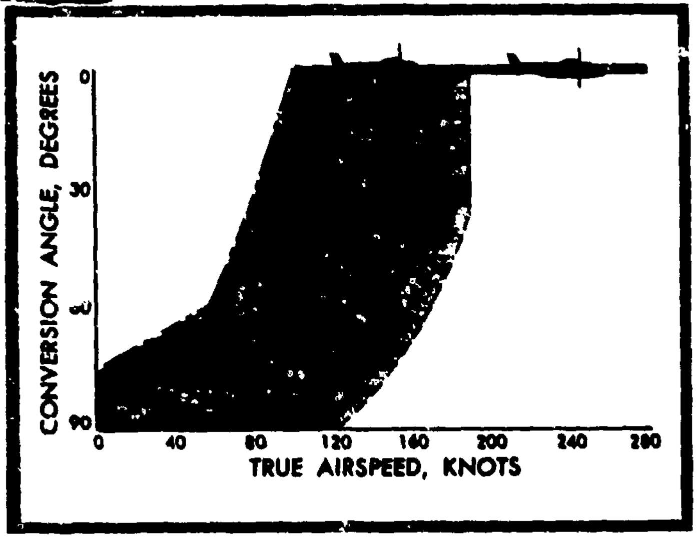


Productivity of the tilt rotor is greater than that of conventional aircraft due to its VTOL capability. Departure-to-destination time is drastically reduced due to the tilt rotor's ability to take-off and land at designed locations. It shares the helicopter's independence of runways or other prepared landing areas.

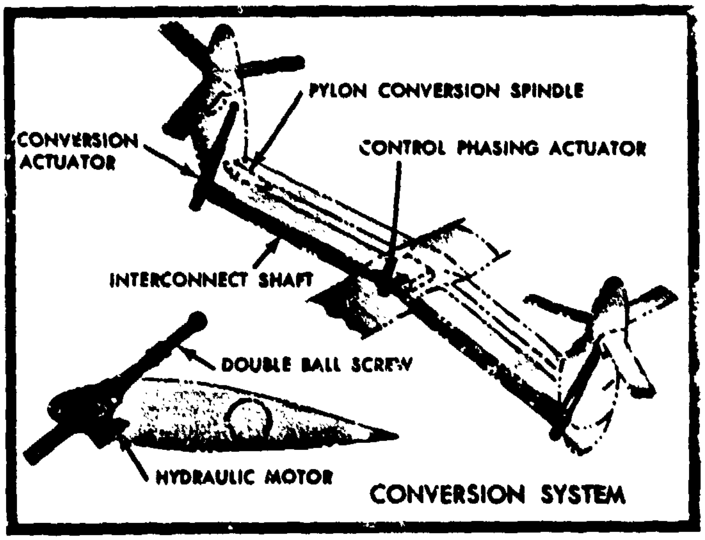
Conversion is a simple, straight-forward maneuver. Taking off with pylon vertical, the aircraft then accelerates in helicopter mode. At some low speed the pilot begins to transition the pylons. As rotors tilt forward, the aircraft accelerates or climbs. The pilot may elect to climb at an intermediate mast angle or may continue conversion directly into airplane mode. With pylons in the forward position, the pilot reduces RPM, climbs to cruise altitude and adjusts power for the desired cruise speed.

The flight and power control systems smoothly and automatically phase from helicopter to airplane mode during conversion.

At any point during the conversion cycle, the pilot may stop the conversion and operate continuously, or begin reconversion and return to helicopter mode.



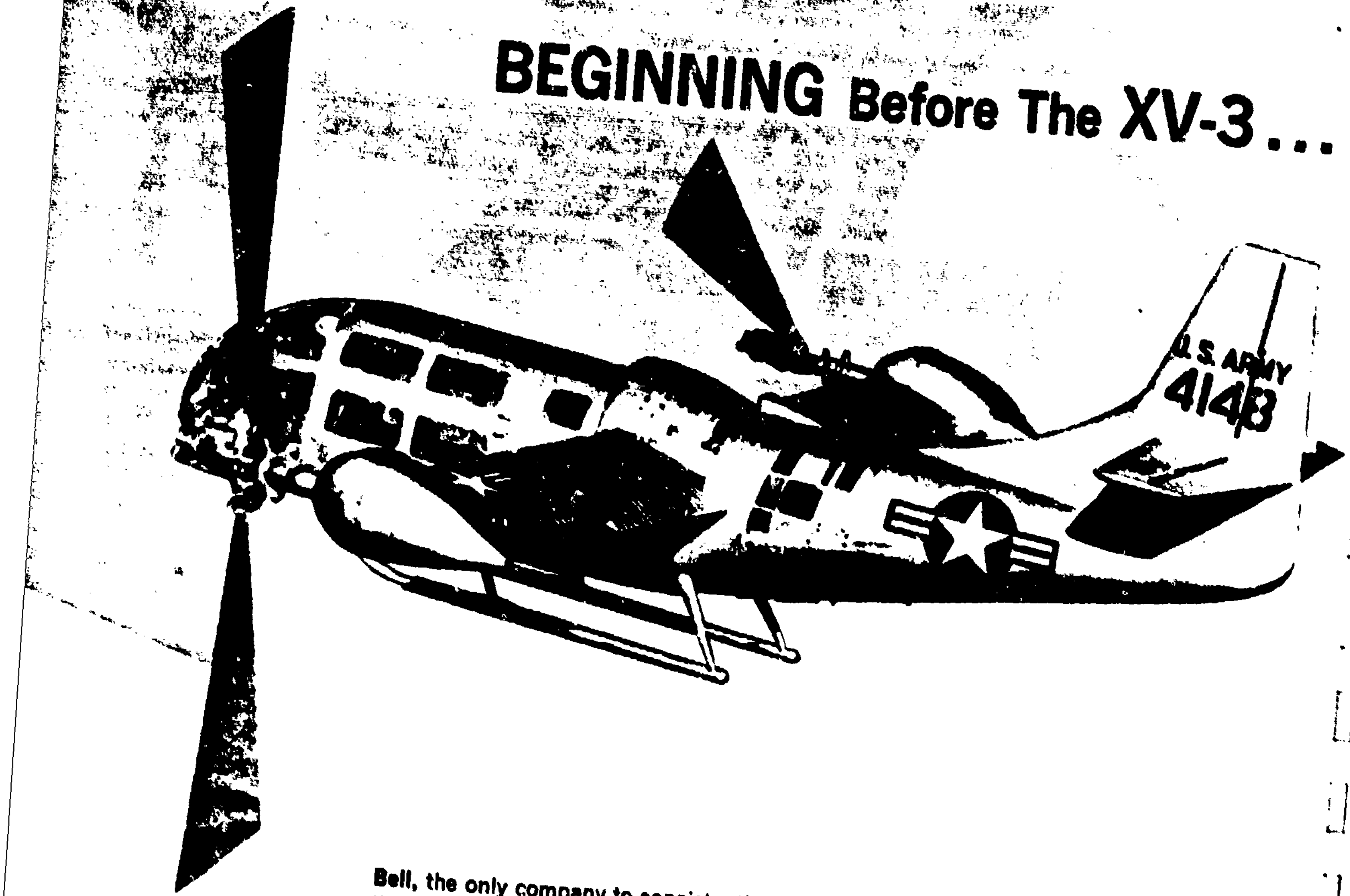
The conversion and reconversion corridor of the tilt rotor aircraft is over 80 knots wide. This gives the pilot a wide latitude in performing his conversion maneuver. Unlike for many VTOL aircraft types, there is no rigid conversion schedule which must be followed. Continuous flight is possible at any point in the corridor.



Dual redundant hydraulic systems and an electrical back-up provide a fail-safe conversion system for the tilt rotor aircraft. Either of two actuator drive motors or either of two hydraulic pumps could power the conversion of both pylons through hydraulic and mechanical interconnections.

In the event of total engine power failure in high speed airplane mode, the pilot can safely reduce airspeed into the conversion corridor, convert, and perform a normal helicopter-like autorotation.

# BEGINNING Before The XV-3 . . .



**Bell**, the only company to consistently pursue and support the tilt rotor concept, brings over 25 years of testing, analyses, design, flight test experience and hardware to the Model 301 tilt rotor program.

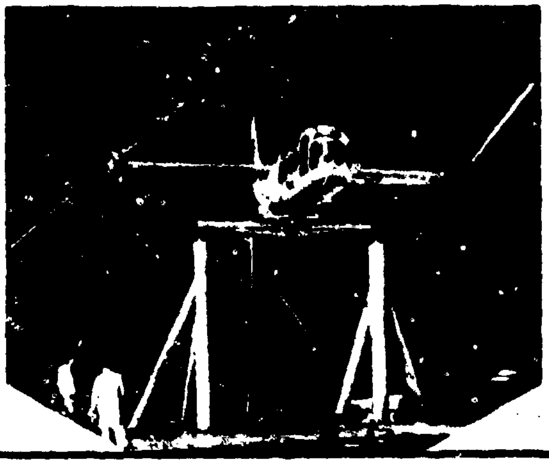
In 1951, Bell received a contract to build the XV-3 tilt rotor aircraft under a joint Air Force-Army program. Over 100 successful conversions were made in 125 hours of flight tests. The aircraft proved the concept feasibility and safety features inherent to the design.

For the Model 301, several years of analyses, model testing, and development and testing of critical components has gradually reduced the program risk. Full-scale flightworthy rotors and transmissions have been thoroughly and successfully tested.

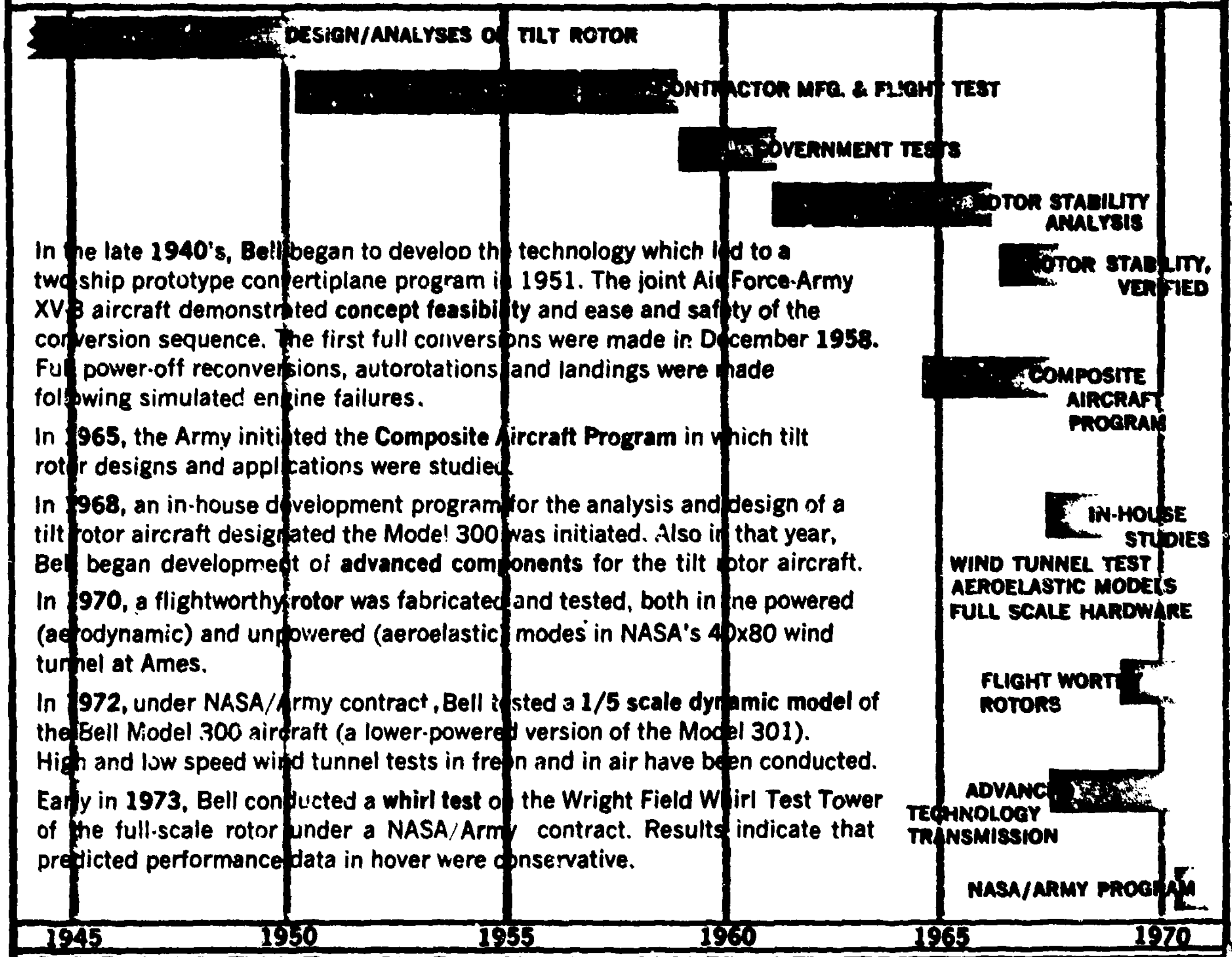
Over 15 separate model and full-scale wind tunnel tests have been conducted to determine the aerodynamic and aeroelastic parameters necessary to complete the design of the tilt rotor aircraft.

All necessary work prior to final detail aircraft design has been completed.

# ... Bell's 25 Years Of Tilt Rotor Experience Is Focused On The Model 301



## A CHRONOLOGY OF TILT ROTOR PROGRESS



In the late **1940's**, Bell began to develop the technology which led to a two-ship prototype convertiplane program in 1951. The joint Air Force-Army XV-3 aircraft demonstrated **concept feasibility** and ease and safety of the conversion sequence. The first full conversions were made in December **1958**. Full power-off reconversions, autorotations and landings were made following simulated engine failures.

In **1965**, the Army initiated the **Composite Aircraft Program** in which tilt rotor designs and applications were studied.

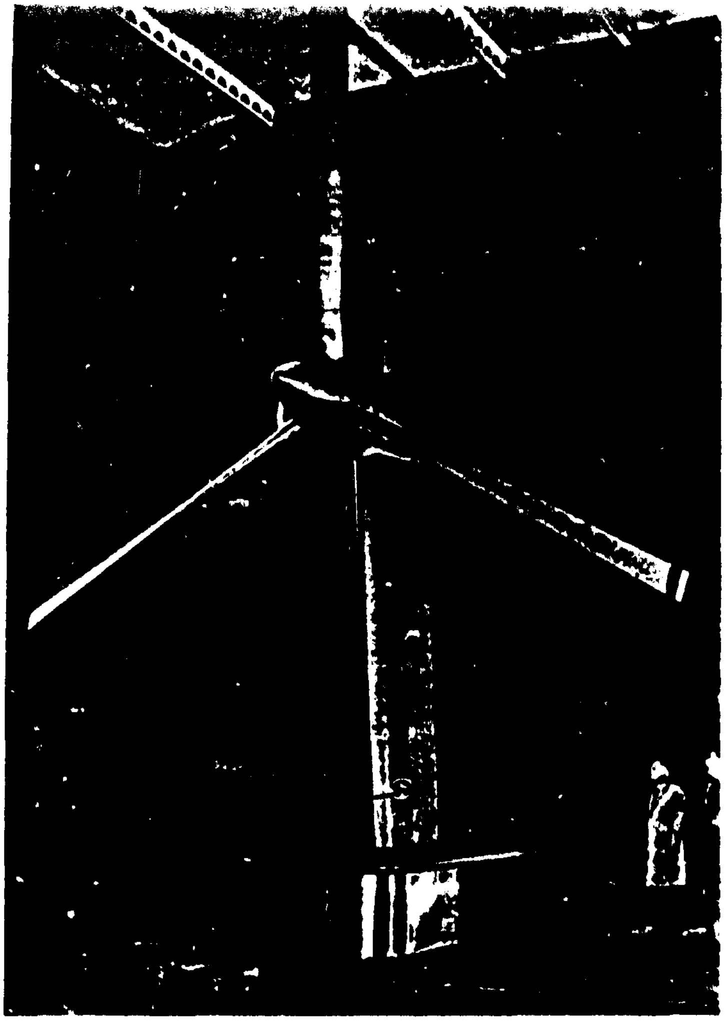
In **1968**, an in-house development program for the analysis and design of a tilt rotor aircraft designated the Model 300 was initiated. Also in that year, Bell began development of **advanced components** for the tilt rotor aircraft.

In **1970**, a flightworthy **rotor** was fabricated and tested, both in the powered (aerodynamic) and unpowered (aeroelastic) modes in NASA's 40x80 wind tunnel at Ames.

In **1972**, under NASA/Army contract, Bell tested a **1/5 scale dynamic model** of the Bell Model 300 aircraft (a lower-powered version of the Model 301). High and low speed wind tunnel tests in freon and in air have been conducted.

Early in **1973**, Bell conducted a **whirl test** of the Wright Field Whirl Test Tower of the full-scale rotor under a NASA/Army contract. Results indicate that predicted performance data in hover were conservative.

**Thus, over 25 years of tilt rotor experience has been accumulated at Bell. This knowhow will now be applied to the Army/NASA flight research program.**



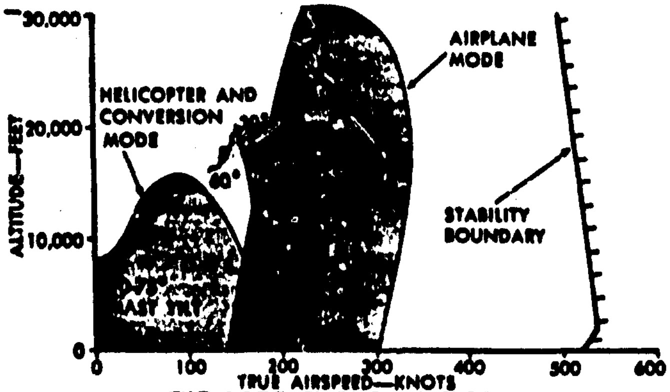
# FOUR YEARS' DEVELOPMENT

## Verifies Rotor Design For Structure, Performance And Stability

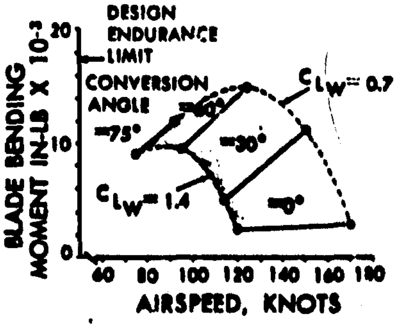
In 1968, Bell began development of a full-scale 25′ diameter 3-bladed prop-rotor. A gimbaled hub design with high in-plane stiffness was selected to achieve inherent mechanical stability, load reducing characteristics and simplicity. An elastomeric hub spring provides increased control power and damping, particularly in low speed flight.

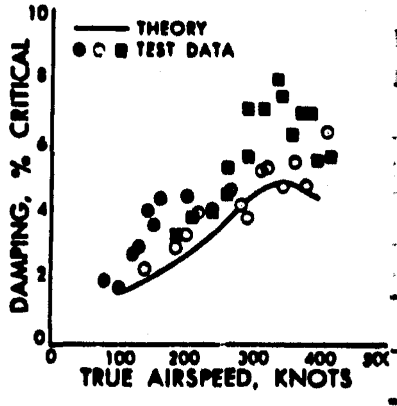
Aeroelastic tests verified that blade loads are below the design limit throughout the flight envelope, including the conversion corridor. Dynamic rotor/pylon stability investigations in model and full-scale tests indicate that the rotor is stable and flutter-free with margins well beyond aircraft dive speed.

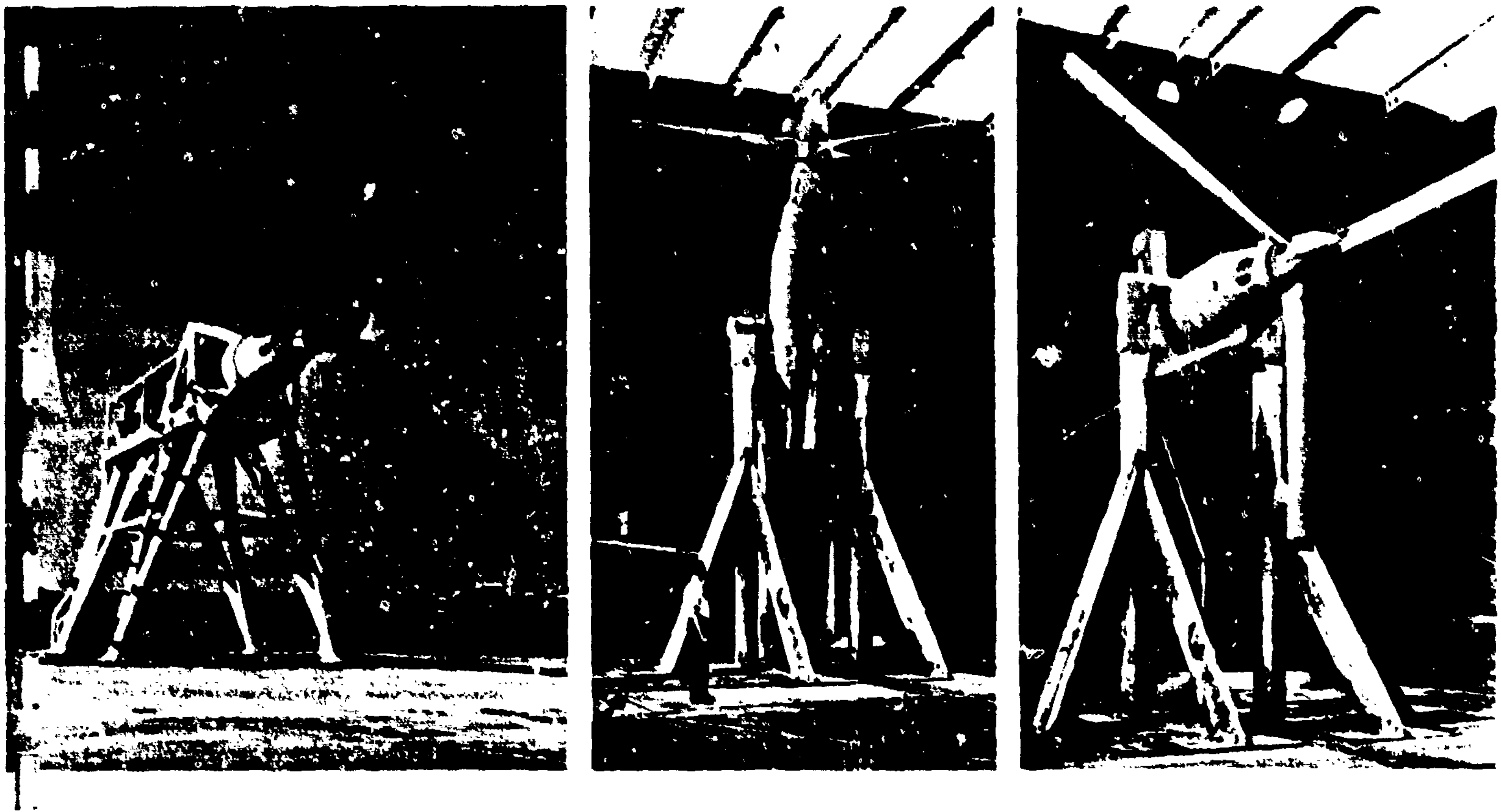
During Bell's development phase, both left and right-hand flightworthy rotor components have been fabricated. Existing parts include blades, rotor hub parts and spares.



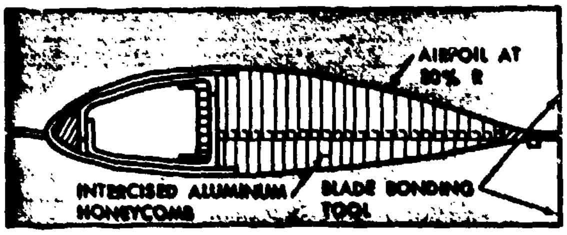
TILT ROTO FLIGHT ENVELOPE

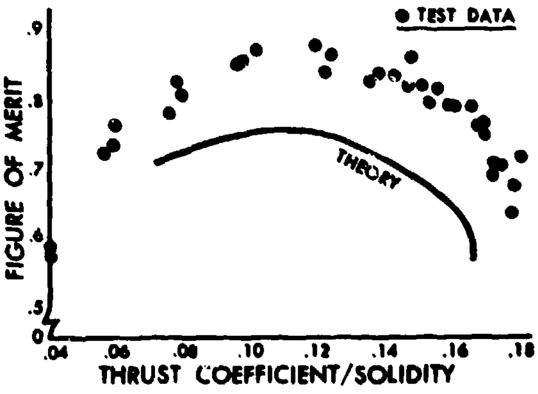


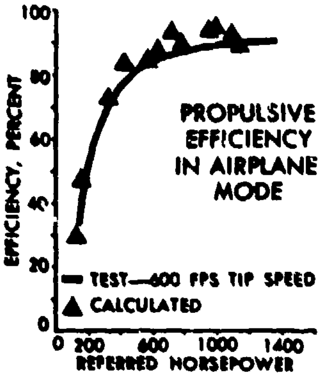




Blades have been fabricated using Bell's latest technology double cavity tooling for **precise blade contour** control. Steel spars and skins provide high static and fatigue strength, corrosion resistance, and low weight. Blade design parameters were chosen to optimize performance in both hover and cruise modes. Constant chord (14"), a continuous taper from 35% root thickness to an 8% tip thickness, NACA 64 series airfoils and a high (45°) twist are combined to meet the design objective. Performance testing has shown that aerodynamic **predictions were exceeded** in both modes of operation. Compared to a helicopter blade in which design twist is constrained by high speed forward flight conditions, the prop-rotor high twist blade is more efficient in hover (figure of merit = .85). Further, it converts for cruise, thus avoiding helicopter blade stall limitations.

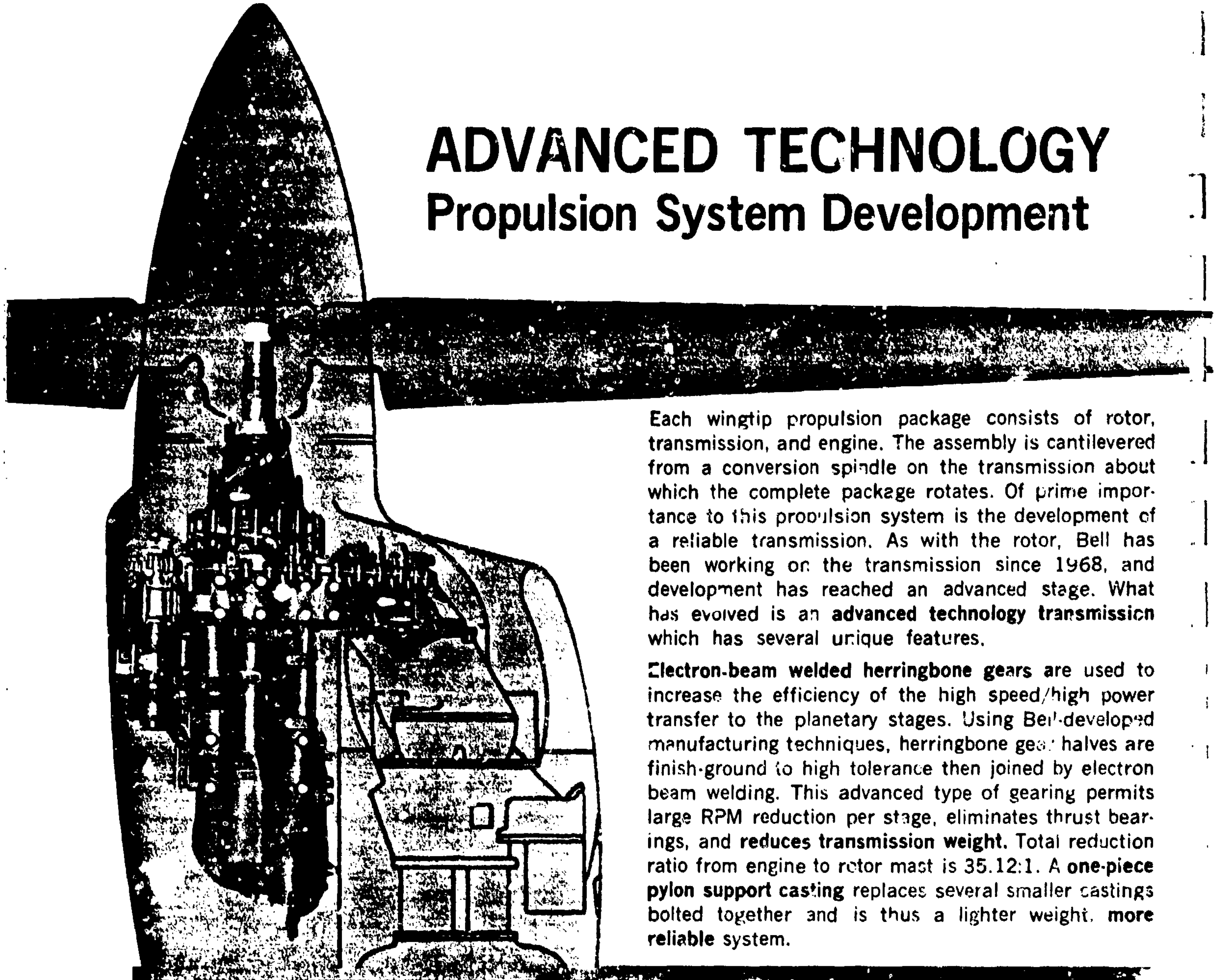






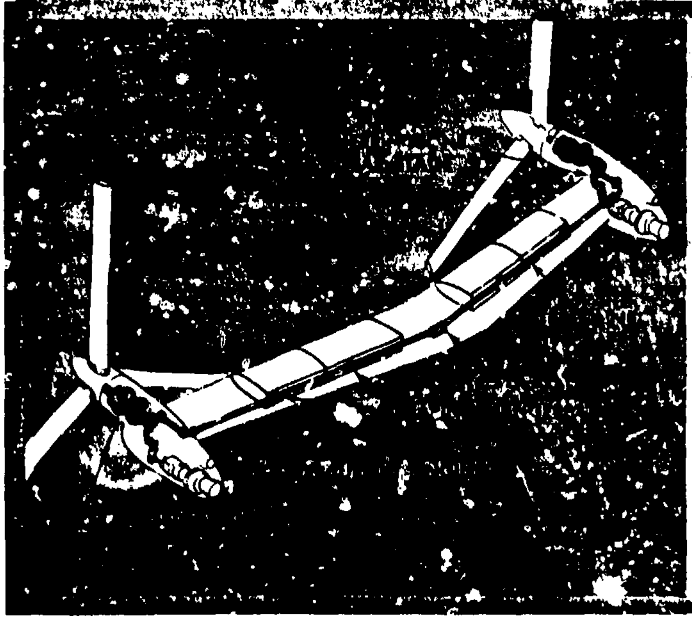
# ADVANCED TECHNOLOGY

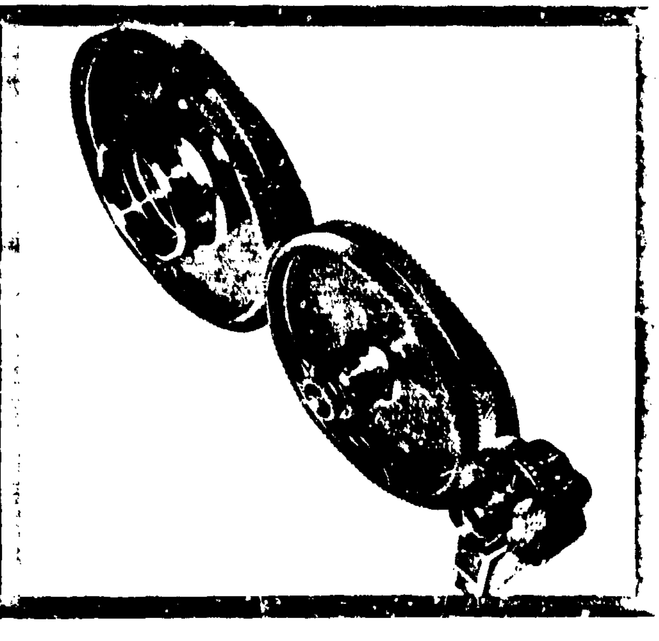
## Propulsion System Development



Each wingtip propulsion package consists of rotor, transmission, and engine. The assembly is cantilevered from a conversion spindle on the transmission about which the complete package rotates. Of prime importance to this propulsion system is the development of a reliable transmission. As with the rotor, Bell has been working on the transmission since 1968, and development has reached an advanced stage. What has evolved is an **advanced technology transmission** which has several unique features.

**Electron-beam welded herringbone gears** are used to increase the efficiency of the high speed/high power transfer to the planetary stages. Using Bell-developed manufacturing techniques, herringbone gear halves are finish-ground to high tolerance then joined by electron beam welding. This advanced type of gearing permits large RPM reduction per stage, eliminates thrust bearings, and **reduces transmission weight.** Total reduction ratio from engine to rotor mast is 35.12:1. A **one-piece pylon support casting** replaces several smaller castings bolted together and is thus a lighter weight, **more reliable** system.



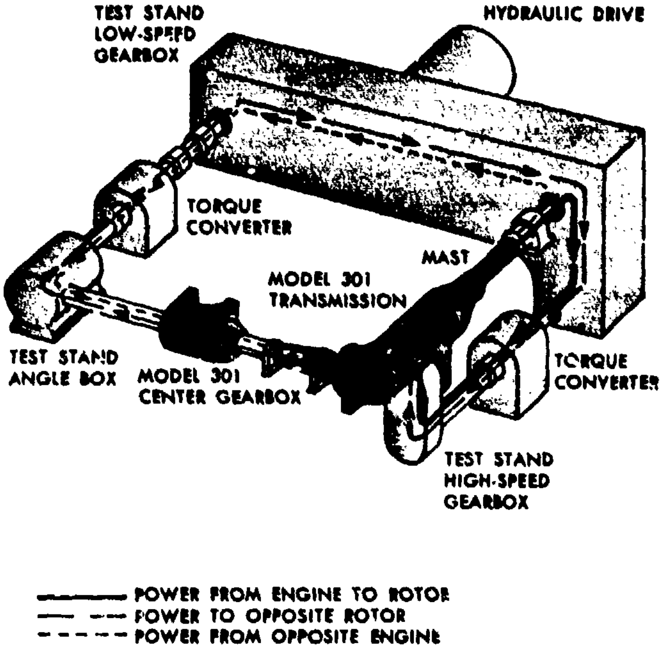


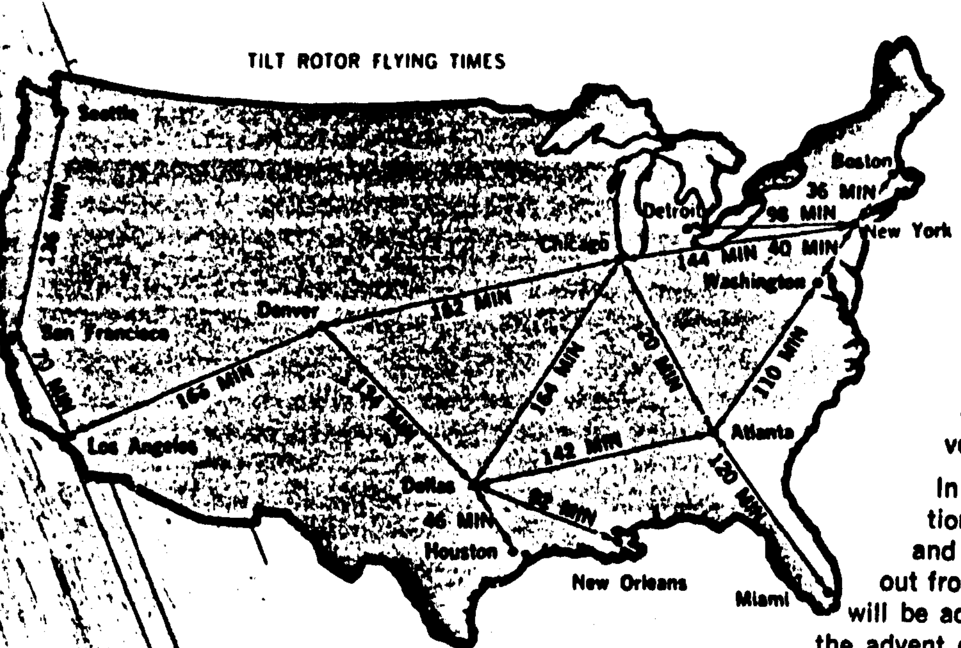
## [illegible]

New **failsafe design** techniques have been used which will allow the transmission to operate for up to 45 minutes after complete loss of lubrication.

An interconnect drive shaft connects the two propulsion packages. It normally is unloaded and serves to synchronize thrust and RPM. In the event of single engine operation, it transfers power, permitting continued safe operation. At the center of the interconnect system is an angle gearbox which also has been developed to a flightworthy stage.

A special bench test rig was designed to permit full spectrum testing of the tilt rotor transmission. This regenerative test stand allows simulation of twin-engine operation, single-engine operation from either engine, and operation in either airplane or helicopter mode. To date, a series of test runs have been completed on the right hand transmission. Included is a successful run of 50 hours at **125% of design torque.** The stand can be rearranged for left hand transmission testing.


TEST STAND LOW-SPEED GEARBOX
HYDRAULIC DRIVE
TORQUE CONVERTER
MAST
MODEL 301 TRANSMISSION
TEST STAND ANGLE BOX
MODEL 301 CENTER GEARBOX
TORQUE CONVERTER
TEST STAND HIGH-SPEED GEARBOX
——— POWER FROM ENGINE TO ROTOR
— — — POWER TO OPPOSITE ROTOR
- - - - - POWER FROM OPPOSITE ENGINE


TILT ROTOR FLYING TIMES
Seattle
136 MIN
San Francisco
72 MIN
Los Angeles
165 MIN
Denver
134 MIN
182 MIN
Chicago
Detroit
98 MIN
Boston
36 MIN
New York
144 MIN
40 MIN
Washington
220 MIN
164 MIN
110 MIN
Atlanta
142 MIN
120 MIN
Dallas
46 MIN
82 MIN
Houston
New Orleans
Miami

# COMMERCIAL

## Users Will Share

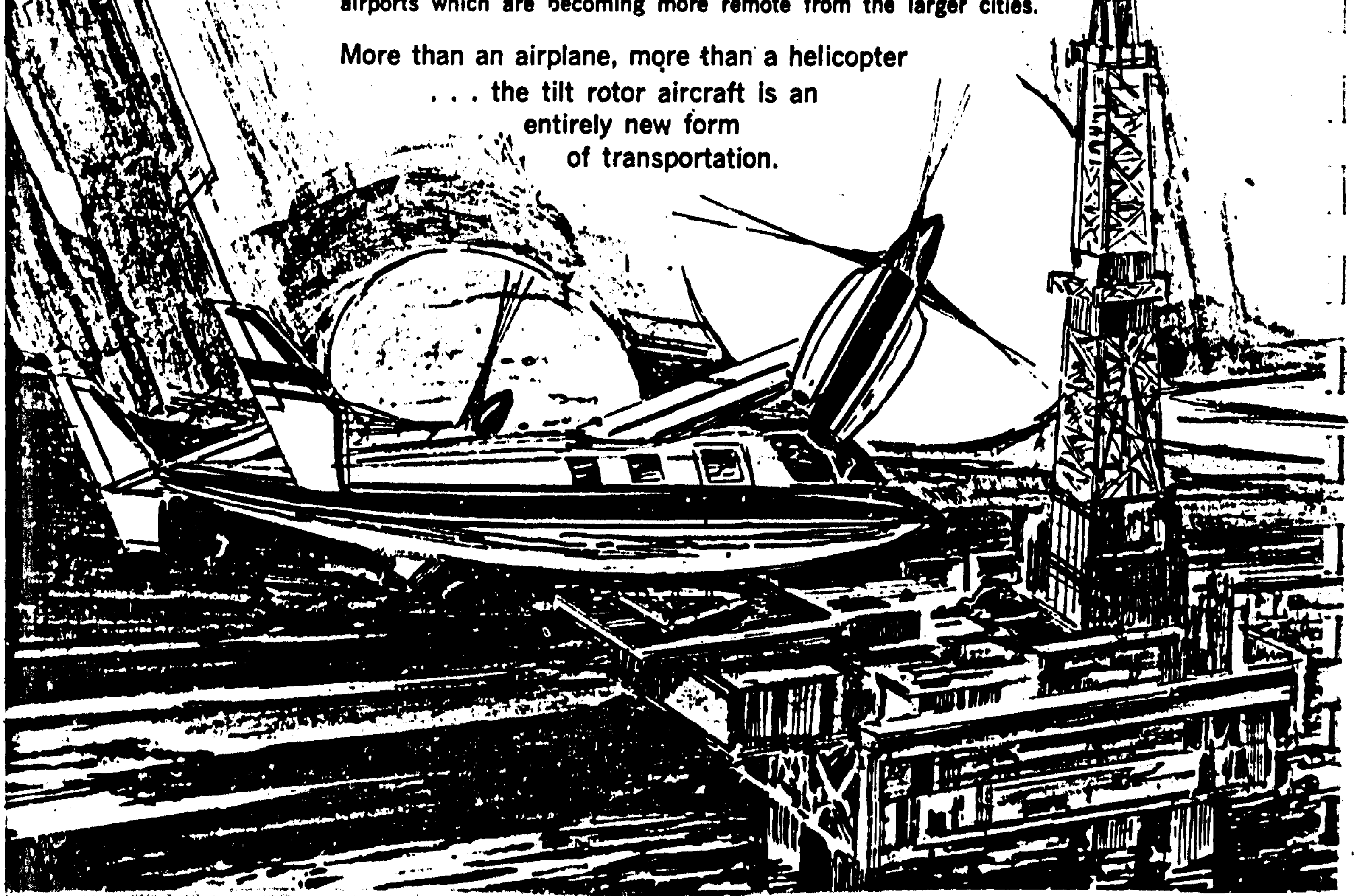
Tilt rotor aircraft will evolve in all sizes from the 13,000 pound Model 301 to 100 passenger transport aircraft. Many users now operating medium helicopters or turboprop airplanes will find improved versatility in the tilt rotor aircraft.

In off-shore oil operations for example, national energy demands will result in more and and more drilling sites being located further out from coastal waters. Rotation of drilling crews will be accomplished in less than half the time with the advent of the tilt rotor. Needed supplies could be transferred directly from an inland airport to an off-shore rig avoiding intermediate surface transfer.

Corporate executives have become accustomed to helicopter or private aircraft travel. The versatility of the tilt rotor will speed the VIP traveler from office to destination and back with helicopter convenience in less than half the time, **avoiding airplane/airport congestion.**

Larger tilt rotor aircraft will enhance commercial air carrier short haul operations over stage lengths of 100 to 700 miles. Tilt rotor aircraft with a dozen to 100 passengers will move between numerous outlying airports in city-pairs, such as New York-Washington or San Francisco-Los Angeles. It will also serve to distribute or collect passengers from regional airports which are becoming more remote from the larger cities.

More than an airplane, more than a helicopter
. . . the tilt rotor aircraft is an
entirely new form
of transportation.



# AND MILITARY

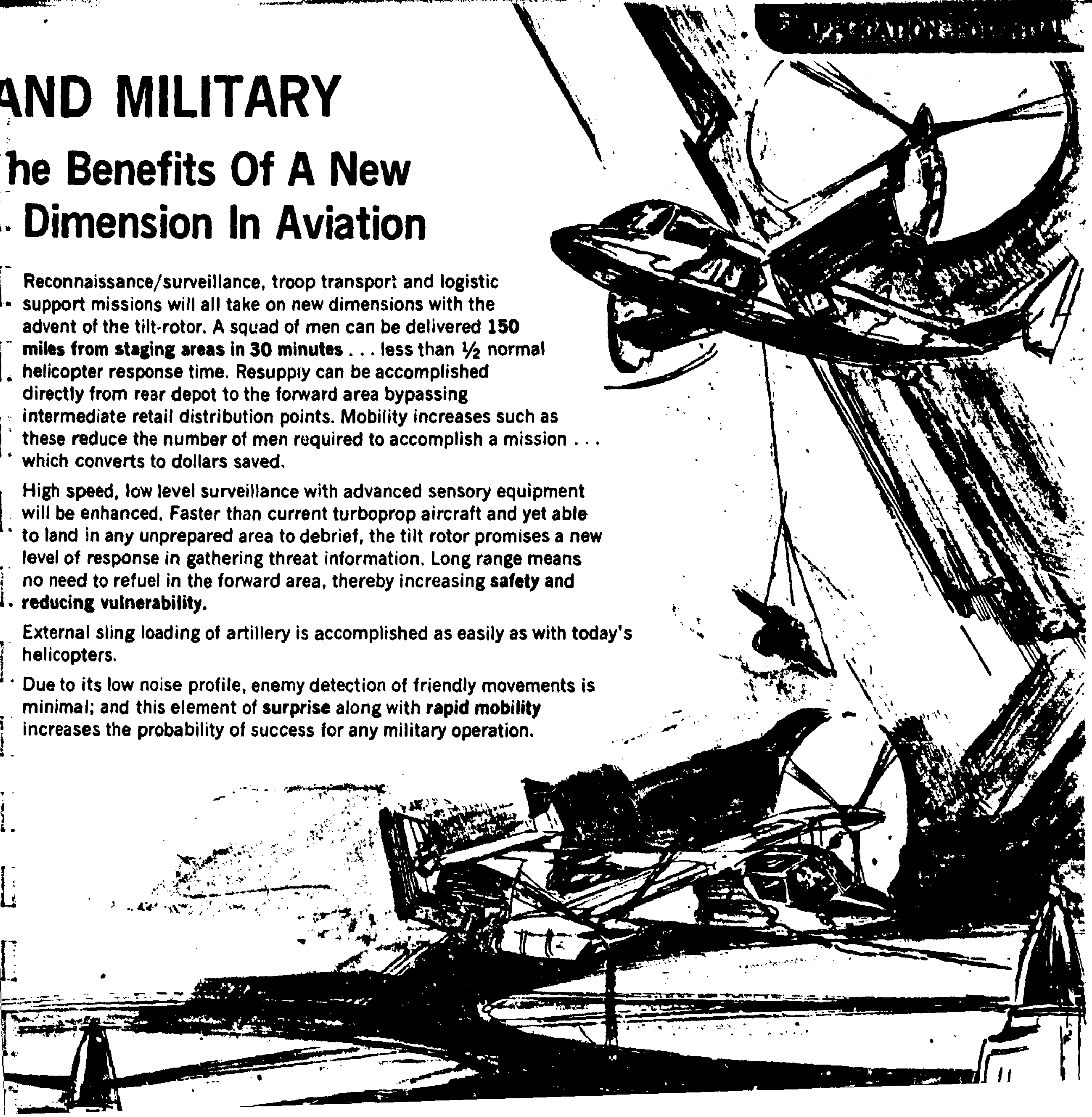
## The Benefits Of A New Dimension In Aviation

Reconnaissance/surveillance, troop transport and logistic support missions will all take on new dimensions with the advent of the tilt-rotor. A squad of men can be delivered **150 miles from staging areas in 30 minutes** . . . less than ½ normal helicopter response time. Resupply can be accomplished directly from rear depot to the forward area bypassing intermediate retail distribution points. Mobility increases such as these reduce the number of men required to accomplish a mission . . . which converts to dollars saved.

High speed, low level surveillance with advanced sensory equipment will be enhanced. Faster than current turboprop aircraft and yet able to land in any unprepared area to debrief, the tilt rotor promises a new level of response in gathering threat information. Long range means no need to refuel in the forward area, thereby increasing **safety** and **reducing vulnerability.**

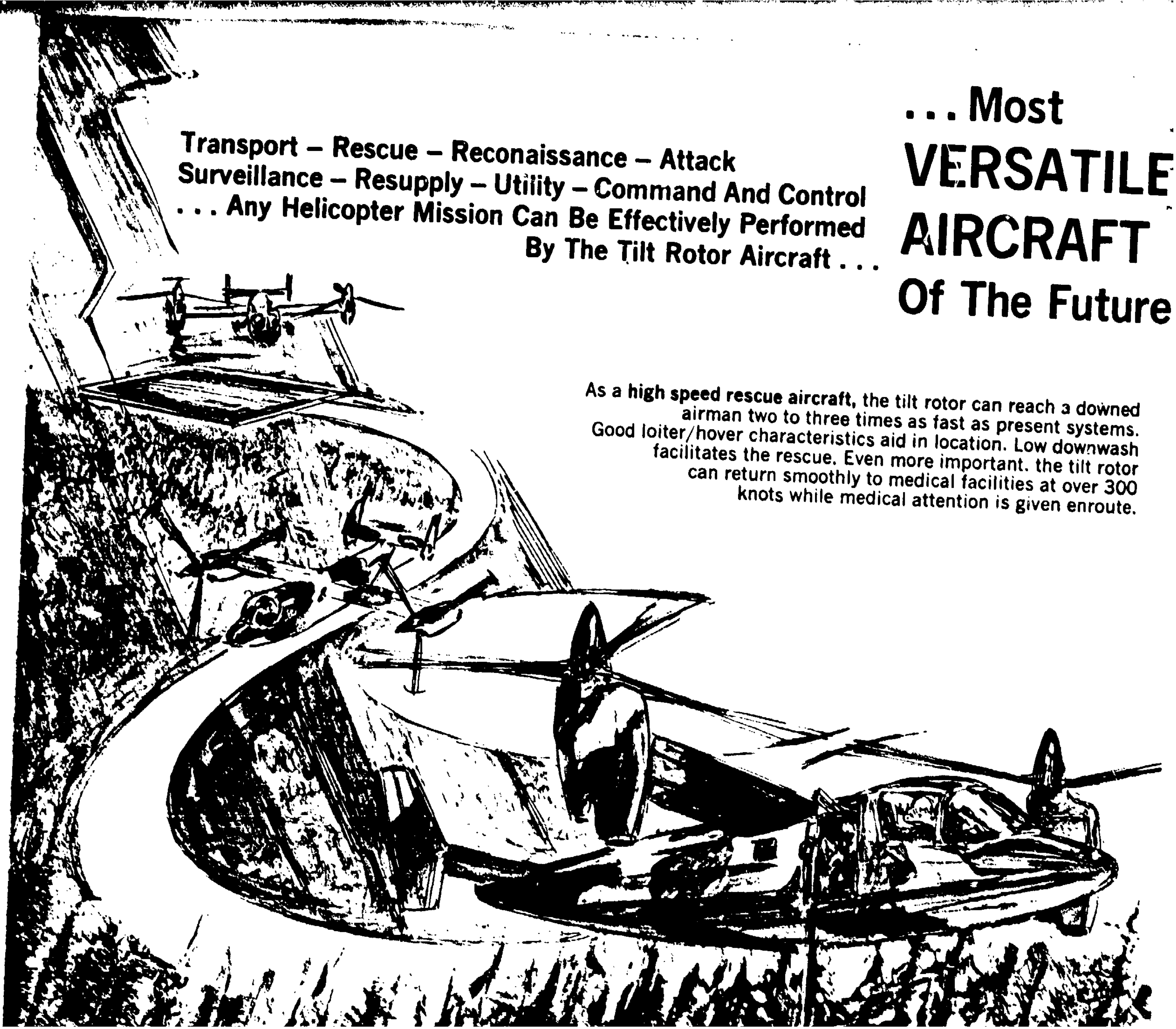
External sling loading of artillery is accomplished as easily as with today's helicopters.

Due to its low noise profile, enemy detection of friendly movements is minimal; and this element of **surprise** along with **rapid mobility** increases the probability of success for any military operation.

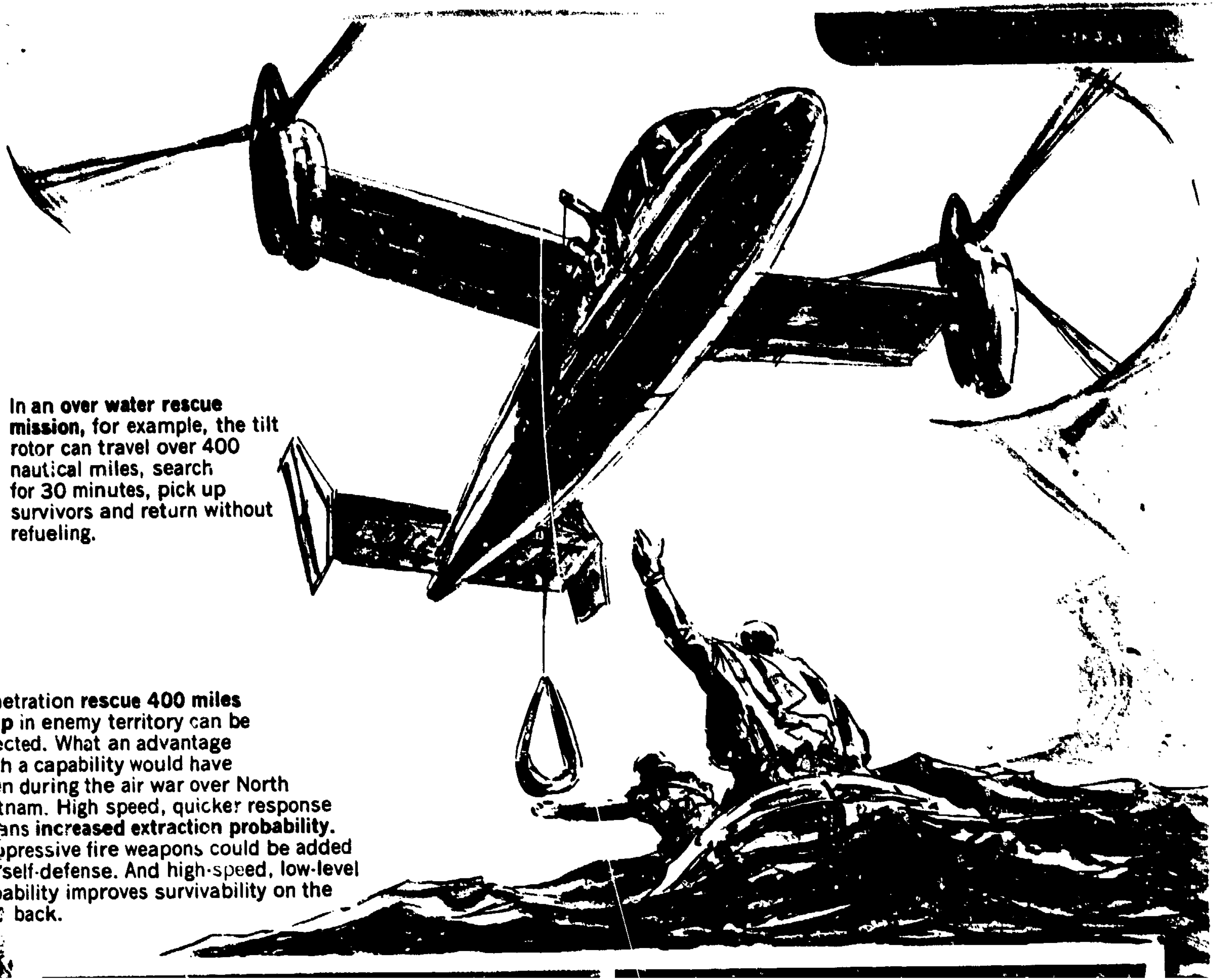


# . . . Most VERSATILE AIRCRAFT Of The Future

**Transport – Rescue – Reconaissance – Attack**
**Surveillance – Resupply – Utility – Command And Control**
**. . . Any Helicopter Mission Can Be Effectively Performed**
**By The Tilt Rotor Aircraft . . .**

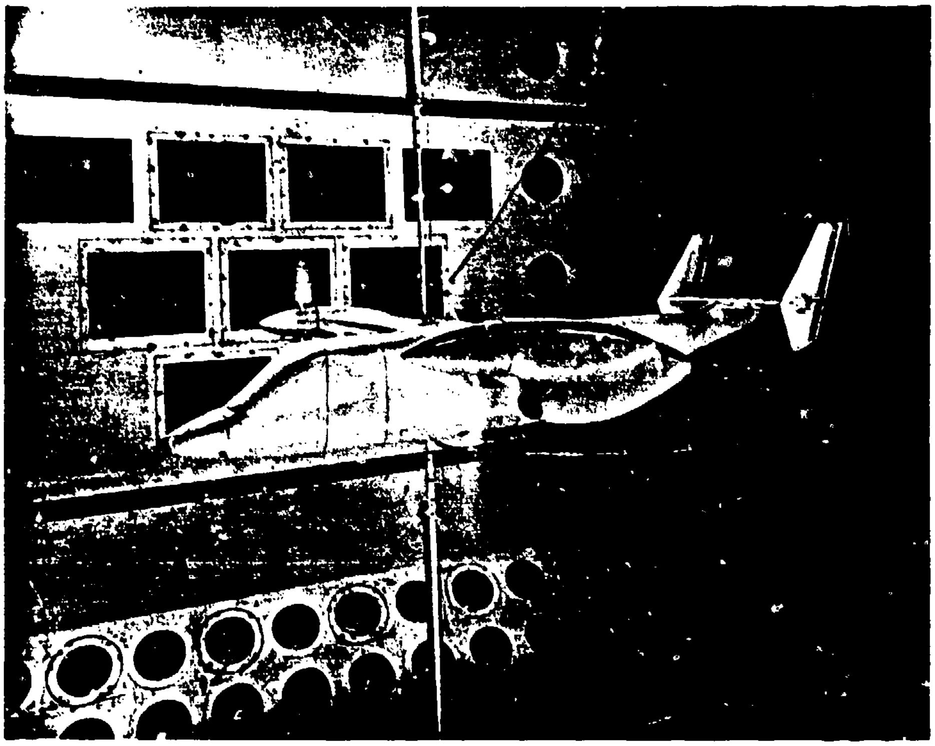


As a **high speed rescue aircraft,** the tilt rotor can reach a downed airman two to three times as fast as present systems. Good loiter/hover characteristics aid in location. Low downwash facilitates the rescue. Even more important, the tilt rotor can return smoothly to medical facilities at over 300 knots while medical attention is given enroute.



**In an over water rescue mission,** for example, the tilt rotor can travel over 400 nautical miles, search for 30 minutes, pick up survivors and return without refueling.

Penetration **rescue 400 miles deep** in enemy territory can be effected. What an advantage such a capability would have been during the air war over North Vietnam. High speed, quicker response means **increased extraction probability.** Suppressive fire weapons could be added for self-defense. And high-speed, low-level capability improves survivability on the way back.



**Bell**
HELICOPTER
a textron company

MAY 1973

# APPENDIX E

# CURRENT UNITED STATES COAST GUARD PROGRAM OBJECTIVES AND DESCRIPTIONS*

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*Includes excerpts from *The U.S. Coast Guard: Its Missions and Objectives*, U.S. GPO, 1977.

## E-1. INTRODUCTION

The following sections detail the USCG programs and objectives listed below:

a. ENFORCEMENT OF LAWS AND TREATIES (ELT)
b. MARINE ENVIRONMENTAL PROTECTION (MEP)
c. MILITARY OPERATIONS/PREPARED (MO/MP)
d. PORT SAFETY AND SECURITY (PSS)
e. SEARCH AND RESCUE (SAR)
f. SHORT-RANGE AIDS TO NAVIGATION (A/N)
g. MARINE SCIENCE ACTIVITIES (MSA)
h. ICE OPERATIONS (IO).

## E-2. ENFORCEMENT OF LAWS AND TREATIES

### OBJECTIVE

The objective of the ELT program is to enforce all federal laws in the marine environment, except those specifically assigned to other Coast Guard programs (ie, vessel safety, marine pollution, vessel traffic control, and port safety and security). In recent years ELT enforcement efforts have focused particularly on laws relating to fisheries protection, immigration, and drug smuggling.

### PROGRAM DESCRIPTION

ELT can claim to be the oldest Coast Guard program since the Revenue Marine, the ancestor of the modern Coast Guard, was established in 1790 to suppress smuggling. Today, as the federal maritime enforcement agency, the Coast Guard is responsible for enforcing all federal laws on the navigable water of the United States and its possessions, and on the high seas. The laws to be enforced fall into two categories: laws relating to marine safety for which the Coast Guard has sole responsibility; and laws relating to customs and revenue, immigration, quarantine, neutrality, protection of fish and game, marine environmental protection, and other matters that fall within the jurisdiction of other federal agencies for which the Coast Guard shares enforcement responsibility, and the unique facilities of the Coast Guard are required to accomplish maritime law enforcement.

The ELT program encompasses a wide variety of duties covering a broad geographic area; included are the enforcing of laws and regulations governing the fishery conservation zone extending 200 nautical miles off the U.S. coasts; interdicting drug and alien smuggling in areas such as the Caribbean; ensuring that U.S. tuna boats off the shores of South America comply with the inter-American Tropical Tuna Convention; and minimizing of damage and loss of fishing gear caused by conflicting deployment of mobile and fixed equipment, such as the simultaneous use of lobster pots and bottom trawls off the New England coast.

The functional elements of an enforcement system are detection, surveillance, and apprehension.

## E-3. MARINE ENVIRONMENTAL PROTECTION PROGRAM

### OBJECTIVE

The primary objective of the MEP program is to maintain or improve the quality of the marine environment through preventive measures. The secondary objective is to minimize the damage caused by pollutants discharged into the marine environment by providing coordinated and effective response to remove discharges of oil or hazardous substances.

### PROGRAM DESCRIPTION

Congress has established the restoration and maintenance of the chemical, physical, and biological integrity of the waters of the nation as a national objective. The Coast Guard is the primary maritime agency empowered to meet this national objective.

The role for the Coast Guard in marine environmental protection is a logical extension of its traditional missions in marine and port safety, and law enforcement.

The MEP program is divided into six major operational components, namely, response, enforcement, prevention, monitoring and surveillance, impact assessment, and in-house abatement.

Initial efforts were designed to solve the immediate problem of minimizing the effects of pollution. More recent actions have concentrated on developing an adequate cleanup (response) capability to effectively remove most oil discharges. Current efforts in this area are concentrating on special technical problems for oil removal, removal of hazardous substances, and the removal of pollutants in the arctic environment.

In addition to attempting to resolve the immediate problems of cleanup, a second phase has been initiated to eliminate all types of discharges. Efforts are being directed at establishing an effective enforcement program, coupled with public awareness and education campaigns. Future efforts in this area will attempt to improve the level of enforcement in the coastal areas and to provide limited coverage in those outlying areas where little or no enforcement activity is presently conducted.

The U.S. Coast Guard Pollution Prevention Regulations for vessels and oil transfer facilities, which went into effect on 1 July 1974, signaled the beginning of the third phase of the program, prevention. Additional regulations, such as those dealing with hazardous substances, will be developed as necessary in conjunction with public education efforts, in a unified enforcement approach.

Several other initiatives support the response, enforcement, and prevention phases of the MEP program. Monitoring and surveillance serve to meet program objectives in two ways; first, adequate detection enhances enforcement capabilities as well as being a deterrent which aids in preventing discharges; second, this activity provides the Coast Guard with an impact assessment capability which can be used to judge the damage or the impact of pollutants on the marine environment. This information is required to ensure effective cleanup and to establish effective prevention policies. Initial steps to accomplish this are taken by providing surface and air surveillance in coastal and port areas.

To complement the aircraft, cutters, and boats that conduct the bulk of the MEP program, three major items of response or cleanup equipment are in use. These are the Air-Deliverable Antipollution Transfer System, a high-seas oil-containment device, and two types of oil recovery devices.

## E-4. MILITARY OPERATIONS/PREPAREDNESS PROGRAM

### OBJECTIVE

The objective of the MO/MP program is to maintain the Coast Guard as an effective and ready armed force prepared for, and immediately responsive to, assigned tasks in time of peace, war, or national emergency. This includes readiness to function as a specialized service in the Navy in time of war, responding to national disasters and domestic emergencies, and the efficient conduct of peacetime missions. The program unifies both preparedness and operations.

### PROGRAM DESCRIPTION

The command and control system, and the operational training provided by MO/MP are essential to respond rapidly and effectively under all conditions.

In order to maintain the Coast Guard as an effective and ready armed force, MO/MP combines training with the preparation of contingency plans based on realistic assessments of Coast Guard capabilities.

Personnel readiness is achieved for both peacetime and wartime tasks through on-the-job training, augmentation training, specialized training exercises, and formal classroom instruction. Training standards and programs are based on Coast Guard routine and contingency responsibilities. Joint command post and joint operational, multi-unit, and individual exercies, are scheduled periodically to promote military preparedness. The Coast Guard participates in the DOD Worldwide Military Command and Control System. Participation in fleet and interservice exercises is geared to ensure that personnel and material performance are to Navy standards. Personnel contingency requirements to be met by reserve personnel are established in conjunction with the Reserve Forces Program. Reserves constitute a very valuable and essential element of the overall Coast Guard military capability.

Material readiness consists of equipping and maintaining Coast Guard operating facilities and personnel with combat gear necessary to maintain a state of readiness to perform its combat, combat support, and peacetime duties, such as law enforcement. The goal is to ensure the operating forces are outfitted and equipped as required for full-mission performance.

Typical tasks which may be required of the Coast Guard in wartime are surveillance for enemy forces, antisubmarine warfare (AWS), protection of offshore installations, convoy escort, and logistics supply.

## E-5. PORT SAFETY AND SECURITY PROGRAM

### OBJECTIVE

The objective of the PSS program is to safeguard the navigable waters of the nation and adjacent shore areas, including ports and their related facilities, from accidental or intentional harm. By assuring the safety of the ports and waterways, vital transportation links are facilitated.

### PROGRAM DESCRIPTION

The Ports and Waterways Safety Act (PWSA) of 1972 was written to prevent damage to, or destruction or loss of any vessel, bridge, or other structure on, in, or near the navigable waters of the U.S., and to protect the navigable waters and the resources therein from environmental harm resulting from vessel or structure damage.

PSS is administered by the Coast Guard Captains of the Port (COTPs). The program is complex and interfaces with several other program areas.

Currently, there are over 50 Captains of the Port with approximately 1600 field billets designated for PSS and MEP duties. These functions include monitoring and supervision of oil transfer and hazardous cargo operations, cleaning up pollution, conducting harbor patrols, inspecting and surveying waterfront facilities, establishing safety and security zones as required, and controlling movements and anchorages.

The activities of the PSS program are many and varied, but can be categorized into the following major areas:

a. Prevent intentional or accidental mishandling of cargo in U.S. ports and waterways

b. Prevent threats and acts of espionage, sabotage, and intelligence gathering

c. Reduce the likelihood of fires and explosions in the port areas

d. Reduce the probability of ship collisions or groundings

e. Assist vessels to transit U.S. ports safely and economically in a minimum of time

f. Promote unified and consolidated rules of the nautical road in accordance with international regulations for preventing collisions at sea

g. Enhance cargo security within the entire marine terminal complex.

Vessel traffic management is an important means of ensuring safe operation in certain ports and waterways. This function is provided by Coast Guard Vessel Traffic Services (VTS) using the following procedures. Using a VHF/FM communication network, and in most cases some form of electronic surveillance, information on vessel positions and movements is collected by a shore-based vessel-traffic center. After analyzing the data, VTS provides accurate and comprehensive information to vessels on the status of other vessels and other relevant navigation information. In addition, congestion or other conflict situations are predicted as far in advance as possible. Vessels are alerted to such potential problems so that corrective measures can be taken.

## E-6. SEARCH AND RESCUE PROGRAM

### OBJECTIVE

The objective of the SAR program is to minimize loss of life, injury, and property damage by rendering aid to persons and property in distress in the marine environment, including the inland navigable waters.

## PROGRAM DESCRIPTION

Search and rescue is the mission most readily identified with the Coast Guard. This mission is one of the earliest and most traditional functions of the Coast Guard, and continues to demand the highest priority in all aspects of Coast Guard operations. The origins are twofold: the Revenue Marine was tasked by the Secretary of the Treasury in the early 19th century to render assistance to vessels in distress in the course of conducting its antismuggling patrols; within the same general time frame, the U.S. Lifesaving Service was established to provide a network of beach patrols which launched surf boats to rescue crews from distressed ships. In 1915 these two services were combined as elements of the Coast Guard.

Economic and technological advances have changed the search and rescue clientele. The rapid expansion of recreational boating, the increase of powered fishing vessels, and the accepted responsibility of the United States to provide a greater degree of assistance to the mariner on the high seas, has created new demands for providing search and rescue capability. The Coast Guard has responded to these demands by evolving search and rescue systems encompassing stations, ships, aircraft, and boats linked by modern communications networks, and centrally controlled and directed by rescue coordination centers.

The current national SAR plan has established three SAR regions; inland, maritime, and overseas. The Coast Guard is the designated coordinator for the maritime region. SAR facilities have been established at numerous points along the East, West, and Gulf Coasts, and in Alaska, Hawaii, American Samoa, and Puerto Rico.

Although the maritime SAR region reaches deep into the Atlantic and Pacific, and embraces all of the Gulf of Mexico, it should be noted that 92 percent of all SAR incidents occur within 25 miles of the U.S. coastline.

The Automated Mutual-Assistance Vessel Rescue (AMVER) system, operated by the Coast Guard, is an international program designed to assist the safety of merchant vessels on the high seas. Merchant vessels of all nations on offshore passages throughout the world are encouraged to send sailing plans upon departure from port, and periodic position reports enroute to cooperating radio stations. These reports are forwarded to the AMVER Center located on Governors Island in New York Harbor. There, the information is entered into a computer which calculates positions by dead reckoning for the ships throughout their voyages, based upon most recent information. When a recognized rescue center of any nation learns of an emergency at sea, it may obtain a computer-predicted listing of ships in the vicinity of the emergency to determine which, if any, might be well suited to provide help. Valuable search and rescue data, such as the radio watch schedule of each ship and whether she carries a doctor, is kept on file in the computer and is also printed for each ship listed. The location of a participating individual vessel may also be obtained by rescue authorities if her safety is in question. Predicted vessel locations are disclosed only for reasons related to maritime safety. This system has proved to be an extremely cost-effective means of providing mid-ocean SAR.

## E-7. SHORT-RANGE AIDS TO NAVIGATION PROGRAM

### OBJECTIVE

The objective of the A/N program is to assist the mariner in determining his position and to warn him of dangers and obstructions so that he may follow a safe course. This is accomplished by providing navigational references such as audio, visual, or electronic signals, and using buoys and lights.

### PROGRAM DESCRIPTION

In order to understand the application and impact of the short-range aids to navigation program it is useful to have historical perspective of the evolution of the program. The A/N program has a broad geographical scope in that aids to navigation are established and maintained in or near U.S. navigable waters, territories and possessions of the United States, the Trust Territory of the Pacific Islands, and where required to support the Department of Defense.

Effective use of the services provided requires some degree of knowledge by the user in order to employ the system properly. Users range from the sophisticated professional navigator to the relatively untrained and unskilled recreational boater. The differing level of these abilities means that the Coast Guard must satisfy a broad spectrum of user needs.

Of the roughly 78,000 short-range aids to navigation in use, nearly 60 percent are aids for which the Coast Guard is wholly responsible. The remainder are privately owned aids for which the Coast Guard has a management responsibility.

The popularly held image of the traditional A/N program, exemplified by manned lighthouses and "Bee-Ohh" sound signals, is not completely accurate today since the current operations of the program incorporate many modern technological advances. For example, transistorized flashers and photocell daylight controls are standard equipment on minor aids to navigation. Similarly, automation and remote monitoring of lighthouses have reduced operating costs considerably, and have released many Coast Guard personnel for other duty. A major effort to replace lightships with less expensive and more effective offshore towers and large navigational buoys has left only two lightship stations in existence.

In summary, the main areas of Coast Guard involvement are the monitor, repair, and replacement of buoys.

## E-8. MARINE SCIENCE ACTIVITIES PROGRAM

### OBJECTIVE

The objectives of the MSA program are to provide marine science support to all Coast Guard programs and to support national economic, scientific, defense, and social needs.

The specific objectives of the MSA program are to conduct the international ice patrol, provide oceanographic services for the support of the SAR, MEP, IO, and other Coast Guard programs and to cooperate with and provide assistance to other government and scientific organizations in support of national marine science objectives.

### PROGRAM DESCRIPTION

The Coast Guard marine science effort emphasizes applied oceanography in support of Coast Guard programs and missions. Coast Guard activities in SAR, MEP, and IO rely heavily on the oceanographic and meteorological information obtained through MSA operations.

The Coast Guard has the greatest federal presence in the coastal zone, and has the sole U.S. capability for surface transit of ice-covered waters.

In fulfilling its MSA responsibilities, the Coast Guard cooperates with other government agencies to ensure the efficient use of public resources and the furtherance of national interests in the marine environment.

The Coast Guard has a long history of cooperation with the National Oceanic and Atmospheric Administration (NOAA) through projects with the National Weather Service (NWS), National Marine Fisheries Service (NMFS), and National Ocean Survey (NOS). Additionally, mutual interests have stimulated exchanges of services between the Coast Guard and the Department of Defense.

The following brief summary highlights some of the most significant activities carried out by the Coast Guard through MSA:

a. International Ice Patrol. Commenced in 1914 after the sinking of the *Titanic*, now conducted under international agreement. Aircraft and ships are deployed each year from February to August to detect icebergs near the North Atlantic shipping lanes, and to study ice and current conditions.

b. Oceanographic Services. Applied oceanography to support Coast Guard operations. Sea surface current studies are conducted to assist in computer SAR planning. Computerized models of sea currents for the entire U.S. coastline are being developed. In addition to SAR operations, these models have application in pollutant drift prediction and the planning of deep-water ports. Other coastal projects being conducted include estuarine pollution studies, time dependent current modeling, and bays and sounds modeling.

c. Data Buoy Project. This project is administered by NOAA with the Coast Guard providing operational support for deployment and servicing of buoys, a technical staff, and a communications system to relay buoy data. An extensive network of buoys provides marine environmental data over the coastal U.S. from the Gulf of Maine to the Gulf of Alaska, and the Great Lakes.

d. Marine and Coastal Weather Observation and Reporting. This project is conducted as a cooperative effort with the NWS and the Naval Weather Service Command for use in preparation of marine weather forecasts. Approximately 170 shore stations and 50 cutters report weather data several times daily. NWS-prepared weather forecasts are broadcast to local marine users over Coast Guard communications facilities.

e. Cooperative Projects. The Coast Guard engages in cooperative projects with various federal agencies, and provides marine science expertise and resources to further national goals in open-ocean and coastal programs. Many of these projects represent unique efforts, where the Coast Guard contributes most or all of the data and services.

(1) Airborne Radiation Thermometer Surveys. Charts of sea-surface temperatures in continental-shelf regions are compiled from data acquired monthly by Coast Guard aircraft using infrared radiation thermometers. These charts of both the East and West coasts are provided to U.S. Government agencies and the civilian maritime community for use in search and rescue, marine environmental protection, and fisheries-related problems.

(2) Ocean Sounding Program. Bathymetric data is routinely supplied to the Defense Mapping Agency Hydrographic Office by cutters engaged in regular Coast Guard functions. This data becomes an input to charts used by all members of the maritime community.

(3) IGOSS Marine Pollution Monitoring Pilot Project (MARMOPP). High-endurance cutters conduct tarball sampling on a regular basis. Tarballs are lumps of floating petroleum residue of both natural and human-induced origins. The monitoring of ocean surface tar is useful in evaluating the effectiveness of oil control measures and the dispersion of marine pollutants.

## E-9. ICE OPERATIONS PROGRAM

### OBJECTIVE

The objective of the IO program is to facilitate maritime transportation and other activities in the national interest in ice-laden domestic and polar waters. The services provided in the IO program also assist in meeting the needs of marine safety and environmental protection in the ice environment.

### PROGRAM DESCRIPTION

In 1936, a presidential executive order established national policy on use of vessels for icebreaking operations in channels and harbors. The Coast Guard was directed to keep channels and harbors open for the reasonable demands of commerce insofar as practicable by performing icebreaking operations. In response to a determination that the national interest would best be served by concentrating all icebreaking resources in one agency, the U.S. Navy transferred its icebreakers to the Coast Guard in 1965.

Icebreaking services are provided for three major purposes:

a. To assist in the safe and timely movement of maritime traffic

b. To prevent and control flooding resulting from ice accumulation on domestic waterways

c. To support scientific research and other national interests in the polar regions.

Because of the differences between the geographic areas in which these activities are conducted, the IO program can be best understood by considering polar and domestic operations separately.

### POLAR OPERATIONS

In the polar regions, icebreakers escort resupply ships into ice-laden areas, carry fuel and cargo to isolated U.S. installations, survey uncharted waters, collect meteorological and oceanographic data, and serve as platforms to carry research scientists into remote and otherwise unreachable areas.

The polar icebreaking fleet currently consists of one *Glacier*-class vessel, built in 1955, three smaller and older *Wind*-class vessels (two of which have been reengined to extend their service lives) and two new *Polar*-class icebreakers. Three other *Wind*-class icebreakers were decommissioned in recent years as construction of the *Polar* class was nearing completion, and an additional *Wind* is scheduled for decommissioning in 1978.

The replacement of the *Wind*-class vessels by the two *Polar*-class icebreakers will decrease the total number of available icebreaking days. This deficit may be partially overcome by increasing the operation of the *Polar* class by 33 percent over previous icebreakers. This increase would exceed personnel constraints for time away from home port, and will require the use of a multiple-crewing concept similar to that used on Navy nuclear submarines. As planned, the ashore crew, together with a small permanent staff, would comprise the Icebreaker Support Facility located in Seattle, Washington (the *Polar*-class home port). They would be tasked with coordination of crew training and maintenance for the *Polar*-class icebreakers.

## DOMESTIC OPERATIONS

One of the most important responsibilities of the Coast Guard is to keep open to shipping domestic traffic routes and ports that are normally utilized year-round. The IO program also attempts to extend navigation seasons in ice-laden areas when such extensions are considered in the national interest. For example, the Coast Guard has been one of the major participants in the multi-agency Great Lakes season extension project. The Coast Guard also cooperates with other agencies to prevent and control flooding caused by ice jams. Performance of these duties requires icebreaking services as well as the collection and dissemination of information (mapping).

The United States domestic icebreaking fleet currently consists of one dedicated icebreaker (on the Great Lakes) assisted part-time by a *Wind*-class polar icebreaker and a multitude of smaller, multipurpose cutters with icebreaking capabilities.

Aircraft perform surveillance patrols to evaluate ice conditions and recommend ship routes through areas having ice formations.

# APPENDIX F

## MPA MISSION PROFILES AND PAYLOADS

## F-1. INTRODUCTION

The following tables give the representative profiles for each of the MPA missions.

## F-2. ELT REPRESENTATIVE PROFILE*

### TABLE F-1. ELT SEARCH AND BOARD

| | | HR |
|---|---|---|
| 1. | Warm-up, takeoff @ SL TOGW, standard day (59°F) | 0.25 |
| 2. | Climb to 5000 ft | 0 |
| 3. | Cruise 250 nmi @ 50 kt | 5.00 |
| 4. | Sweep @ 50 kt for 5 hr | 5.00 |
| 5. | Dash @ 90 kt for 0.5 hr | 0.50 |
| 6. | Descend to 50 ft | 0 |
| 7. | Hover for 0.25 hr | 0.25 |
| 8. | Loiter @ 30 kt for 1 hr | 1.00 |
| 9. | Hover for 0.25 hr | 0.25 |
| 10. | Climb to 5000 ft | 0 |
| 11. | Sweep @ 50 kt for 4 hr | 4.00 |
| 12. | Repeat steps 5-11 once | 6.00 |
| 13. | Cruise 250 nmi @ 50 kt | 5.00 |
| 14. | Descend and land @ SL with 10% fuel remaining | 0.25 |
| | Total | 27.50 |

### TABLE F-2. ELT MISSION PAYLOAD

| | | LB |
|---|---|---|
| 1. | Crew of 11 (@ 200 lb/each) | 2200 |
| 2. | Provisions, general store, and potable water (@ 25 lb/person/day) | 315 |
| 3. | Inflatable boat with motor and fuel | 411 |
| 4. | Rescue equipment | 81 |
| 5. | Dewatering pumps | 110 |
| 6. | Firefighting equipment set | 90 |
| 7. | Smoke and light floats (@ 6 each) | 42 |
| | Total | 3249 |

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*Fixed payload - 4420 lb, mission payload - 3249 lb, total payload - 7669 lb, crew - 11.

## F-3. MEP REPRESENTATIVE PROFILE*

TABLE F-3. MEP INITIAL CLEANUP, $C_3$

| | | HR |
|---|---|---|
| 1. | Warm-up, takeoff @ SL TOGW, standard day (59°F) | 0.25 |
| 2. | Climb to 5000 ft | 0 |
| 3. | Cruise to 50 nmi @ 50 kt | 1.00 |
| 4. | Descend to 100 ft | 0 |
| 5. | Hover (pick-up mission payload) | 0.50 |
| 6. | Climb to 1000 ft | 0 |
| 7. | Cruise 25 nmi @ 50 kt | 0.50 |
| 8. | Off-load payload - hover 0.5 hr | 0.50 |
| 9. | Cruise back 25 nmi @ 50 kt | 0.50 |
| 10. | Repeat steps 4-9 two times | 4.00 |
| 11. | Climb to 5000 ft | 0 |
| 12. | Loiter @ 30 kt for 3.5 hr | 3.50 |
| 13. | Cruise 75 nmi @ 50 kt | 1.50 |
| 14. | Descend and land @ SL with 10% fuel remaining | 0.25 |
| | Total | 12.50 |

TABLE F-4. MEP MISSION PAYLOAD

| | | Lb |
|---|---|---|
| 1. | Crew of 6 (@ 200 lb/each) | 1,200 |
| 2. | Provisions, general stores, and potable water (@ 25 lb/person/day) | 78 |
| 3. | Inflatable boat with motor and fuel | 411 |
| 4. | Rescue equipment | 81 |
| 5. | Pump | 110 |
| 6. | Firefighting equipment set | 90 |
| 7. | Smoke and light floats (@ 6 each) | 42 |
| 8. | Chemicals for spill | 500 |
| 9. | Harbor oil boom (one @ 2 lb-ft) | 440 |
| 10. | Oil recovery devices | 15,000 |
| | Total | 17,952 |

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*Fixed payload - 4420 lb, mission payload - 17,952 lb, total payload - 22,372 lb, crew - 6.

## F-4. MO/MP REPRESENTATIVE PROFILE*

### TABLE F-5. MO/MP TOWED ARRAY ASW, ATTACK

| | HR |
|---|---|
| 1. Warm-up, takeoff @ SL TOGW, standard day (59°F) | 0.25 |
| 2. Climb to 5000 ft | 0 |
| 3. Cruise 300 nmi @ 40 kt | 7.50 |
| 4. Descend to 500 ft | 0 |
| 5. Tow away @ 10 kt for 0.5 hr | 0.50 |
| 6. Cruise 15 nmi @ 30 kt | 0.50 |
| 7. Repeat steps 5-6 fourteen times | 14.00 |
| 8. Dash @ 90 kt for 1 hr | 1.00 |
| 9. Attack (deploy weapons) | 0 |
| 10. Cruise 100 nmi @ 40 kt | 2.50 |
| 11. Descend and land @ SL with 10% fuel remaining | 0.25 |
| Total | 26.50 |

### TABLE F-6. MO/MP MISSION PAYLOAD

| | LB |
|---|---|
| 1. Crew of 11 (@ 200 lb/each) | 2200 |
| 2. Provisions, general stores, and potable water (@ 25 lb/person/day) | 304 |
| 3. Rescue equipment | 81 |
| 4. Towed array system (including processor) | 1500 |
| 5. MK-46NT (3) | 1524 |
| 6. VLA/DIFAR (Dwarf) (20) | 200 |
| 7. Marker, BT, AN | 300 |
| 8. MAD gear | 400 |
| Total | 6509 |

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*Fixed payload - 4420 lb, mission payload - 6509 lb, total payload - 10,929 lb, crew - 11.

## F-5. PSS REPRESENTATIVE PROFILE*

### TABLE F-7. PSS HAZARDOUS VESSEL ESCORT

| | HR |
|---|---|
| 1. Warm-up, takeoff @ SL TOGW, standard day (59°F) | 0.25 |
| 2. Climb to 5000 ft | 0 |
| 3. Cruise 50 nmi @ 40 kt | 1.25 |
| 4. Loiter @ 30 kt for 6 hr | 6.00 |
| 5. Descend to 1000 ft | 0 |
| 6. Cruise 25 nmi @ 40 kt | 0.60 |
| 7. Descend and land @ SL with 10% fuel remaining | 0.25 |
| Total | 8.35 |

### TABLE F-8. PSS MISSION PAYLOAD

| | LB |
|---|---|
| 1. Crew of 6 (@ 200 lb/each) | 1200 |
| 2. Provisions, general stores, and potable water (@ 25 lb/person/day) | 52 |
| 3. Rescue equipment | 81 |
| 4. Dewatering pump (2) | 220 |
| 5. Firefighting equipment set (2) | 180 |
| 6. Smoke and light floats (@ 12 each) | 84 |
| Total | 1817 |

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*Fixed payload - 4420 lb, mission payload - 1817 lb, total payload - 6237 lb, crew - 6.

## F-6. SAR REPRESENTATIVE PROFILE*

### TABLE F-9. SAR SEARCH, BOARD, TOW

| | HR |
|---|---|
| 1. Warm-up, takeoff @ SL TOGW, standard day (59°F) | 0.25 |
| 2. Climb to 5000 ft | 0 |
| 3. Cruise 25 nmi @ 90 kt | 0.30 |
| 4. Search for 1.5 hr @ 60 kt | 1.50 |
| 5. Descend to 100 ft | 0 |
| 6. Hover for 0.5 hr | 0.50 |
| 7. Loiter @ 30 kt for 2 hr | 2.00 |
| 8. Hover for 0.5 hr | 0.50 |
| 9. Tow @ 6 kt for 50 nmi | 8.30 |
| 10. Descend and land @ SL with 10% fuel remaining | 0.25 |
| Total | 13.60 |

### TABLE F-10. SAR MISSION PAYLOAD

| | LB |
|---|---|
| 1. Crew of 8 (@ 200 lb/each) | 1600 |
| 2. Provisions, general stores, and potable water (@ 25 lb/person/day) | 114 |
| 3. Inflatable boat with motor and fuel | 411 |
| 4. Rescue equipment | 81 |
| 5. Dewatering pump | 110 |
| 6. Firefighting equipment | 90 |
| 7. Smoke and Light floats | 84 |
| Total | 2490 |

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*Fixed payload - 4420 lb, mission payload - 2490 lb, total payload - 7910 lb, crew - 8.

## F-7. A/N REPRESENTATION PROFILE*

### TABLE F-11. A/N BUOY MAINTENANCE

| | HR |
|---|---|
| 1. Warm-up, takeoff @ SL TOGW, standard day (59°F) | 0.25 |
| 2. Climb to 1000 ft | 0 |
| 3. Cruise 150 nmi @ 50 kt | 3.00 |
| 4. Descend to 100 ft | 0 |
| 5. Hover for 0.5 hr | 0.50 |
| 6. Climb to 500 ft | 0 |
| 7. Cruise 80 nmi @ 50 kt | 1.60 |
| 8. Repeat steps 4-7 four times | 8.40 |
| 9. Climb to 1000 ft | 0 |
| 10. Cruise 150 nmi @ 50 kt | 3.00 |
| 11. Descend and land @ SL with 10% fuel remaining | 0.25 |
| Total | 17.00 |

### TABLE F-12. A/N MISSION PAYLOAD

| | LB |
|---|---|
| 1. Crew of 8 (@ 200 lb/each) | 1600 |
| 2. Provisions, general stores, and potable water (@ 25 lb/person/day) | 142 |
| 3. Inflatable boat with motor and fuel | 411 |
| 4. Rescue equipment | 81 |
| 5. Dewatering pump | 110 |
| 6. Firefighting equipment set | 90 |
| 7. Smoke and light floats (@ 6 each) | 42 |
| 8. Buoy maintenance kit | 500 |
| Total | 2976 |

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*Fixed payload - 4420 lb, mission payload - 2976 lb, total payload - 7396 lb, crew - 8.

## F-8. MSA REPRESENTATION PROFILE*

### TABLE F-13. MSA ICE PATROL (ST. JOHNS)

| | HR |
|---|---|
| 1. Warm-up, takeoff @ SL, TOGW, standard day (59°F) | 0.25 |
| 2. Climb to 5000 ft | 0 |
| 3. Cruise 100 nmi @ 40 kt | 2.50 |
| 4. Sweep @ 60 kt for 30 hr | 30.00 |
| 5. Cruise 100 nmi @ 40 kt | 2.50 |
| 6. Descend and land @ SL with 10% fuel remaining | 0.25 |
| Total | 35.50 |

### TABLE F-14. MSA MISSION PAYLOAD

| | LB |
|---|---|
| 1. Crew of 11 (@ 200 lb/each) | 2200 |
| 2. Provisions, general stores, and potable water (@ 25 lb/person/day) | 407 |
| 3. Inflatable boat with motor and fuel | 411 |
| 4. Rescue equipment | 81 |
| 5. Dewatering pump | 110 |
| 6. Firefighting equipment set | 90 |
| 7. Smoke and light floats (@ 6 each) | 42 |
| Total | 3341 |

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*Fixed payload - 4420 lb, mission payload - 3341 lb, total payload - 7761 lb, crew - 11.

## F-9. IO REPRESENTATIVE PROFILE*

TABLE F-15. IO ICE MAPPING (GREAT LAKES)

| | | HR |
|---|---|---|
| 1. | Warm-up, takeoff @ SL TOGW, standard day (59°F) | 0.25 |
| 2. | Climb to 5000 ft | 0 |
| 3. | Map @ 60 kt for 20 hr | 20.00 |
| 4. | Descend and land @ SL with 10% fuel remaining | 0.25 |
| | Total | 20.50 |

TABLE F-16. IO MISSION PAYLOAD

| | | LB |
|---|---|---|
| 1. | Crew of 6 (@ 200 lb/each) | 1200 |
| 2. | Provisions, general stores, and potable water (@ 25 lb/person/day) | 128 |
| 3. | Inflatable boat with motor and fuel | 411 |
| 4. | Rescue equipment | 81 |
| 5. | Dewatering pump | 110 |
| 6. | Firefighting equipment set | 90 |
| 7. | Smoke and light floats (@ 6 each) | 42 |
| 8. | Scientific instruments | 1000 |
| | Total | 3062 |

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*Fixed payload - 4420 lb, mission payload - 3062 lb, total payload - 7482 lb, Crew - 6.

# APPENDIX G

## SIMPLIFIED MANUAL APPROACH FOR MARITIME PATROL AIRSHIP DESIGN

## G-1. GENERAL

The simplified manual design approach for establishing the airship design and size for the various missions is characterized by several features, including:

a. Fixed propulsion system weights (modified X-22A) used for all airship sizes and missions

b. Use of heavy-lift airship (reference G-1) subsystem weights proportioned by size and/or load

c. Buoyant lift supports airship weight and half of the disposable load (this choice is made to take full advantage of the reversible thrust, which then can handle the entire range of disposable loads without allowing the airship to become too light or too heavy for VTOL).

d. Rotor thrust is either vertical or horizontal for analysis

e. Altitude capability provided to 5000 feet (full load)

f. Drag, dynamic lift, and fuel consumption from past airship data

g. Airship fuel weight determined by cruise speed and endurance requirements

h. Dash-speed requirement checked independently after size is known.

## G-2. FIXED X-22A PROPULSION SYSTEM

The first requisite in this approach was to select a suitable propulsion system. Because of the difficulty of estimating weights of the various propulsion system components, an existing system was selected for which not only the weight and performance of the engine are known, but also those of the propeller, transmission, controls, tilt mechanisms, and related items. Data of this type was available for two Bell VTOL craft, the four-engine X-22A, and the two-engine XV-15.

The X-22A system uses a 1250-hp T58-GE-8 gas turbine and tilting, ducted propellers. Ducted propellers are not necessarily inappropriate for the maritime patrol airship, but they are not adaptable to reversible thrust, and in any case the advantage of reduced diameter and noise is obtained at some cost in ductwork. Therefore, the X-22A system is herein assumed to be adapted for a free propeller. If the shroud weight is omitted and the propeller is assumed replaced by a free propeller of the same diameter, the resulting weight of four units, including propellers, gearboxes, tilt mechanisms, controls, drive system, electrical system, etc, is 5520 pounds. The propeller is 7 feet in diameter and, as a free propeller, can generate a static thrust of 3,485 pounds per unit or 13,940 pounds for four units (see figures G-1 and -2 which assume a figure of merit of 0.7 and show the effect on thrust of varying engine power, propeller diameter, and altitude, as a function of airspeed).

Each XV-15 prop-rotor is 25 feet in diameter, and the propulsion system installation (including tilt mechanism) is 4049 pounds for two units lifting a gross weight of 13,000 pounds. Four would weigh about 8100 pounds and have a total hover thrust of 26,000 pounds. The entire propulsion system, including engines, is tilted.

Preliminary sizing of airships for the various missions indicated that the X-22A propulsion system is close to what is required for the maritime patrol airship, although a propeller diameter larger than 7 feet may be desired if a free propeller is used. The XV-15 appears to be larger than required. The X-22A system was therefore assumed for the analysis.

The payload requirement for each mission is given in table 1 of this report. It includes 4420 pounds of fixed equipment (sensor suite, avionics suite, winch and controls, and handling lines) to be carried on all missions.

## G-3. EMPENNAGE DESIGN

To provide a basis for the analysis, historical data on the characteristics and performance of airships was collected and reviewed. Figure G-3 shows airship empennage areas as a function of envelope volume. A typical weight of airship tail surface is 1 pound per square foot; this curve can easily be used to estimate airship empennage weights.

## G-4. FUEL CONSUMPTION

No fuel consumption data exists for airships equipped with gas turbine engines such as the T-58's used on the X-22A. However, a considerable amount of historical data on fuel consumption for nonrigid airships equipped with reciprocating engines is available, and is plotted in figure G-4. Figure G-5 shows some additional data for rigid airships (two of these, the *Hindenburg* and the R-101, used diesel engines). The specific fuel consumption (SFC) of reciprocating engines estimated from the more recent historical data is about the same as for the better gas turbines at maximum power. For reciprocating engines, the SFC is relatively independent of power, but for gas turbines at low power, it can increase appreciably at low power settings.

Within the limited scope of the present study, it appears expeditious to make use of the historical data, since it obviates the need to be concerned with the airship drag coefficient, which is also a factor of considerable uncertainty

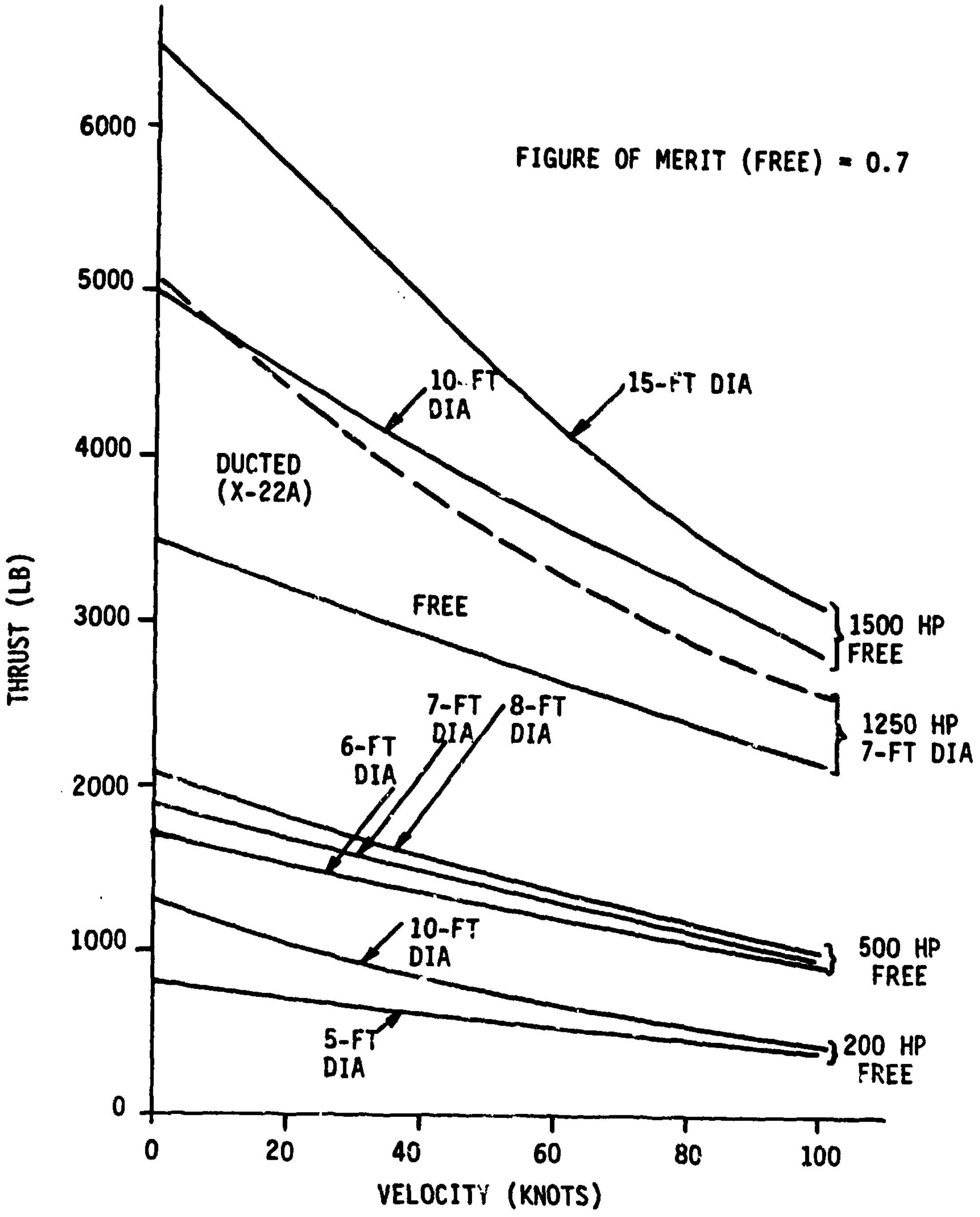


Figure G-1 EFFECT OF AIRSPEED ON PROPELLER THRUST (STANDARD CONDITIONS AT SEA LEVEL)

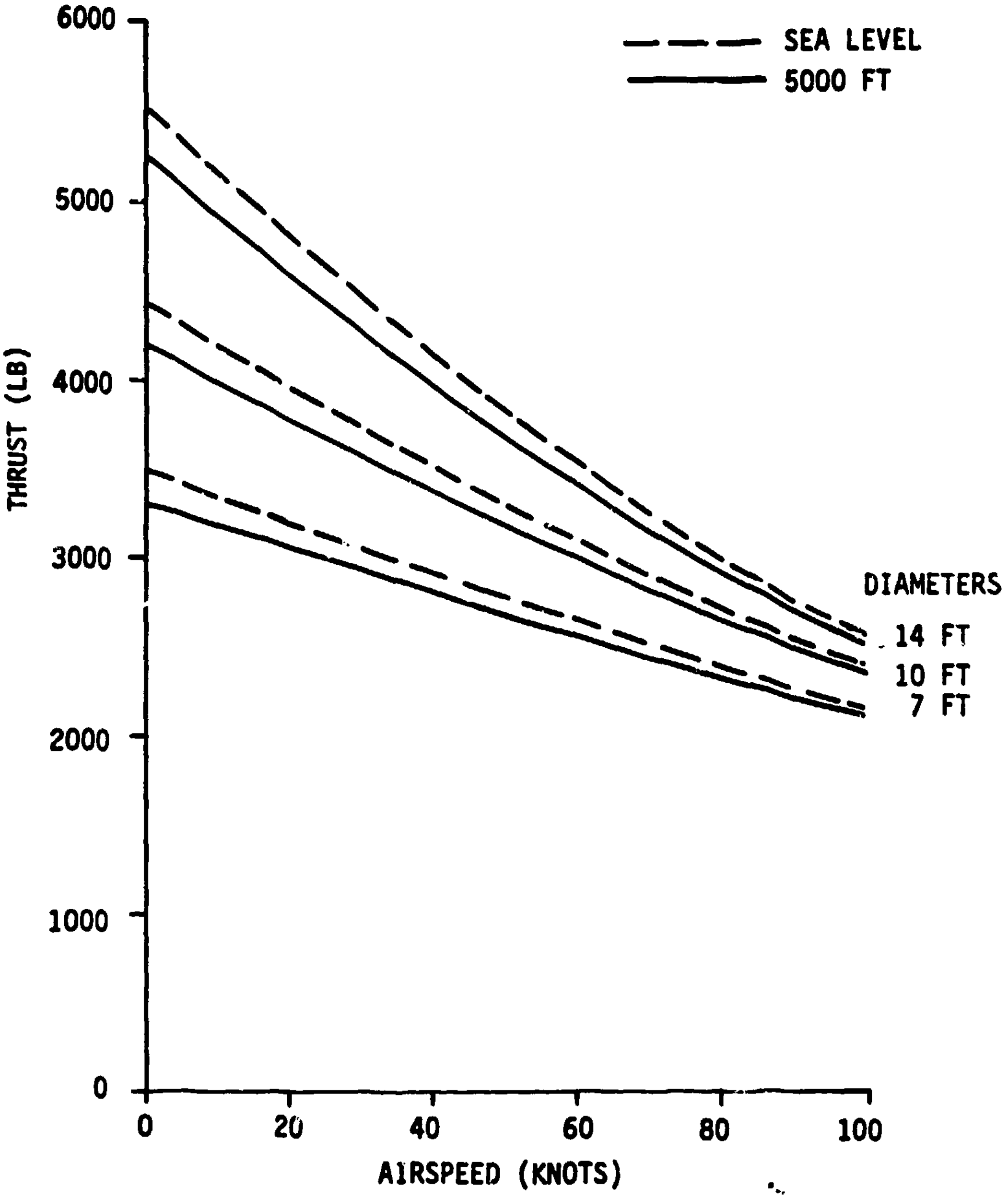


Figure G-2 EFFECT OF AIRSPEED AND PROPELLER DIAMETER ON THRUST (1250-HP TURBOPROP)

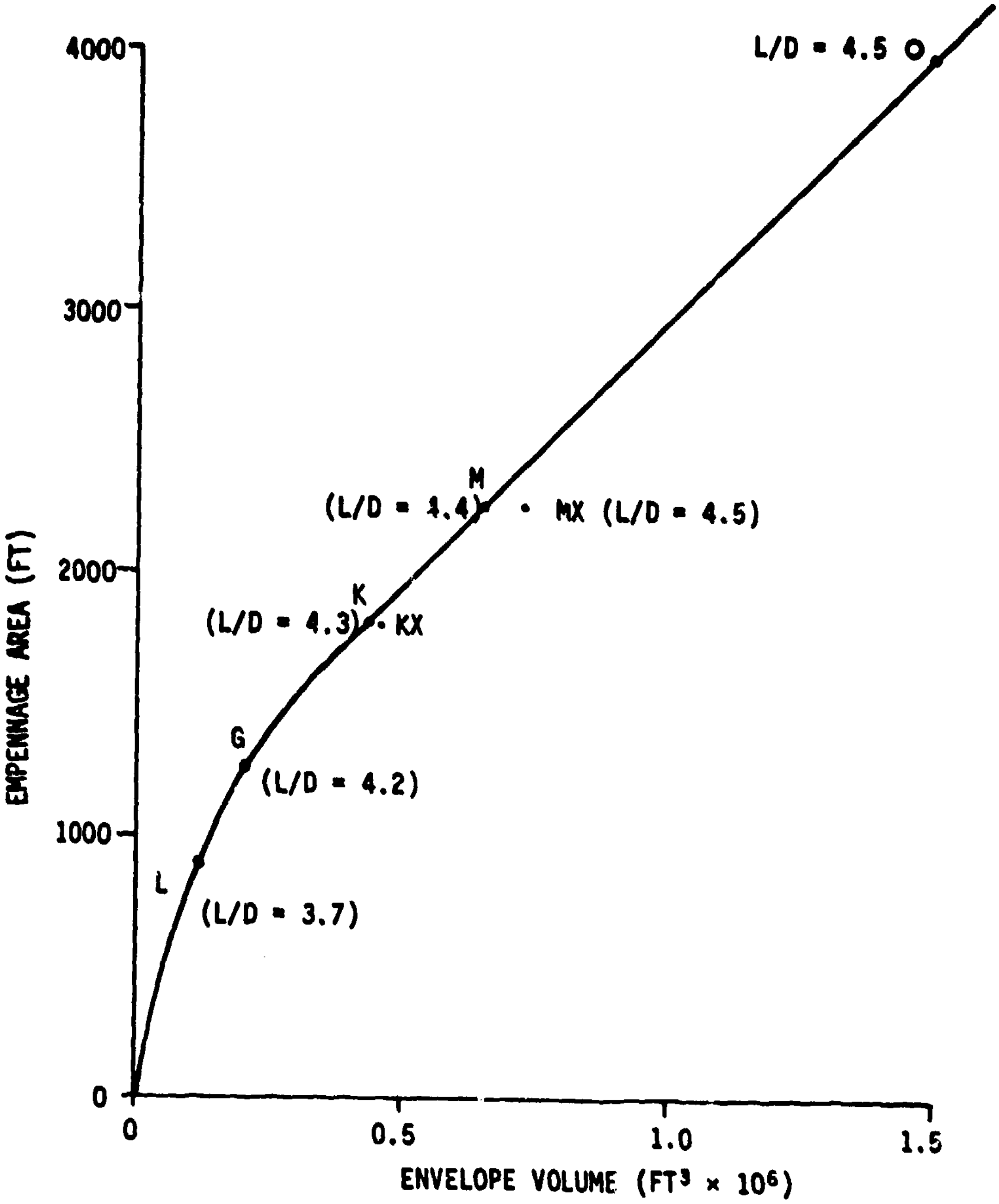


Figure G-3 AIRSHIP TAIL AREAS

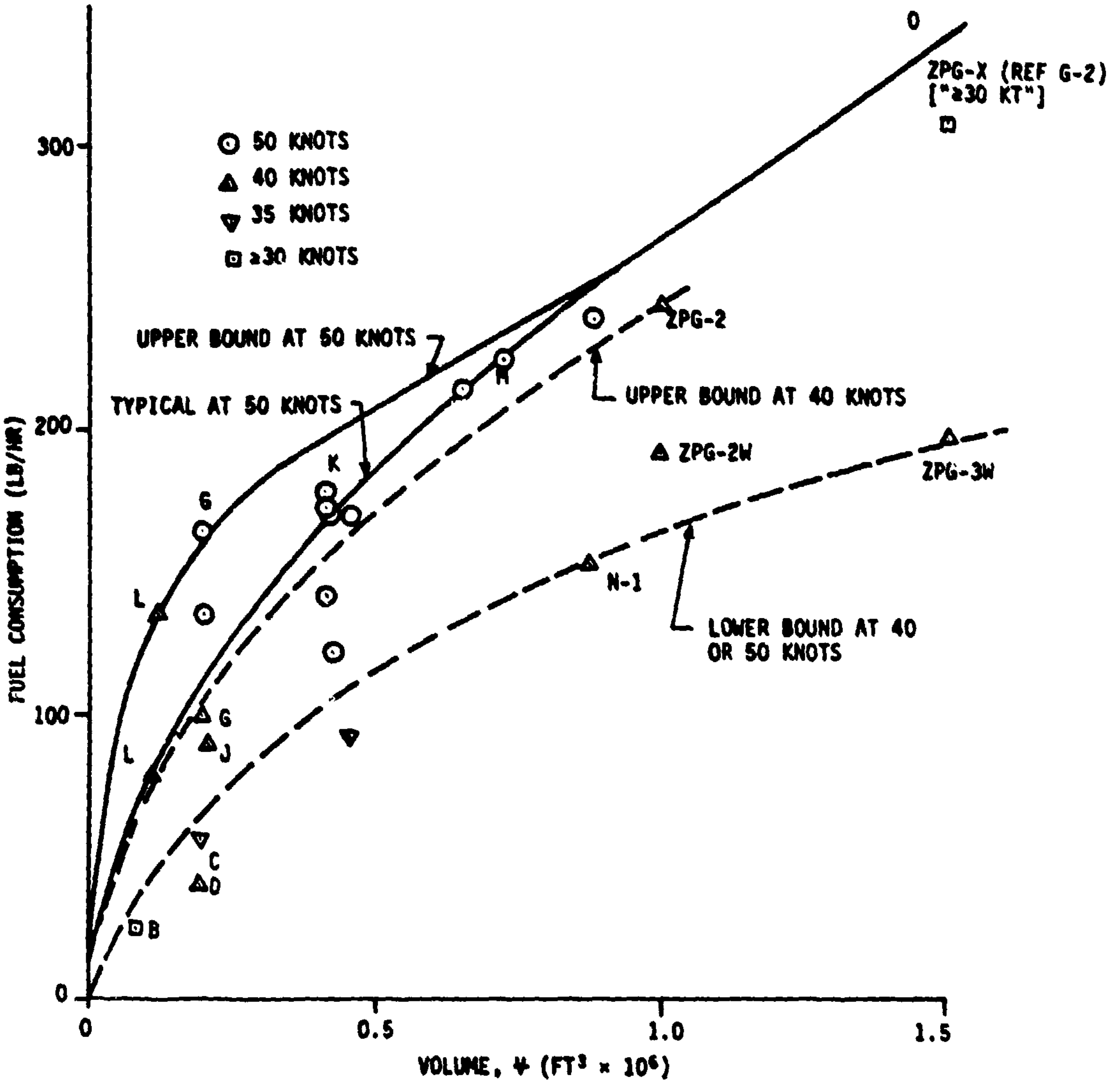


Figure G-4 FUEL CONSUMPTION OF NEUTRALLY BUOYANT, NONRIGID AIRSHIPS (RECIPROCATING ENGINES AT SEA LEVEL)

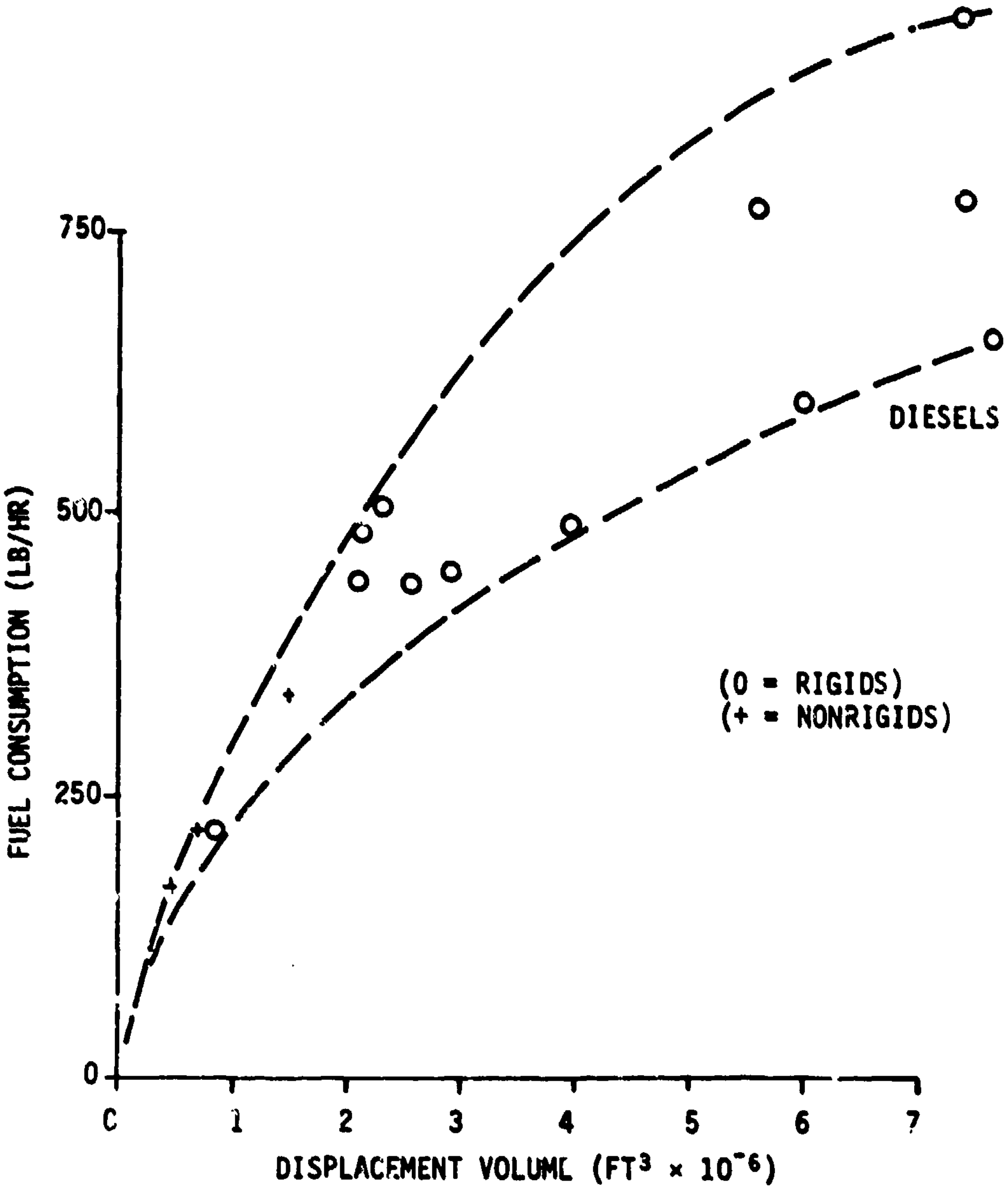


Figure G-5 FUEL CONSUMPTION OF RIGID AIRSHIPS AT 50 KNOTS because of Reynolds number effects. From figure G-4, selecting a 1,000,000-ft$^3$ airship as a convenient reference point, a fuel consumption of 250 lb/hr at 50 knots seems conservative enough to account for moderate increases in SFC at reduced power with gas turbines. The further possibility exists of shutting down one or more of the four engines when power requirements are low, so that very high SFCs at low power are largely eliminated. The inclusion of such complications in the present limited study does not seem justifiable. Furthermore, the advancement of engine technology should make it possible to bring the higher fuel consumption rate of gas turbines down to the level of reciprocating engines of 20 or 30 years ago. Therefore, the historical data is used as explained below.

Figure G-6 shows the increase in drag coefficient, $C_D$, with angle of attack for a ZPG-2 airship, and figure G-7 shows dynamic lift as a function of airspeed and angle of attack. It then becomes possible to construct figure G-8, which relates fuel consumption, angle of attack, envelope volume, and dynamic lift, with the following assumptions:

a. Fuel consumption is proportional to power and time and, therefore, to drag.

b. The fuel consumption for a neutrally buoyant 1,000,000-ft$^3$ airship is 250 lb/hr at 50 knots, based on figure G-4. The number also appears reasonable when compared to the propulsion studies conducted for the Navy's Advanced Naval Vehicle Concept Evaluation (ANVCE) program.

c. Drag is proportional to the volume to the 2/3 power, other things being equal.

d. Fuel consumption is proportional to power.

e. Dynamic lift for a 1,000,000-ft$^3$ airship at various angles of attack is given by figure G-7.

f. Dynamic lift is proportional to the volume to the 2/3 power, other things being equal.

Figure G-8 is the key to the analysis, since the fuel is the predominant design element. Note that the $\alpha = 0^\circ$ curve does not coincide with zero dynamic lift because the airship car makes the craft profile unsymmetrical and because the forward thrust line is below the envelope axis of symmetry.

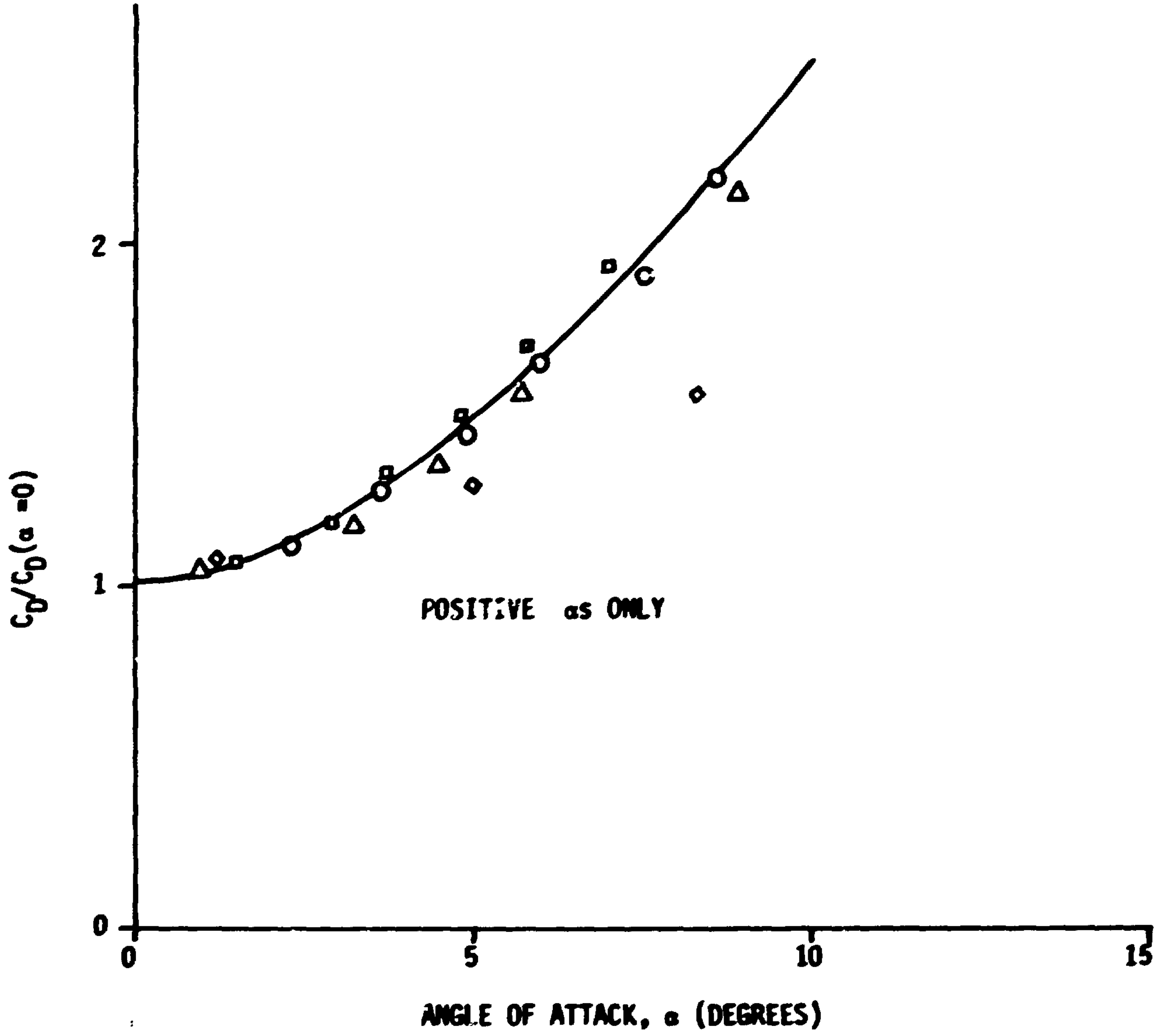


Figure G-6 EFFECT OF ANGLE OF ATTACK ON DRAG OF A ZPG-2 AIRSHIP

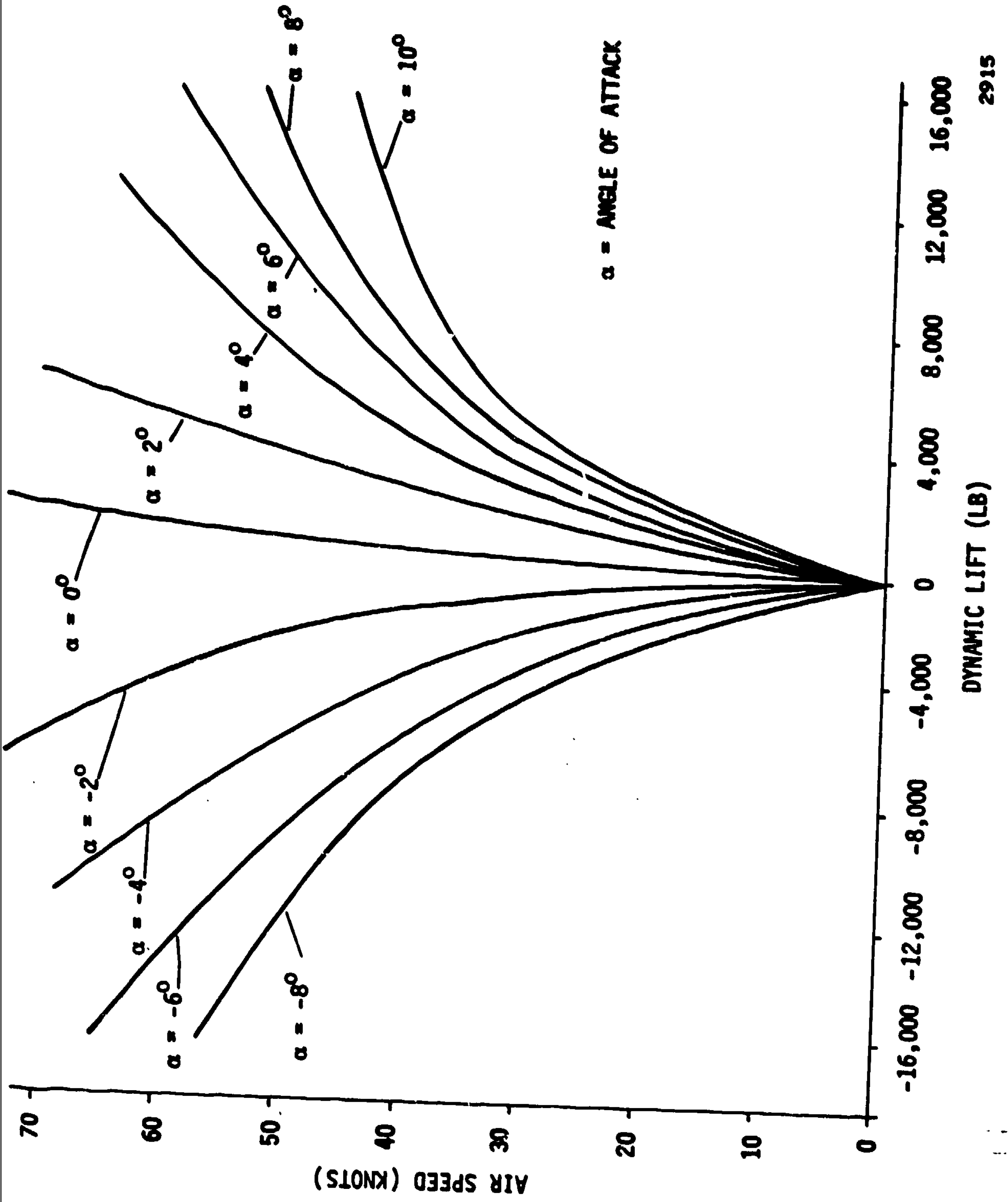
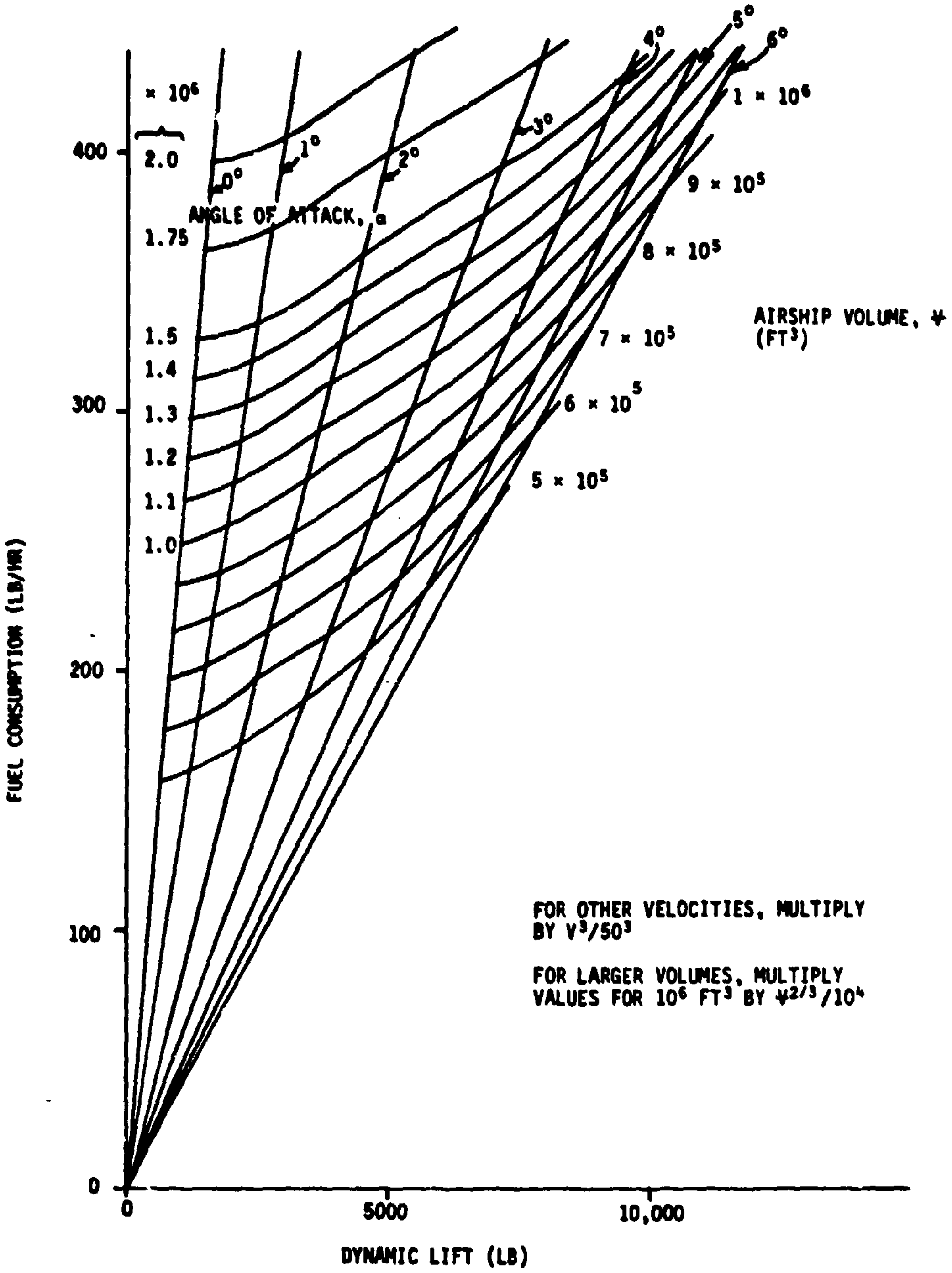


Figure G-7 ZPG-2 DYNAMIC LIFT VERSUS AIRSPEED AND ANGLE OF ATTACK AT SEA LEVEL



FOR OTHER VELOCITIES, MULTIPLY BY $V^3/50^3$

FOR LARGER VOLUMES, MULTIPLY VALUES FOR $10^6$ $FT^3$ BY $\forall^{2/3}/10^4$

Figure G-8 AIRSHIP LIFT/FUEL TRADEOFFS AT 50 KNOTS

## G-5. AIRSHIP SIZING PROCEDURE

Taking the ELT mission as an initial example, the procedure was as follows:

a. Establish the total payload to be carried from the data in appendix E.

b. Select a reasonable trial value for the airship volume, and guess the amount of disposable load (ie, takeoff load minus return load). The dynamic lift required will be just half of that. Given the average dynamic lift and the volume, the fuel consumption at 50 knots can be found from figure G-8.

c. Multiply the fuel consumption, corrected for the proper speed, by the mission time at each speed to get the total fuel-weight consumed. In the ELT mission, most of the time is spent at 50 knots, so assume that low speed, high speed, and hover conditions all balance out at about the same fuel consumption as at 50 knots, and let the whole mission be taken as cruise at 50 knots.

d. Divide the fuel weight by 0.9 to allow for a 10-percent reserve.

e. Add the resulting total fuel weight to the total payload to get takeoff useful load.

f. Subtract 90 percent of the fuel weight and the expendable payload from the takeoff useful load to get the return useful load.

g. Half of the difference between the takeoff useful load and the return useful load is the maximum hover or takeoff rotor thrust required, and also the maximum dynamic lift required. This value should check reasonably well with the original assumption in step b, above. In using figure G-8, however, note that the maximum dynamic lift will occur only at the beginning of the mission, and the maximum negative dynamic lift only at the end, so that the average is about half the maximum. Also note that the dynamic-lift-versus-angle-of-attack curves are not symmetrical, thus this assumption is not precise. Figure G-8 is for positive angles of attack.

h. Iterate steps b through g until the dynamic lift is consistent with fuel consumption.

i. The propulsion module weight is assumed to be 5520 pounds, based on the X-22A minus ducting (ie, with a free propeller).

j. The mass that an airship landing gear must decelerate is approximately proportional to the airship volume. Assume that about 0.005 × volume in $ft^3$ is the weight in pounds of the landing gear, based on some preliminary estimates.

k. The loads designing the outriggers and, therefore, the weight of the outriggers are assumed to be proportional to the sum of the rotor thrust found in step g, the weight of the propulsion system from step i, and the landing gear weight from step j. This assumes that the critical loading is a flight condition with the MPA light and the rotor thrust acting down, as distinguished from the configuration of reference G-1 which cannot have downward thrust. Since the weight is also assumed proportional to the weight of the corresponding framework of reference G-1, see step m, this may be conservative if the reference G-1 design is critical for a landing condition instead of a flight condition.

l. The outrigger weight is also assumed proportional to its length. The fineness ratio of the envelope is assumed to be 4.5, so that the radius is 0.376 $(\text{volume})^{1/3}$. If the intersection of the plane of the rotors with the envelope is at 30 degrees from the horizontal, and the clearance from the rotor axis (based on reference 2) is 1.43 times the rotor radius, the outrigger length is $1.43\ R_R + 0.326\ (\text{volume})^{1/3}$. For purposes of weight estimation, the rotor radius $R_R$ is assumed to be 7 feet (rather than the 3.5 feet of the original X-22A).

m. The framework weight is assumed to be proportional to the weight of the corresponding framework of the HLA operational design in reference G-1. The URTA frame is H-shaped in plan, and the longitudinal carry-through structure is assumed to weigh half as much as the four outriggers.

n. The car weight is assumed to be 500 pounds per crew member, including all crew dependent equipment such as seats, air conditioning, etc.

o. Instruments and standard equipment are assumed to weigh 1300 pounds, based on reference G-3.

p. The airship empennage is assumed to weigh 1 $\text{lb/ft}^2$ of area. The area is taken from figure E-3 using the envelope volume arrived at in steps b through h.

q. The fuel system is assumed to weigh 7 percent of the fuel weight of step d, based on reference G-4.

r. The sum of all weights, less the rotor or dynamic lift of steps g and h, is the net lift required of the envelope.

s. The weight of the envelope is assumed proportional to the net lift required, using the ratio for the $2{,}000{,}000\text{-ft}^3$ operational HLA of reference G-1, where it was 0.325. Since the envelope volume of the MPA must be increased to enable the payload to be carried to 5000 feet without valving helium, the envelope weight is also increased by the appropriate air-density factor (0.8616 for 5000 feet).

t. The gross buoyant lift required is obtained by adding the envelope weight to the previous weight sum.

u. A lift of 0.062 $lb/ft^3$ for helium at sea level is assumed, which corresponds to a conservative helium purity of 94 percent. This is reduced for the 5000-foot altitude by multiplying by 0.8616. The envelope volume is obtained by dividing the buoyant lift required by the unit lift at 5000 feet.

v. The gross weight is obtained by adding the buoyant lift of step t to the dynamic lift. The empty weight is the gross weight minus the useful load of step e.

w. The drag coefficient for a typical airship, based on the volume to the 2/3 power, is about 0.02, as may be seen from table G-1. The drag is given by $D = 0.02q\,(\text{volume})^{2/3}$.

TABLE G-1. AIRSHIP DRAG COEFFICIENTS

| SOURCE (REFERENCE NUMBER) | $C_D$ (BASED ON VOLUME) | FINENESS RATIO | REYNOLDS NUMBER | FULL SCALE OR MODEL |
|---|---|---|---|---|
| Eshbach (G-5) | 0.022 | ? | $>2.00 \times 10^5$ | Model |
| Arnstein & Klemperer (G-6) | 0.019<br>0.022<br>0.025 | Macon<br>Los Angeles<br>Bodensee | ? | Full Scale |
| Strumpf (G-7) | 0.019 | 4.18 | $2.22 \times 10^8$ | Full Scale From Model Data |
| Goldschmied (G-8) | 0.024<br>0.021 | 4.5<br>4.0 | $2.16 \times 10^6$<br>$2.16 \times 10^6$ | Model |

x. From figure G-2, it may be seen that at 5000 feet and 90 knots, 2200 pounds per unit is available with a 7-foot-diameter free propeller and 2720 pounds with a 14-foot free propeller. (From figure G-1, it can be seen that a ducted 7-foot propeller would have about the same thrust as the 14-foot free propeller.) There are four units, and it is assumed that there are no losses in efficiency for the aft propellers because of prop wash from the forward propellers.

y. Comparison of the available thrust with the drag should show that enough thrust is available to drive the airship at 90 knots.

z. With the airship size obtained by this procedure, the fuel consumption is rechecked. If the fuel consumption differs greatly from the original assumption, the entire calculation must be iterated until reasonable agreement between initial and final values is reached.

aa. Two of the missions (SAR and MO/MP) include a significant amount of towing. In the SAR mission, it is required to tow a small ship at 6 knots for 8.3 hours. A relationship between the drag of a ship in calm water and its length, velocity, and displacement is given on page 90 of reference G-9. Three specific vessels were fitted to the relationship to get the lower curve in figure G-9. The upper curve is an estimate assuming the drag to be doubled in waves, plus an allowance for aerodynamic drag due to a 25-knot head wind. Comparison of figure G-9 with the airship drag suggests that the sum of ship drag and airship drag at 6 knots should be no greater than the airship drag at a 70-knot airspeed. There is a downward force on the airship from the cable tension, but it is a function of the tow cable angle and is probably not critical. Thus, for estimating fuel consumption, the SAR tow condition is assumed equivalent to the same amount of time at 60 knots.

bb. The MO/MP towing requirement is more complicated. A submerged array is to be towed at 10 knots, alternating with equal periods when the sonar device is carried out of the water at 30 knots. The cable tension in the first case is estimated at 2300 pounds. The weight of the towed array is 1200 pounds, exclusive of a 300-pound signal processor which remains on board. Assuming that the drag of the array is such as to leave the vertical component of the cable tension at 1200 pounds avoids complications of vertical equilibrium of the MPA and yields a drag of 1960 pounds during tow. This drag is added to the estimated MPA drag at 10 knots and zero angle of attack; the airspeed giving the same drag without the tow is calculated and used as the equivalent speed for estimating fuel consumption. The resultant equivalent speed was 55 knots. For the alternating periods when the array is carried in the air, a drag of 100 pounds is estimated for the array. Adding this drag to the airship at 30 knots and zero angle of attack gives, for fuel consumption, an equivalent 32.5-knot airspeed.

The results of the analyses are presented in table G-2. One significant result is that the 9-knot dash requirement is easily met in all cases with the assumed propulsion system, as are the VTOL thrust requirements. Superficially, it appears that the X-22A propulsion system is larger and heavier than needed for the MPA. However, this does not take into account the desirability of the airship to hold position while hovering in a crosswind. Precision hover capability is a function of the thrust components available from the propulsion system, as discussed later. A propulsion system without reversible thrust, when the airship is at or near neutral buoyancy, must essentially be idling and, hence,

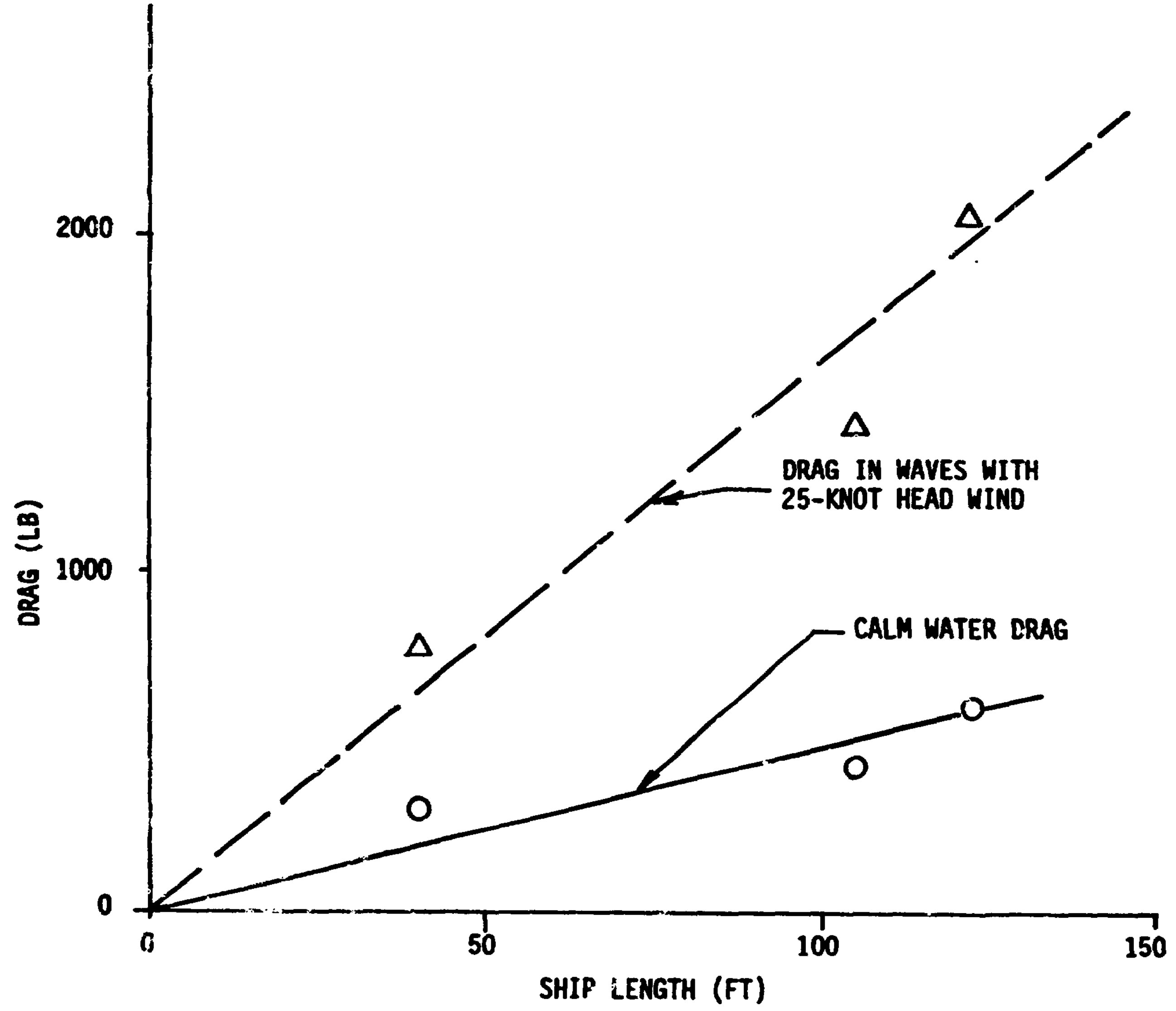


Figure G-9 SHIP TOW DRAG AT 6 KNOTS VERSUS SHIP LENGTH

## TABLE G-2. MPA DESIGNS WITH X-22A PROPULSION (FREE PROPELLER)

| MISSION DATA | ELT | MEP | MD/MP | PSS | SAR | A/N | MSA | IO |
|---|---|---|---|---|---|---|---|---|
| Max Altitude with Payload (ft) | 5000 ft | 5000 ft | 5000 ft | 5000 ft | 5000 ft | 5000 ft | 5000 ft | 5000 ft |
| Total Mission Time (hr) | 27.5 hr | 12.5 hr | 7.5 @ 55 kt | 6 @ 30 kt | 11.3 hr @ 60 kt | 17.0 hr | 5.5 hr @ 40 kt | 20.5 hr |
| Cruise Speed (kt) | 50.0 kt | 50.0 kt | 7.5 @ 32.5 kt<br>1.0 @ 90.0 kt<br>10.5 @ [illegible]0.0 kt | 2.35 @ 40 kt | 0.3 hr @ 90 kt<br>20 hr @ 30 kt | 50 kt | 30 hr @ 60 kt | 60 kt |
| Fixed Payload (lb) | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 | 4,420 |
| Variable (Mission) Payload (lb) | 3,250 | 17,950 | 6,510 | 1,820 | 2,490 | 2,980 | 3,340 | 3,060 |
| Total Payload (lb) | 7,670 | 22,370 | 10,930 | 6,240 | 6,910 | 7,400 | 7,760 | 7,480 |
| Expendable Payload (lb) | 350 | 16,060 | [illegible] | 140 | 200 | 600 | 450 | 170 |
| Crew, 200 Lb Each (lb) | 2,200 | 1,200 | 2,200 | 1,200 | 1,600 | 1,600 | 2,200 | 1,200 |
| Estimated Volume (ft$^3$) | 850,000 | 550,000 | 940,000 | 550,000 | 730,000 | 700,000 | 1,050,000 | 800,000 |
| Fuel Consumption @ 50 kt (lb/hr) | 230 | 300 | 245 | 165 | 210 | 200 | 300 | 225 |
| Fuel (100% Cruise) (lb) | 7,030 | 4,170 | 6,330 | 460 | 5,070 | 3,870 | 17,280 | 8,860 |
| Takeoff Useful Load (lb) | 14,700 | 26,540 | 17,260 | 6,700 | 11,980 | 11,180 | 25,040 | 16,340 |
| Return Useful Load (lb) | 8,020 | 6,730 | 11,260 | 6,150 | 7,220 | 7,100 | 9,320 | 8,200 |
| Rotor Thrust (VTOL) or DL (lb) | 3,340 | 9,910 | 3,000 | 280 | 2,380 | 2,040 | 7,860 | 4,070 |
| Propulsion Module Weight (lb) | 5,520 | 5,520 | 5,520 | 5,520 | 5,520 | 5,520 | 5,520 | 5,520 |
| Landing Gear Weight (lb) | 4,250 | 4,750 | 4,700 | 2,750 | 3,650 | 3,500 | 5,250 | 4,000 |
| Outrigger Struct Load (lb) | 13,120 | 20,180 | 13,220 | 7,850 | 11,550 | 11,060 | 18,630 | 13,590 |
| Rotor Radius (ft) | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 |
| $1.43(0) + 0.326(F)^{1/3}$ (ft) | 40.6 | 42.1 | 41.9 | 36.7 | 39.4 | 39.0 | 43.1 | 40.3 |

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## TABLE G-2 (Cont)

| MISSION DATA | ELT | MEP | MD/MP | PSS | SAR | A/N | MSA | IO |
|---|---|---|---|---|---|---|---|---|
| Outrigger Weight (lb) | 1,120 | 1,790 | 1,170 | 610 | 960 | 910 | 1,690 | 1,150 |
| Carry-Through Struct Length (ft) | 81.2 | 84.2 | 83.8 | 73.4 | 78.8 | 78.0 | 86.2 | 80.4 |
| Carry-Through Struct Weight (lb) | 560 | 890 | 580 | 300 | 480 | 450 | 850 | 580 |
| Car Weight (lb) | 5,500 | 3,000 | 5,500 | 3,000 | 4,000 | 4,000 | 5,500 | 3,000 |
| Instruments & Std Equip (lb) | 1,300 | 1,300 | 1,300 | 1,300 | 1,300 | 1,300 | 1,300 | 1,300 |
| Empennage Wt @ 1.0 lb/ft$^2$ (lb) | 2,670 | 2,880 | 2,860 | 2,050 | 2,420 | 2,360 | 3,080 | 2,560 |
| Fuel System (@ 7% of H) (lb) | 490 | 290 | 440 | 30 | 350 | 260 | 1,210 | 620 |
| Envelope Net Lift (lb) | 32,770 | 37,050 | 36,330 | 21,980 | 28,280 | 27,440 | 41,580 | 31,000 |
| Envelope Group Weight (lb) | 12,360 | 13,980 | 13,700 | 8,290 | 10,670 | 10,350 | 15,680 | 11,690 |
| Envelope Gross Lift Req (lb) | 45,130 | 51,030 | 50,030 | 30,270 | 38,950 | 37,790 | 57,260 | 42,690 |
| Envelope Volume (ft$^3$) | 844,800 | 955,200 | 936,600 | 566,700 | 729,100 | 707,400 | 1,072,000 | 799,200 |
| Gross Weight (lb) | 48,470 | 60,940 | 53,030 | 30,550 | 41,330 | 39,830 | 65,120 | 46,760 |
| Empty Weight (lb) | 33,770 | 34,400 | 35,770 | 23,850 | 29,350 | 28,650 | 40,080 | 30,470 |
| Drag @ 90 kt (lb) | 4,230 | 4,590 | 4,530 | 3,240 | 3,830 | 3,750 | 4,950 | 4,070 |
| Available Thrust @ 90 Kt @ Alt | 10,880 | 10,880 | 10,880 | 10,880 | 10,880 | 10,880 | 10,880 | 10,880 |
| Altitude (ft) | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 |
| Reestimated Fuel/Hr @ 50 Kt (lb) | 230 | 300 | 258 | 170 | 210 | 202 | 300 | 225 |

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incapable of providing lateral thrust. The Bell URTA, in the same condition, reverses two diagonally opposite propellers while running each pair at whatever power is needed. The more power available, the greater the precision-hover capability. Assuming a 10-degree-vector tilt to be a practical response to a lateral gust, table G-3 shows that the X-22A system can provide a crosswind hover capability of between 20 and 30 knots for any of the configurations in table G-2, but that if the thrust is limited to the maximum otherwise needed for the mission, the crosswind hover capability is as low as 12 knots. In case of engine outage, crosswind hover is possible if the remaining engines are geared to drive all four rotors; loss of half the power, for example, would reduce the values in table G-3 by 20.6 percent. Otherwise, the airship must be headed into the wind.

TABLE G-3. PRECISION-HOVER CAPABILITY AT SEA LEVEL (10-DEGREE-VECTOR TILT)

| | MISSION | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ELT | MEP | MO/MP | PSS | SAR | A/N | MSA | IO |
| | CROSSWIND VELOCITY (KNOTS) | | | | | | | |
| ull Thrust -Ft Free Propeller (13,940 Lb) | 20.8 | 20.0 | 20.1 | 23.8 | 21.8 | 22.1 | 19.2 | 21.2 |
| Full Thrust 14-Ft Free ropeller (22,120 Lb) | 26.2 | 25.2 | 25.3 | 30.0 | 27.5 | 27.8 | 24.2 | 26.7 |
| Ma Thrust Required ble G-2) | 12.3 | 16.8 | 12.3 | 12.3 | 12.3 | 12.3 | 14.4 | 12.3 |

## G-6. COMPARISON OF COMPUTER AND MANUAL AIRSHIP DESIGN APPROACHES

The computer design approach and the simplified manual design approach were used in parallel to define a design for each of the specific missions. Some overall comparisons can be made using the results in that general observations of design trends can be made. However, no direct comparisons of the two designs can be made because the basic assumptions of the two approaches are substantially different.

Table G-4 briefly summarizes the differences between the computer and manual design approaches. The table lists most of the significant differences; the one most significant difference is in the propulsion system. The computer approach uses a rubberized propulsion system whereas the manual approach uses a fixed, X-22A propulsion unit weight and thrust for all MPA sizes.

Figure G-10 shows the differences in the envelope volume obtained by the two approaches. The smaller the payload and mission duration requirement, the greater the difference in the required airship volumes to accomplish the mission. It takes extra volume to support the extra weight of the oversized, fixed propulsion system used in the manual approach. The computer design approach, which minimizes the propulsion system weight for the mission requirement, tends to give a much smaller airship volume for the smaller payload requirements. On the other hand, for the higher payload missions, the MPA volumes tend to be closer because the computer rubberized-propulsion-system weights are closer to the fixed X-22A propulsion weights of the manual approach.

Also contributing to the differences, the computer design uses the explicit mission profile specified for each case, while the manual design approach approximates the profile. The manual approach designs for a 5000-foot operating altitude and the larger propulsion system always provides a 90-knot or greater dash speed, whether called for by the explicit mission profile or not. There are also some differences in the drag coefficients assumed.

There is also some difference in the general philosophy of design in the two approaches. The computer airship design program is configured so that the airship is designed to have the buoyant lift support the vehicle empty weight plus 50 percent of the disposable load. This was done so that the airship is designed to fly at the smallest possible angle of attack, minimizing drag and, hence, fuel consumption. This design is then checked for the horsepower required to achieve dash speed. If the horsepower required for dash is less than that required for hover, such as in the MEP mission, the airship simply has a dash speed capability greater than that required. If, however, the dash speed requires a propulsion horsepower greater than that required for hover, as in the ELT, MO/MP, and SAR missions, the dash propulsion

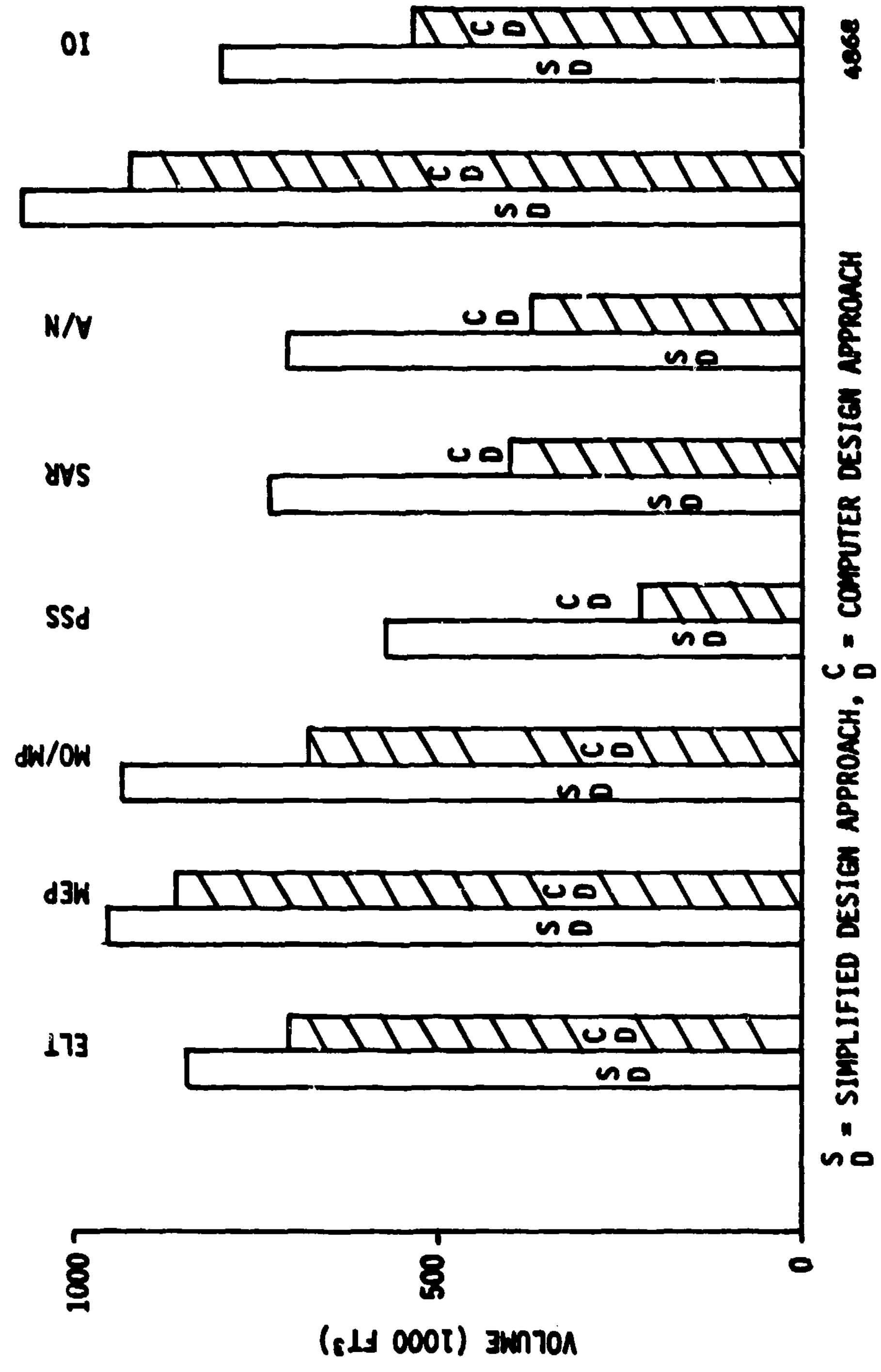


Figure G-10 MPA VOLUMES - VARIOUS MISSION DESIGNS

TABLE G-4. COMPARISON OF COMPUTER AND MANUAL MPA DESIGN APPROACHES

| COMPUTER | MANUAL |
|---|---|
| 1. Uses rubberized propulsion system | 1. Uses modified X-22A propulsion unit weights and thrust |
| 2. Uses NASA CR 151976 (ref G-3) equations for major subsystems (ie, ENV WT ∝ VOL, $W_{PS}$ ∝ $T_{PS}$) | 2. Uses original HLA subsystem weights proportioned by size or load |
| 3. Adds 665 lb/person for car with larger crew, A/C, and furnishings | 3. Adds 500 lb/person for car, A/C, and furnishings |
| 4. Adds empennage weights at half are of historic airship tails and 1 lb/$ft^2$ | 4. Uses empennage weight based on historical designs |
| 5. Adds 5 percent fuel system weights | 5. Adds 7 percent fuel system weights |
| 6. Assumes navigation instruments and electronics in avionics suite | 6. Includes an added 577 lb of instrumentation and electronics over avionics and sensor suites |
| 7. Fuel weights based on constant specific fuel consumption = 0.5 lb/hp/hr for each mission profile | 7. Fuel consumption is based on historic airship data assuming an average angle of attack for the entire mission |
| 8. Airship is sized for maximum power required by either hover, tow, or dash conditions | 8. Airship sized for buoyant lift to support airship weight + 1/2 disposable load |

horsepower governs the design and that propulsion horsepower is also used to configure the airship for hover. In these cases, utilization of the larger dash propulsion thrust permits a reduction in the envelope size required for hover. This envelope size reduction thereby permits a further reduction in envelope drag and dash horsepower, and the two conditions are iterated to minimize the airship envelope and the propulsion size.

The manual approach also sizes the design so that the buoyant lift supports the airship weight plus 50 percent of the disposable load, and the MPA can fly at the minimum angle of attack in the same manner as the computer approach does for the dominant hover condition. However, in this case, no volume reductions are incorporated to utilize the larger propulsion thrust for the hover condition. Only part of the vertical thrust capability is used, and the buoyant lift must still support the structural weight and 50 percent of the disposable load. But, table G-5 shows that for a 1 × $10^6$ $ft^3$ airship at a speed of 60 knots, vertical lift can be achieved more efficiently with less drag

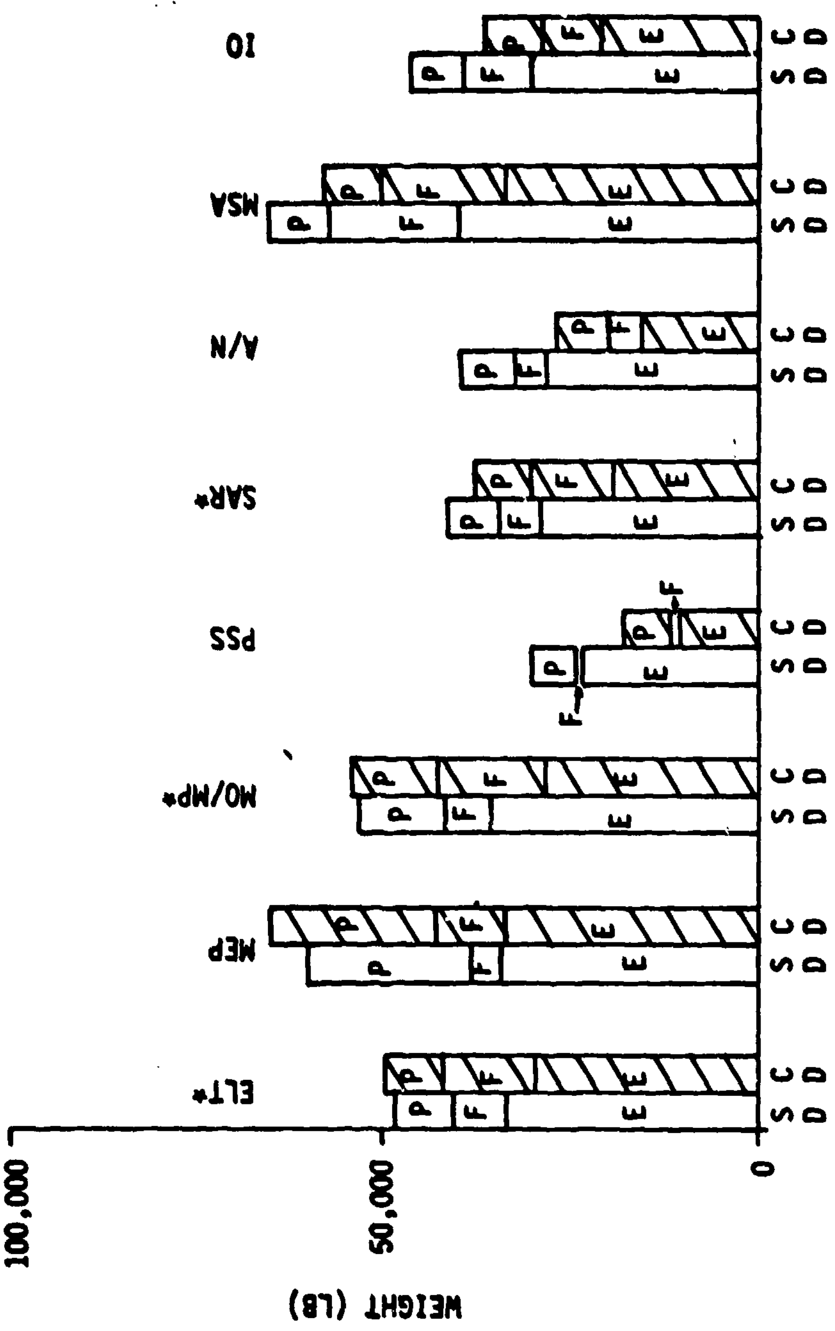
## TABLE G-5. SIZE-VERSUS-ANGLE-OF-ATTACH (α) TRADEOFF

| (α) DEG | L = LIFT<br>D = DRAG | TOTAL LIFT AND DRAG AT 60 KNOTS | | | |
|---|---|---|---|---|---|
| | | $\mathcal{V}_0$ 1.0 × $10^6$ ($FT^3$) | $\mathcal{V}_1$ 1.1 × $10^6$ ($FT^3$) | $\mathcal{V}_2$ 1.2 × $10^6$ ($FT^3$) | $\mathcal{V}_3$ 1.3 × $10^6$ ($FT^3$) |
| 0 | L<br>D | 63,463<br>2,439 | 69,760<br>2,599 | 76,053<br>2,755 | 82,343<br>2,906 |
| 2 | L<br>D | 67,000<br>2,683 | 73,529<br>2,859 | 80,047<br>3,030 | 86,540<br>3,196 |
| 4 | L<br>D | 72,367<br>3,293 | 79,253<br>3,509 | 86,114<br>3,719 | 92,956<br>3,922 |
| 6 | L<br>D | 77,733<br>4,025 | 84,969<br>4,289 | 92,171<br>4,545 | 99,345<br>4,794 |
| 8 | L<br>D | 81,043<br>4,512 | 90,686<br>5,329 | 98,229<br>5,647 | 105,735<br>5,956 |
| 10 | L<br>D | 88,498<br>6,226 | 96,436<br>6,628 | 104,322<br>7,024 | 112,162<br>7,409 |

by an increase in airship volume, rather than a large increase in flight angles of attack. In other words, there is a cross-over point, since it is more efficient to use dynamic lift at small angles of attack and at 90 knots.

This essentially means that an airship designed for a higher dash speed, when operated at low speeds, will use more fuel than one actually designed for the low-speed operation. The ultimate tradeoff must be examined in terms of life-cycle costs, which is beyond the scope of the present program.

Figure G-11 shows that the empty weight of the computer airship design is always less than that of the manual airship design. However, in the case of the larger airships such as the ELT, MEP, and MO/MP designs, which have the higher dash speeds, the total weights for the computer designs exceed those of the manual designs because of the added fuel weight determined by the computer iterations.



E = EMPTY WEIGHT, F = FUEL WEIGHT, P = PAYLOAD

$S_D$ = SIMPLIFIED DESIGN APPROACH, $C_D$ = COMPUTER DESIGN APPROACH

*90-KNOT DASH

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Figure G-11 MPA WEIGHTS - VARIOUS MISSION DESIGNS

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# APPENDIX H

# FUEL CONSUMPTION ANALYSIS

For the computer analysis, a single large propulsion unit with a specific fuel consumption (SFC) of 0.5 lb/hp/hr was used as a simplifying assumption to generate the airship parametric data in this report.

This assumption is valid because there are several counterbalancing factors that affect the fuel consumption. The SFC of gas turbines is normally sensitive to throttle setting, and when the engine is not being run at maximum rated power, the SFC can increase significantly. On the other hand, a larger number of propulsion units is more efficient than a smaller number of units. Moreover, the staging of multiple units is also possible.

However, because the missions for the MPA require large amounts of time at low speed, the computer program was later modified for subsequent design studies and to investigate the validity of the simplifying assumption of constant SFC (assumption A). A brief investigation based on Advanced Naval Vehicle Concept Evaluation (ANVCE) fuel consumption studies (reference H-1) was made, taking into account not only the increased SFC at low power, but also the quad-rotor design, which allows one, two, or three engines to be shut down during loiter or low-speed periods of a mission (assumption B). The results are compared in figure H-1 for the ELT mission and in table H-1 for best ELT mission designs.

As the table shows, the assumption of SFC = 0.5, as compared with assumption B with the minimum SFC = 0.5, is optimistic by 2 or 3 percent on volume and vehicle weight and by 7 percent on fuel weight in this example. Therefore, the results in the main body of this report correspond to a minimum SFC of slightly lower than 0.5. Such differences appear to be well within the tolerance of the other analysis assumptions. If, however, for future analysis, it is desired to incorporate the refinement of variable throttle settings, the capability now exists in the program to do so.

## REFERENCE

H-1. *Standard Power Plant Characteristics for Advanced Naval Vehicles in the 1980-2000 Time Period* (ANVCE Working Paper 011, Initial Issue, August 31, 1976).

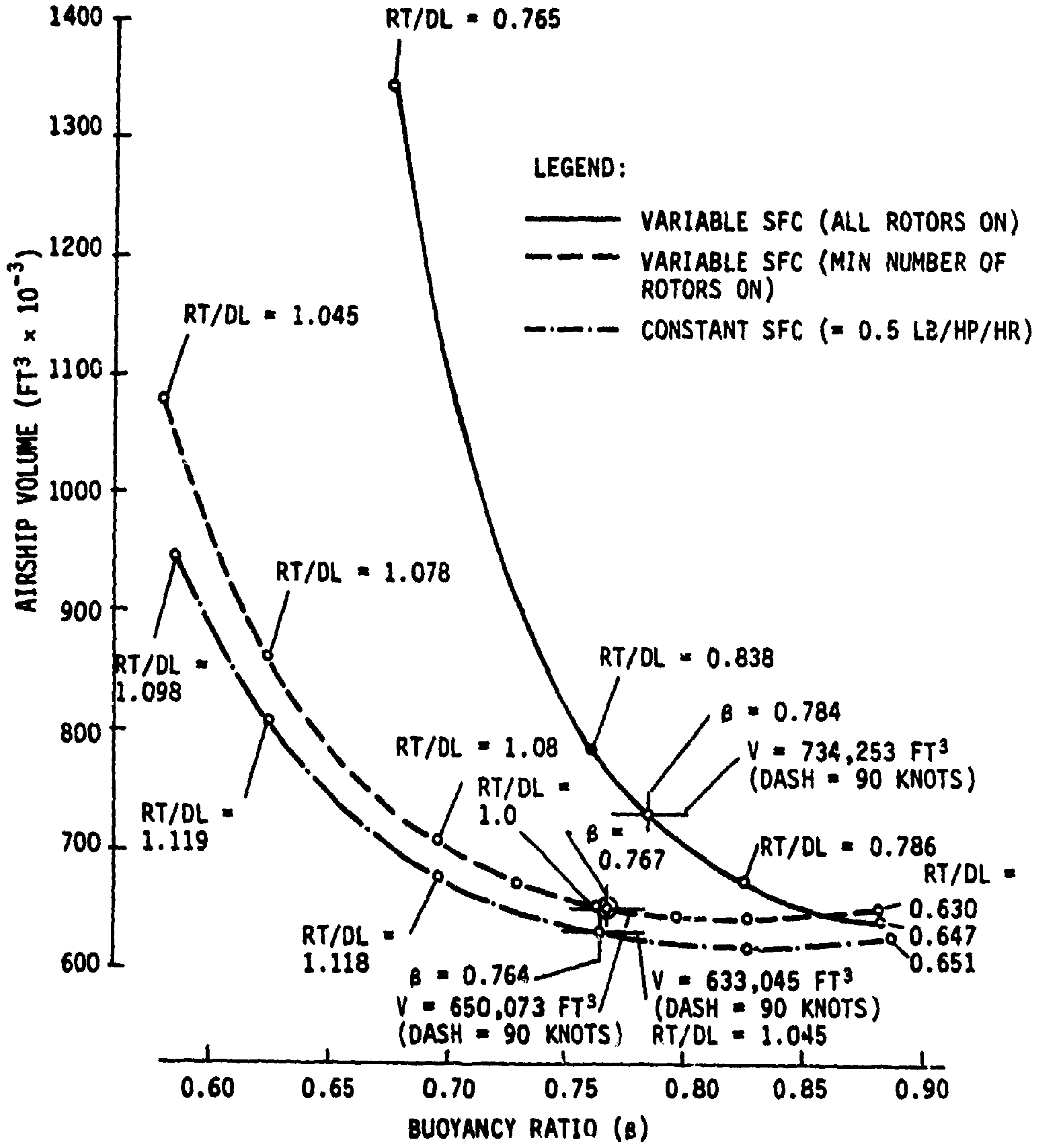

Figure H-1 AIRSHIP VOLUME VERSUS BUOYANCY RATIO FOR ELT MISSION

TABLE H-1. EFFECTS OF SPECIFIC FUEL CONSUMPTION ASSUMPTIONS
(ELT MISSION, MINIMUM SFC = 0.5)

| ITEM RATIO | $\frac{\text{ASSUMPTION B}}{\text{ASSUMPTION A}}$ |
|---|---|
| Airship Volume | 1.028 |
| Airship Empty Weight | 1.025 |
| Vehicle Gross Weight | 1.030 |
| Fuel Weight | 1.072 |
| Horsepower Required for Hover | 1.050 |
| Maximum Horsepower Required for Cruise | 1.016 |

# APPENDIX I

## SUBSYSTEM DESIGN INVESTIGATIONS

## I-1. INTRODUCTION

To investigate the weight of some major subsystems, calculations were made to investigate outrigger and framework weights, and landing gear and flotation gear weights. For these calculations, a typical airship volume of 800,000 ft$^3$ was used with a maximum envelope radius of 36 feet. In most of the analysis, loads were based on an early MPA mission configuration, but each rotor was assumed to deliver a maximum thrust of 3500 pounds, based on the X-22A propulsion system.

## I-2. FRAME

A brief investigation of the best method of supporting the propulsion units and the car was made. The propulsion units are assumed to be centered along a line that is 45 degrees below the horizontal from the center of the envelope, and that extends 45 feet from the envelope center. The car weight is assumed concentrated at the vertical centerline. Also, the propulsion units are assumed to be 54 feet apart, forward to aft.

The three different basic types of structure considered were a yoke design, consisting of outriggers extending out from the car and upward along the envelope to the level of the propulsion units, a stiff ring support running around the full circumference of the envelope, and a spoked ring, otherwise similar to the stiff ring. A limit load factor of 1.5 with the usual 1.5 factor of safety for aircraft was assumed; however, the use of large amounts of rotor or dynamic lift will increase g-loadings over those experienced by conventional, fully buoyant airships.

A triangular truss section made of welded 6061-T6 round tubing was assumed for the ring, and compared with a similar yoke design. The weight of the car and carry-through structure is assumed carried out in the internal suspension system without causing any bending moment in the carry-through structure. Also, half of the engine thrust loads are carried into the envelope through the internal suspension, and half through an external suspension. Essentially, the carry-through structure is assumed to be a uniformly loaded beam on end supports. With the ring design, it is assumed that at least most of the car loads would be transferred by bending of the carry-through structure to the rings, rather than through the suspension system, and thence to the envelope. The ring bending moments were calculated using conventional ring equations, assuming the engine and car load components as concentrated normal and shearing forces and couples.

The estimated weight of the rings, carry-through structure, and outriggers was 4888 pounds, and for the yoke design and carry-through structure, 2373 pounds. However, the suspension system for the ring design might be partially or even entirely eliminated.

Some preliminary analysis was done on the spoked ring, but this type of structure is too redundant for a brief investigation.

## I-3. LANDING GEAR

Based on reference I-1, a taxi condition and a landing condition were checked. The load for taxiing was assumed to be equal to the rotor thrust of 13,940 pounds, divided equally among the three wheels. A 1.5 safety factor and a side load equal to 0.8 times the vertical reaction in any lateral direction were assumed.

However, the landing load was more critical. For it, 1.5g (limit) minus the buoyant lift were assumed, where 0.5g is the acceleration of the airship mass and 1.0g is the static weight of the airship with its maximum heaviness. The mass of the airship must include the mass of its helium, which in a vacuum weighs 0.0765 - 0.062 = 0.0145 lb/ft$^3$ at standard conditions (including the impurity factor). There is also an additional mass of air to be decelerated, although it is not clear how much of it creates load on the landing gear. For an envelope with a fineness ratio of 4.5, this additional mass is 87 percent of the mass of the air displaced by the airship (reference I-2, p 36). For the 845,000-ft$^3$ ELT airship, the estimated gross weight is 48,470 pounds and the buoyant lift 45,130 pounds, leaving 3,340 pounds of heaviness. The airship mass, including helium, is 60,720 pounds, and the additional mass of air is 56,240 pounds. The total, vertical landing-gear load is then 3,340 + 0.5(60,720 + 56,240) = 61,820 pounds. Assuming a two-wheel landing, the ultimate load per wheel would be 61,820 (1.5)/2 + 46,360 pounds. For a drift landing, a side load of 0.8(46,360) = 37,090 pounds inward may occur (reference I-1).

An analysis of the landing-gear design sketched in figure I-1 led to a main landing-gear framework weight of 1700 pounds, assuming 180,000 psi heat-treated alloy steel tubing. Wheels, brakes, retraction mechanism, oleo struts, and bearings are estimated to add 1100 pounds, and about 200 pounds are allowed for car reinforcement. The forward gear weight is proportioned to half of the X-22A main-gear weight times the ratio of ultimate landing-gear loads, based on 3g at maximum gross weight for the X-22A, which gives 500 pounds. The total landing-gear weight is then 3500 pounds, exclusive of floats.

## I-4. FLOATS

To support the maximum airship heaviness, a flotation volume with a margin of 50 percent is required. For the 845,000 ft$^3$ ELT airship, this would be (3340)(1.5) = 5010 pounds, which requires a displacement of 78.3 ft$^3$ in sea water or 80.3 ft$^3$ in fresh water. The lateral drag force on this size airship would be about 2000 pounds in a 30-knot wind. Dividing this among four floats gives 500 pounds per float; however, add 50 percent for waves to make this 750 pounds per float.

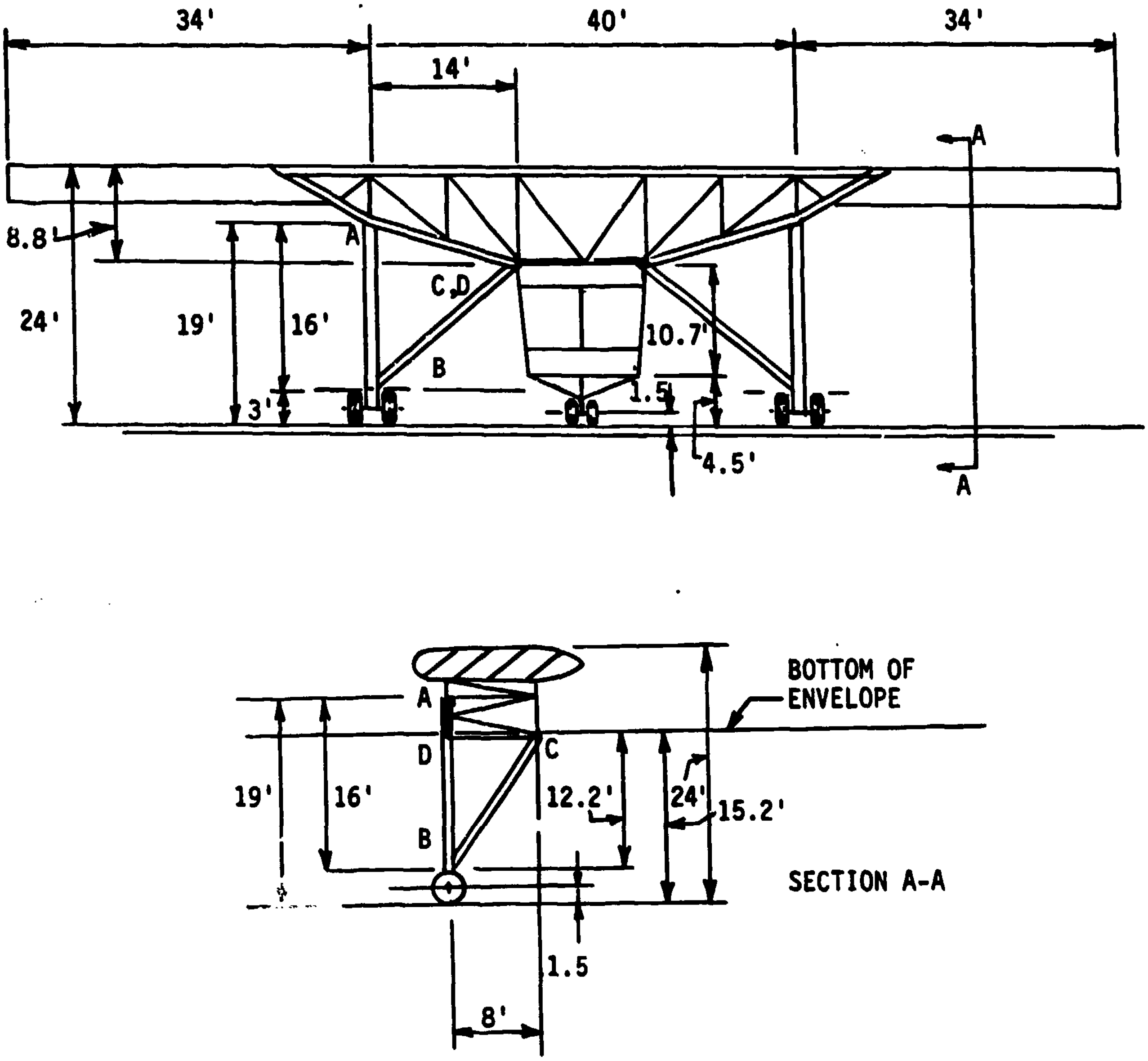
34'
40'
34'
14'
A
8.8'
24'
19'
16'
A
C,D
B
10.7'
1.5
3'
4.5'
A
BOTTOM OF ENVELOPE
A
D
C
B
19'
16'
12.2'
24'
15.2'
1.5
8'
SECTION A-A

Figure I-1 LANDING GEAR

A relation between the diameter (d) and the immersion (x) for a cylindrical float (in sea water) is

$$(64\pi)(d^2/4)(x) = 78.3(1728)/4 \, ^* \qquad \text{(I-1)}$$

Also, for bending,

$$I/c = \pi d^3/16 \quad . \qquad \text{(I-2)}$$

The critical condition is assumed to occur when the bending compressive stress plus the axial compressive stress, due to the weight supported, equals the tension in the fabric due to the inflation pressure at limit loads:

$$pd/4 = Mc/I + P/\pi d \qquad \text{(I-3)}$$

(The actual collapse moment will, for practical fabric materials, be more than 1.5 times as great as the critical moment defined by this relationship). The side load for bending is assumed to be uniformly distributed below the water. For the aft floats, the maximum bending moment is assumed to occur at the water surface where the float can be assumed to be supported by the landing gear. For the forward floats, the bending moment is assumed to be approximately 3 times as great. By eliminating x from equations (I-1) and (I-3) (M being a function of x), an equation of the form

$$Ad^6 - Bd^4 - C = 0 \qquad \text{(I-4)}$$

may be obtained and solved by trial for d, provided the inflation pressure (p) is known.

The maximum permissible value for p is limited by the fabric strength. Assume a maximum fabric strength of 500 lb/inch, and a factor of safety of 5 to cover overload, material degradation, and creep or fatigue phenomena. Then, since the hoop stress is pd/2, p = 200/d, and the equation to be solved is reduced to fifth order. Table I-1 gives the results.

Assuming a strength-to-weight ratio of 300,000 inches for a coated fabric suitable for this application, the fabric weight for two forward floats is about 76 pounds and for the aft floats, 70 pounds. To this should be added the weight of the compressed air inflating the floats (a total of about 13 pounds), about 10 percent for seams, and an increment for canisters, pumps,

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*For four floats.

TABLE I-1. RESULTS

| Aft Floats | Forward Floats |
|---|---|
| d = 19.3 in. | d = 24 in. |
| x = 9.63 ft | x = 6.25 ft |
| p = 10.6 psi | p = 8.33 psi |

attachments, etc; these are assumed to double this weight to give a total of around 400 pounds for all four floats.

The forward floats might be supplemented or perhaps replaced by a simple bag float under the pilot's compartment.

The system could further include sea anchors. These might be placed at the forward outriggers, if floats are not extended there, and at the nose and tail. A winching system would be required, plus compartments for storing the sea anchors. Local loads on the envelope would require reinforcement. If sea anchors are not used, however, it will be necessary to use floats extending deeper into the water than the above calculations assumed, in order to reduce vertical motions due to wave action. An allowance of an additional 350 pounds is included in the landing-gear weight (which includes floats and/or sea anchors) in table G-2 of appendix G to give a total weight of 4250 pounds.

## REFERENCES

I-1. *Ground Loads* (Issued by the Subcommittee on Air Force-Navy-Civil Aircraft Design Criteria of the Munitions Board Aircraft Committee, U.S. Government Printing Office, October 1952) ANC 2.

I-2. *Aerodynamic Theory* (New York: Dover Publications, Inc., William F. Durand, ed., 1963) volume VI, p 36.