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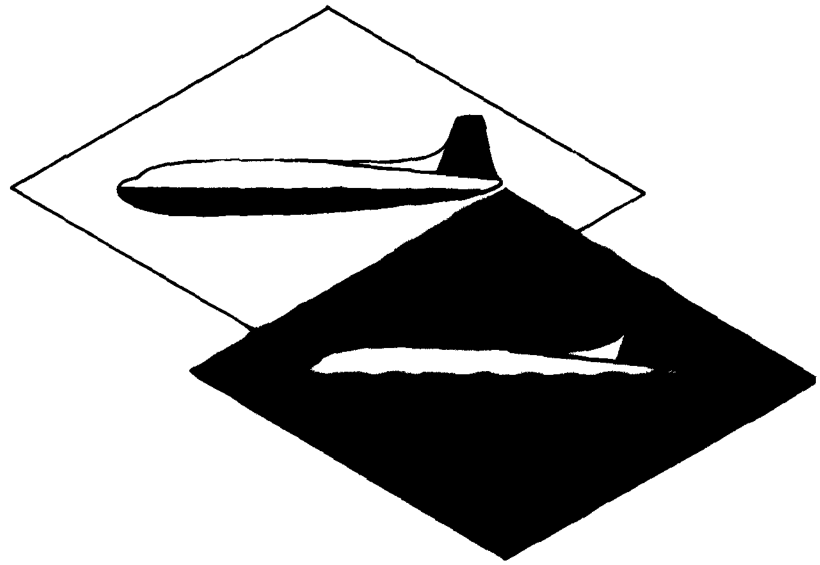
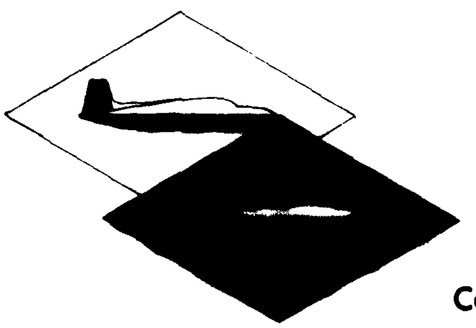


THE ROLE OF PAINT IN MID-AIR COLLISION PREVENTION

DECEMBER 1961



Contract FAA/BRD-127
Project Tasks 8 and 18

Prepared for FEDERAL AVIATION AGENCY by
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THE ROLE OF PAINT

IN

MID-AIR COLLISION PREVENTION

Final Report (One of Five)

December 1961

prepared for

Federal Aviation Agency

under

Contract FAA/BRD-127

Project Tasks 8 and 18; and
Portions of Tasks 1, 3, 6, 10, 12, 13, 14

by

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This report has been prepared by the Applied Psychology Corporation for the Aviation Research and Development Service (formerly Bureau of Research and Development), Federal Aviation Agency, under Contract No. FAA/BRD-127. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the ARDS or the FAA.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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John E. Robinson, Jr.
Program Director

Applied Psychology Corporation, Arlington, Virginia
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ABSTRACT

This report summarizes that portion of a research program on visual collision avoidance techniques which deals with the use of exterior surface treatments. Specifically, the aim of the research was to identify the human factors considerations and the related design requirements for a maximally effective paint pattern. Methods and results of laboratory studies, field observations, and flight tests designed or conducted in this program are summarized, and pertinent literature is reviewed. Economic considerations in applying and maintaining paint treatments are described.

Findings indicate that, for conspicuity purposes, some paint on the exterior surfaces of an aircraft is measurably better than no paint. The primary function of paint would seem to be to provide information useful in making collision avoidance maneuvers at close- or intermediate-ranges, hence standardized paint patterning principles are essential. An optimum standardized pattern would have to include elements for positive and negative brightness contrast, and color contrast. This is best accomplished with high-reflectance paints on upper surfaces of fuselage, low-reflectance paints on under surfaces, and color on fixed surfaces of empennage. Fluorescent paints in the orange and red portions of the spectrum are to be preferred over other colors where visual recognition of color is important. However, present methods for applying and maintaining these paints are relatively expensive and complicated. The contractor feels that the Federal Aviation Agency should encourage the use of fluorescent paints or films for their conspicuity value in close- and intermediate-range situations, but at the option of the aircraft owner or operator.

I. HISTORICAL BACKGROUND

Aircraft surfaces have historically constituted a basic aid to visual detection. Even though the earliest flying machines, when viewed from some angles, presented little more than a network of wires and struts, they presented from other directions broad expanses of fabric or wood. The visibility of most present-day airplanes during daytime flight depends heavily upon their exterior surfaces, which reflect and absorb light in distinctive ways. Whether these surfaces are fabric, wood, metal, or plastic, they provide solid areas which may be treated in one or more ways to increase aircraft visibility.

A broad variety of treatments has been used. Fabrics and woods have been doped, varnished, oiled, waxed, and painted, and metals have been buffed, burnished, polished, anodized, and painted. Accessories such as flat or rotating mirrors have been attached. By far the most widespread practice among all classes of aircraft operators has been painting, either complete or partial, which appears to be the most feasible surface treatment.

Aircraft exterior paints serve a number of purposes, some of which are closely related to visibility factors. White or other light-colored paints tend to reduce absorption of sun radiation, and when used on the upper surfaces of the fuselage result in lower interior temperatures than would be the case with dark-colored coatings. Flat black paint is used on such surfaces as the inboard portions of engine nacelles and the portion of the fuselage immediately in front of the windshield, in order to reduce glare and specular reflections which disturb pilots. Special colors and patterns are commonly used for aesthetic and identification purposes, e.g., distinctive paint schemes of individual transport airlines.

In recent years there have been many attempts to apply paints in ways that would improve the conspicuity of the aircraft in the hope that greater conspicuity would help pilots to avoid colliding in mid-air. Among available paints, certain fluorescent coatings have received considerable publicity and have been used with varying degrees of enthusiasm and satisfaction. It has not been generally agreed, however, that presently available fluorescent paint is sufficiently more visible than other surface coatings to justify its comparatively high cost and complicated application. Among its advocates, furthermore, there have been differences of opinion about the patterns and colors that ought to be used.

Historically, Civil Air Regulations (CAR) have not imposed paint schemes of given color or material upon aircraft operators. Thus, in civil aviation, use of fluorescent paint has been voluntary and somewhat individual. In military aviation steps have been taken toward standardization when certain commands have adopted particular patterns and colors for aircraft under their control.

In one such case the Air Training Command (ATC) of the U. S. Air Force began, in June 1957, a fluorescent painting program involving some 1600 single-engine training aircraft. There was an immediate change in collision statistics. In the twelve-month period prior to the painting there had been nine mid-air collisions involving ATC aircraft within the Primary and Basic school complex; during the twelve-month period following the start of the painting there were only two mid-air collisions--and in neither case had the aircraft received fluorescent painting.

The Director of Flying Safety at Randolph Air Force Base, Texas (Headquarters of the Air Training Command), attributed the improved safety record primarily to the fluorescent paint:

> "Many things are being done to prevent these accidents, but we believe that the biggest factor for our reduction in the number of mid-air collisions is the fact that our aircraft are painted so that they can be seen in flight."[1]

Information about the Air Training Command's experience was widely disseminated among members of the aviation community. The Air Force has since qualified its position, according to a spokesman for the Office of the Inspector General, to acknowledge the importance of modified traffic procedures, special training sessions, and intensified safety measures. Furthermore, it is interesting to note that the Coast Guard, using a different pattern of fluorescent painted areas and additional dark- and light-painted surfaces, has never been involved in a "see and be seen" mid-air collision. Even allowing for the difference in mission and traffic volume, this is an impressive record. It raises the obvious question: Which paint scheme is more effective or are they equally effective?

On November 12, 1958, the Bureau of Safety of the Civil Aeronautics Board (CAB) circulated notice that it was

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1 From a press release issued July 8, 1958 by the Public Information Division, Office of Information Services, Air Training Command, Randolph AFB, Texas.

considering CAR amendments which would require all operators to use fluorescent paint. The draft release[1] read in part as follows:

> "The subject of mid-air collisions has been under study by the Bureau of Safety for a considerable period of time. Among the various safeguards being considered is the use of ... fluorescent paints on aircraft .... Experiments with high-visibility daylight fluorescent paints, which have recently become available, give promise of making aircraft more conspicuous ...."

The Bureau of Safety invited comment, including detailed suggestions about the particular surface areas to be covered. The number of responses (as the Bureau had indicated it anticipated) was large. A number of these responses expressed the belief that further investigation was desirable before the use of fluorescent paint was made mandatory.

Extremes of comment on the visibility of fluorescent paints are represented on the one hand by a respondent who stated that fluorescent color increases the visibility of an object by three or four times, on the other hand by one who asserted that, after hundreds of observations, not a single case was observed of conspicuity enhancement by fluorescent paint. Special characteristics of fluorescent paint also drew sharp disagreement: one respondent mentioned tests showing that fluorescent paint has no measurable advantage over low-reflectance dark brown paint, while another asserted that even the faded areas of fluorescent paint are more visible than ordinary paint. Regarding durability of presently available fluorescent paints, comments again run the gamut: "We expect present paint jobs to remain effective from nine to 16 months without hangaring," said one party, while another complained that " ... under operating conditions in the Southwest (high heat and bright light) the life of fluorescent paint is less than 90 days."

On the matter of which is seen first, the paint or the aircraft, one writer told of a pilot who while flying at 40,000 feet could make out none of the objects on the runway beneath him except "a blazing bright object" which turned out to be a taxiing aircraft with fluorescent paint; but another writer reported that during one program of observations more than 25 aircraft bearing fluorescent paint designs were seen in silhouette long before the paints were visible. In terms of application and maintenance, one respondent stated that complexity of application, critical need to achieve correct coating thickness, long "down time" for drying, and necessity

1 Published in the Federal Register (23 F.R. 9038) on November 20, 1958.

for near-surgical cleanliness all represent very difficult requirements for the average operator; while in the view of another respondent, these difficulties of application and maintenance are "not serious enough to present any unsurmountable problems."

There was general agreement that if no flexibility in paint color, shade, and pattern were permitted, resistance would be encountered from owners and operators.

After duly considering the information submitted to CAB, and other available information, the Federal Aviation Agency in September 1959 decided not to require owners and operators to use fluorescent paint. Among the reasons stated were the following:

(1) Precise evaluation of the effectiveness is not now available, although research work is continuing.

(2) High visibility characteristics of the various paints deteriorate with time and atmospheric conditions.

(3) There is some evidence of adverse effects of the paint on the life and condition of fabric surfaces, such as are used on light aircraft.

(4) The technique and cost of applying the paint would impose a burden on many operators not commensurate with the gain in safety.

In November of 1958 the Federal Aviation Agency had been constituted as successor to the Civil Aeronautics Administration. Among the safety research designated to be within the purview of the new Agency's Bureau of Research and Development (BRD) was the problem of determining the most effective visual aids for preventing collisions during Visual Flight Rules (VFR) operations. In July of 1959, BRD designated the Applied Psychology Corporation contractor for a comprehensive research program to investigate such visual aids.

One principal part of this research has been evaluation of a variety of aircraft paint treatments, including fluorescent materials, in accordance with the following assignments:

Original contract scope (1959):

> "Investigate the relation between surface treatment of aircraft and conspicuity of aircraft in the daytime."

Amended contract scope (1961):

"Establish the human factors and related design requirements for a maximally effective exterior surface treatment of aircraft, specifying such items as information to be conveyed, location and size of areas to be treated, and preferred colors."

This Summary Report describes the work that has been done by the contractor and indicates the conclusions drawn from that work.

II. TECHNICAL BACKGROUND

In determining the ways in which paint treatment may enhance aircraft conspicuity and aid in preventing collisions, brief mention of certain technical matters is necessary.

A. Target Requirements for Visual Detection

Detectability of an aircraft depends on several factors, the most important of which are its size, its distance from the observer, its shape and aspect, the distribution of brightness and color on the surface of the aircraft and in the background, and on the atmosphere.[1]

Considerable technical information is available concerning the visibility of simple targets (uniformly bright circles, squares, or rectangles) observed in front of homogeneous backgrounds (Blackwell, 1946; Duntley, 1948; Hecht, Ross, & Mueller, 1947; Lamar, Hecht, Shlaer, & Hendley, 1947; Middleton, 1958, pp. 86, 91, 108, 126; Ogilvie & Taylor, 1959). But there are only limited data on visibility of complex targets seen against complex backgrounds (Halsey, Curtis, & Farnsworth, 1955; Middleton, 1952). Nevertheless, data for simple target-and-background situations at least suggest how the complex situations may affect aircraft visibility.

Brightness contrast. For a simple target seen large in the field of view against a homogeneous background, contrast between target and background is the primary determinant of target visibility. Contrast may be brightness contrast, color contrast, or both.[2]

Brightness contrast, C, is defined by the equation

$$C = \frac{B_T - B_O}{B_O}$$

where B_T is the target brightness and B_O is the background brightness.

If the target appears bright against a dark background,

---

1 The effects of the atmosphere will be discussed in Section B of this chapter.

2 A dark object may be prominent against a light background through brightness contrast only; or a red object may be quite visible against a green background through color contrast even if the brightnesses of target and background are equal; or a dark red object may be visible against a bright green background as a result of both brightness contrast and color contrast.

the contrast is positive. If the target appears dark against a light background, the contrast is negative.

For a perfectly black target, B_T is zero and the contrast is -1. This is the maximum negative contrast possible. Positive contrast is theoretically limitless--if the target is very bright and the background very dark, extremely high values of contrast are possible. However, positive contrasts higher than 2 to 5 are unusual in the daytime unless the background is very dark or the target aircraft happens to reflect sunlight specularly.

Extensive investigation has shown that the visibility of simple targets is closely related to brightness contrast and to size. As noted above, for large targets (those subtending visual angles of the order of one degree or more) brightness contrast is the principal determinant of visibility (Middleton, 1958, p. 88).

Threshold contrast for large targets has been taken, somewhat arbitrarily, to be 0.02 (Duntley, 1948; Middleton, 1958, p. 219), and this value has been used in defining the "meteorological range." Field measurements of contrast threshold are generally subject to considerable variability. Although there is some inconsistency in data, it is felt that threshold contrast of 0.05 better represents probably sighting thresholds under field conditions of observation of large targets (Douglas, 1953; Douglas & Young, 1945; Middleton, 1958, p. 94). This contrast obtains when the target brightness is about 5% greater or smaller than the background brightness.

If the target subtends less than about 1 degree of visual arc, the threshold contrast required for visibility is higher (Blackwell, 1946). If, for example, the target subtends only 4 minutes of arc, the contrast threshold is about 0.5, ten times as high as the threshold for a large target. For a contrast of 0.5, the target brightness must be at least 1-1/2 times as bright as the background if the contrast is positive, or no more than one-half as bright as the background if the contrast is negative.

Size and shape of target. If the shape of the target is compact (for example, square or rectangular with low aspect ratio) then for equal areas threshold contrasts do not differ materially from those for circular targets. If the shape is not compact (if it is a rather long linear target, for example) then for equal areas higher threshold contrasts are found than those applicable to circular targets. Thus, target aircraft, which are of complex form, and often far from compact in apparent shape, require higher contrasts for threshold visibility than do circular targets of the same apparent cross-sectional area.

Shape and size of an aircraft affect sighting range in two major respects. First, the target's actual shape and size, together with the aspect seen, determine its apparent shape and size. Second, these same elements, together with the lighting conditions and surface treatment, result in a usually quite complex distribution of brightness. Most often, however, the intruder aircraft at the limit of detectability is very small in the field of view, so that its visibility is determined by some kind of over-all effect of the brightness distribution.

A somewhat oversimplified example illustrates both the difficulty of analysis and the manner in which brightness distribution may affect visibility:

> Suppose an aircraft is seen broadside so that the fuselage and vertical tail area are the principal aircraft structures making up the visible cross section.
>
> Suppose further that the illumination and paint pattern are such that the vertical tail area and the upper half of the fuselage is bright and approximately equal in brightness to a sky background, therefore blending with it.
>
> Suppose also that the lower half of the fuselage is quite dark. The appearance of the aircraft then approximates, very roughly, a long rectangle of good negative contrast, say about -0.8. The height of the rectangle is about half the height of the fuselage and its width about equal to the length of the fuselage, say in the ratio 1:20.

Data for the relative visibility of rectangular targets of different aspect ratios (e.g., Lamar et al, 1947) may then be used to obtain a factor which, when applied to data for circular targets (e.g., Duntley, 1948), will give visibility information applicable to this case.

If simplifying assumptions such as those used above cannot be made, then analysis is extremely difficult. If the brightness distribution of the intruder aircraft is broken up into areas too small to be detected individually, the over-all effect on visibility may sometimes be determined by averaging the brightness over the whole cross section and contrasting this average brightness with the brightness of the background. If in the example above the brightness of the upper half of the fuselage had been nearly twice that of the background instead of equal to it, then the over-all appearance would have been that of two rectangles, one on top of the other, the upper having a positive contrast of nearly one and the lower a negative contrast of about the same magnitude. At the limit of detectability, when the aircraft appears very small, the two rectangles might not be resolvable and a blending would occur. The net effect would be nearly perfect camouflage, with resulting reduction of detection range.

Color contrast. If all or part of the target is highly chromatic, or if the background is strongly colored, color contrast may provide visibility under certain conditions when brightness contrast alone would not. Unfortunately, color contrast does not play a significant role in determining aircraft visibility if (1) the target is small, subtending appreciably less than one degree of arc (Middleton & Holmes, 1949), or (2) if the atmosphere between observer and target decisively limits visibility. Thus color contrast is significant in a limited class of conditions.

One such condition occurs when the brightnesses of the target aircraft and its background are close to identical (even though target size and atmospheric conditions may be favorable). Complexity of structure and brightness distribution on an aircraft are such that this condition is relatively rare. More important and more frequent are occasions when the target aircraft is above the brightness contrast threshold, but becomes more visible because color contrast is also present.

B. Effects of the Atmosphere

Light passing through the atmosphere is absorbed, reflected, refracted, or diffracted by the gaseous molecules constituting the atmosphere and by any moisture particles or impurities that may be present. These effects when large enough are visible as haze or fog, but they are present to some extent in all atmospheres, even the clearest in appearance.

In the simple case of a light signal seen at night, absorption, reflection, refraction, and diffraction attenuate or reduce the amount of light reaching the observer from the signal.[1] Effects of the atmosphere on daytime visibility of targets is far more complex, due principally to scattering--multiple reflection, refraction, and diffraction of light by atmospheric particles. As distance to a target increases, or as amount of scattering in a given segment of the atmosphere increases, the target takes on more and more of the appearance of the sky or air background itself, until finally it disappears altogether (even though its size may be well above threshold). The effect is visible generally as a reduction of both color contrast and brightness contrast. In most cases, reduction of color contrast is the more pronounced, and color will become imperceptible before the brightness contrast threshold is reached and the target finally disappears (Middleton, 1958, p. 174).

Detailed analysis of the manner in which the atmosphere affects the visibility of targets is too complex for treatment here, but a general description of the basic facts, together with some examples drawn from the extensive data available for some simple cases, will illustrate the magnitude and nature of the effects. For convenience in the use of such information in flight operation, it is customary to summarize the data in terms of the visual range, the distance to a target at which first sighting is possible or probable. To rationalize the description of atmospheres in which visual operation is considered feasible, some measure of the visual density of the atmosphere is required.

The Civil Air Regulations use the term "flight visibility" in prescribing VFR minimums, and define it as "the average horizontal distance that prominent objects may be seen from the cockpit." But pilots do not always have "prominent objects" at known distances to use for estimating flight visibility; further, the relationship between visibility of

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1 The magnitude of the attenuation is given by Allard's Law:

$$E = \frac{I}{D^2} T^D$$

Where E is the illumination at the observer
I is the intensity of the signal
D is the distance between the light and the observer
T is the transmission of the atmosphere per unit distance.

The expression T^D describes the effect of atmospheric attenuation. In a vacuum, T^D is equal to 1 and Allard's Law reduces to the simple inverse square law:

$$E = \frac{I}{D^2}$$

"prominent objects" and objects such as aircraft is uncertain. It is thus a serious error to consider the "flight visibility," as presently defined, as the range at which aircraft are likely to be detected. It would be more realistic to consider flight visibility as the maximum range at which intruder aircraft may be detected.

Table 1 contains some examples of the interrelationship of target size, contrast, atmosphere, and sighting range, based on data for simple targets and backgrounds (Middleton, 1958, p. 110).

The range of values given for the parameters does not encompass all the values actually found in operation, but includes the bulk of the situations in which visual sighting may be expected or required.

The following conclusions may be drawn from the table:

(1) Actual sightings are likely to be at closer ranges (sometimes much closer) than the reported visual range; and

(2) If a paint pattern provides high contrast in a given flight situation, it can result in a significantly longer sighting range.

The table is based on circular targets and on considerations of brightness contrast only. How might the color of an aircraft paint pattern affect sighting ranges given in the table? At the limit of detectability, color generally has no effect on sighting range. Color contrast, as previously noted, is reduced by the atmosphere. Characteristically, at the limit of detectability, the observer cannot tell whether the target has color. This conforms to theory (Middleton, 1950; Middleton, 1958, p. 174), and has been demonstrated in flight observations (Applied Psychology Corporation, 1961d). Thus, the contribution of color on the aircraft to sighting range (near the limits of detectability) can be evaluated in terms of brightness contrast alone, without reference to color contrast.

C. Visual and Time Limitations on Detection

The variation of capability in different parts of the retina affects the manner in which targets are found and analyzed in VFR operations. The volume in space covered in a single visual fixation has been described (Lamar, 1959) as the lobe pattern, the detection lobe, or, less elegantly, the "visual turnip" (Fig. 1). The shape of this lobe is determined

Table 1

Expected Sighting Range[1] (Statute Miles) for

Targets of Various Sizes and Contrasts, Seen in

Various Atmospheres

Diameter of circular target viewed against sky background (feet)[2]	Reported visual range (statute miles)[3]	Brightness Contrast $\left(\frac{B_T - B_O}{B_O}\right)$			
		2.0	1.0	0.5	0.1
36	20	14.2	11.9	9.9	6.2
	10	9.0	7.9	6.8	4.5
	5	5.7	5.0	4.4	2.9
6	20	6.7	5.3	4.1	2.2
	10	4.8	4.0	3.2	1.8
	5	3.3	2.8	2.4	1.4

1 This is the 95% detection probability as obtained in ideal observing conditions; operational sightings would be generally shorter.

2 These values approximate visual area of a large aircraft (36') and a small aircraft (6').

3 International Visibility Scale categories are: 5 mi. = light haze; 10 mi. = clear; and 20 mi. = very clear.

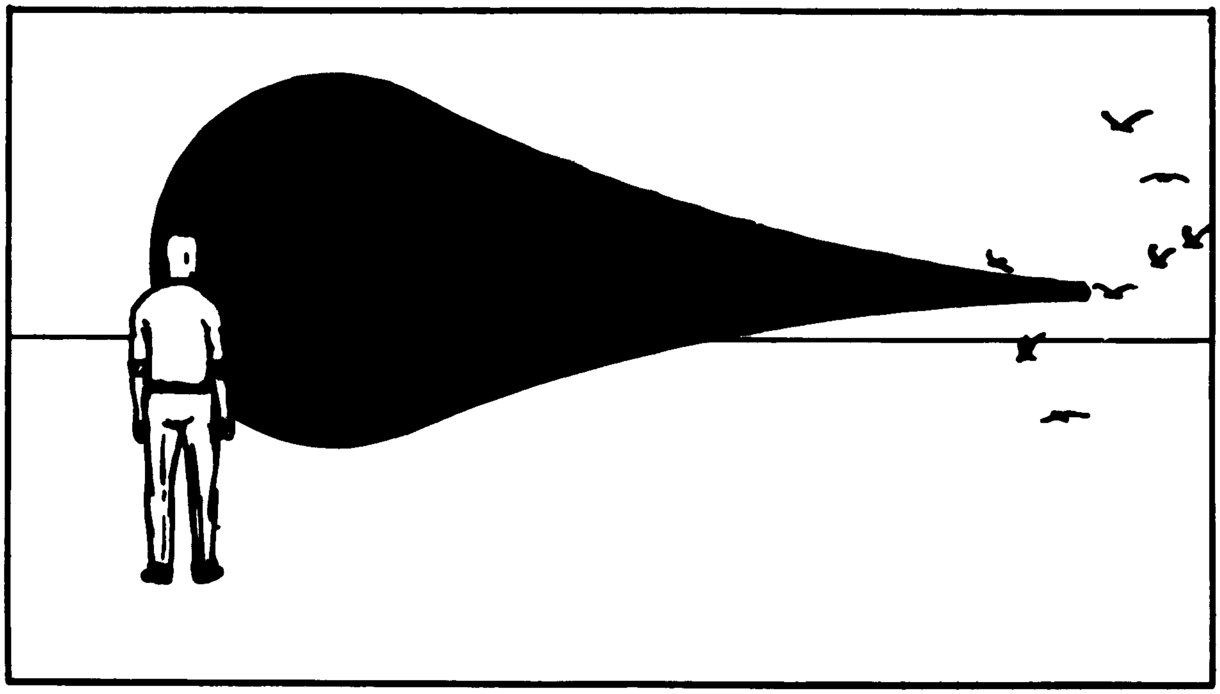

Fig. 1. Shape of the visual lobe as determined by the functional characteristics of the eye. Birds at extreme distances would be seen only if the eye were directed exactly at each one.

by the maximum angle from the center of fixation at which an object of given size and contrast can be seen at a given distance. Very distant objects can be seen only if imaged on the narrow field of the fovea; but the closer the target and the larger the angular subtense, the greater is the fraction of the total retinal area over which the target image can be detected. The typical detection lobe may be thought of as attached at its large end to the eyeball, and having its long stem move about in space as the eyes move from one fixation to the next. Any target which falls within the lobe during a fixation may be seen, while any target which falls outside it will be missed. The eye must, of course, be focused on the distant target, rather than being focused on the nearby empty visual field.

In a recent symposium on visual search techniques, it was stated that:

> "In any given fixation, the chance of detecting the target is simply the chance that the target is within the detection lobe. Since this lobe may be pointed in any direction ... /the probability/ ... is simply the ratio of the angular width of the detection lobe to the angle searched." (Lamar, 1959)

Detection probabilities can be computed using this ratio, provided the assumed conditions of observation (search speed and frequency, etc.) are stated in detail.

The effect of dividing a pilot's attention between monitoring the cockpit and searching for "intruder" aircraft has been examined (Short, 1961). The study develops visual detection models for two cases: first, an observer in a search plane, with no other duties and with prior knowledge of where and when the target will appear; and second, a pilot who, unaware of any target closing on a collision course, conducts his visual search throughout a field of view limited only by physical restrictions of the cockpit. In his report, Short defines a glimpse as a series of fixations on the particular area in space being investigated. To the observer he assigns glimpse times of 5 seconds, in a particular direction, and to the pilot glimpse times of 1.5 seconds (six fixations) at points along a personal scanning pattern. Using these values in conjunction with 150-knot DC-3s as target and observer aircraft, and postulating 25-mile visibility and a maximum detection range of 14 miles, the mathematical model indicates that the observer can probably detect the target at 3.9 miles when it is directly ahead, while the pilot, with other duties and no prior information, will probably detect the target at .9 mile. With the target at a relative bearing of 30° the observer might detect it at 7.3 miles, the pilot at 2.8 miles. The higher ranges for the 30° bearing are due to the decreased closure speed and the increased apparent size (30° aspect view); however, the differences between the observer's detection ranges and the pilot's ranges are caused by two factors: the pilot does not know where to look, and his available time is split between search and cockpit duties.

Thus we note not only that the "detection lobe" seriously limits the area in space which a pilot can effectively search during a given interval of time, but also that dividing his attention between cockpit and search duties further reduces the probability that he will be able to see an aircraft that he doesn't yet know is there.

D. Visual Detection in Operational Situations

Table 1 in Section II-B above provided some indication of sighting ranges for targets equivalent to certain aircraft in specified atmospheres. When other operational factors come into play, the visual detection of aircraft becomes markedly more difficult.

A recent paper on collision avoidance (Lazo and Bosee, 1961) establishes a hypothetically perfect situation against which the realities of flight operations may be compared.

> "As an example, let us consider the F8U and the F4D naval aircraft, both of them being in the category of higher performance craft. The length of the F8U is 60 feet and its wingspan is 40 feet, while the F4D measures 45 feet and 33 feet, respectively. Using these dimensions and assuming that the minimum visual angle which can be effectively resolved is 1 minute of arc, the F8U on a head-on approach under the most ideal atmospheric conditions can be detected as a dot at 25 miles and on a side approach detection can be made at 38 miles. Similar calculations for the F4D give detection distances of 21 miles and 28 miles respectively."

But no one actually makes such visual detections of the aircraft described. The authors discuss the factors which act in great complexity to reduce the range at which real aircraft may be reliably detected in real skies. Reference is made to the Civil Aeronautics Administration flight tests (Howell, 1957), in which threshold detection ranges achieved for a DC-3 aircraft by an experimenter who knew the target's location were between 10 and 15 miles. Simultaneous observations by a test pilot who did not know the target's location produced actual detection distances that were only one-fourth to one-third of the threshold range.

Can an aircraft paint pattern be effective in aiding visual detection in operational situations? The answer, although a modified "Yes," cannot be stated in absolute distance units, unless all other variables affecting the observation are also quantified. But it is possible to describe three kinds of operational situations and to assess the relative importance of paint patterns in each case.

1. Limit of detectability: When the target is sighted at considerable distance, and its apparent size is very small, the observer sees in detail neither its shape, its brightness distribution, nor its color. Visibility is determined by some kind of over-all effect of these factors.

2. Intermediate range: When apparent size of the target is such that the observer can recognize some shape in the cross section, and, if contrast conditions permit, some elements of the distribution of brightness, then, except in cases of unusual camouflage, the target should not be difficult to detect, but the degree of conspicuity may vary, and with it, the possibility that the target, even though visible, may be overlooked.

At this range paint patterns may reveal structures and identify aspects of the target aircraft with varying efficacy. Color contrast may play a significant role: color areas which contrast strongly with the background may have enough color contrast (even after atmospheric attenuation) to provide visibility in the absence of brightness contrast.

3. Close range: When targets are far within the limits of detectability (terminal areas or airport traffic patterns) information about their aspect, course, and maneuver is of great importance. Because of the many demands on the pilot in such situations--takeoff or landing procedures, large numbers of proximate aircraft, complexity of visual backgrounds--paint patterns may contribute positively to flight safety if they can provide unambiguous visual information that can be quickly recognized.

E. The Geometry of Mid-Air Collisions

Investigation of mid-air collisions centers around the reconstruction of the two flight paths. It has been supposed that analysis of this geometry would be helpful in preparing remedial measures. The data, however, have been bewildering: all possible combinations of straight-line, curving, and altitude-changing flight paths can be found. Even the analysis of flight paths for single aircraft is extremely complex, as evidenced in the comprehensive study (Howell and Edwards, 1955) at the Technical Development Center (then CAA), Indianapolis.

Analysis of flight path geometry has exercised considerable influence over the individuals and groups working to develop collision-prevention devices and procedures. Those groups developing electronic or mechanical systems place emphasis on equipment that would determine collision parameters from relative paths and velocities and signal when an intersection or close passage appears to be developing (Bendix Radio, 1958; Collins Radio Company, 1958; Sampson, 1958). Those groups concerned with visual methods of preventing mid-air collisions have similarly stressed the importance of providing information to the pilot that would enable him to determine the intruder's flight path, then to decide whether the threat of collision or near-collision exists, and maneuver accordingly.

As a consequence, aviation literature includes numerous references to the items of information "needed" by the pilot (or by a computer) to accomplish this sensing, comparing, and deciding procedure (Applied Psychology Corporation, 1961a; CAA Technical Development Center, 1955; Douglas Aircraft Company, 1957; Projector and Robinson, 1958; Moseley, 1961; among others). These lists are not alike and particular items of information are sometimes given in somewhat different ways. However, if the lists are consolidated and reduced to essentials, they comprise those items of information necessary to the solution of a four-dimensional space-time vector problem involving two aircraft: heading, airspeed, altitude, and maneuver for both aircraft; distance to the intruder at time of detection; and bearing of the intruder at time of detection.

As a result of our analysis and review of technical material, it is evident that this "complete solution"--for each intruder aircraft sighted along the way--cannot be accomplished within the time necessary and with practicable limits of reasonable visual aids and techniques. But limited information will be sufficient if it can be obtained reliably; for example, altitude separation will guarantee safe passage even when two aircraft fly courses that intersect over the same point on the earth's surface.

Visual flight operations will continue for at least a number of years before they can be supplanted entirely by other techniques. Accordingly we prepared an analysis of the usefulness of various kinds of visually-coded information in preventing mid-air collisions (Applied Psychology Corporation, 1961a). Findings stressed the importance of quadrantal sector information, fixity-of-bearing determination, altitude information, and maneuver information about an intruder aircraft as useful elements for preventing VFR collisions.

Because of the difficulty of presenting coded information in the daytime, it is evident that providing the necessary information for visual collision prevention will be easier with exterior light systems at night than it will with any known techniques in daylight. But identifying the useful information items establishes a frame of reference within which possible effectiveness of paint treatments can be approached realistically. Once the useful limits of paint treatments are known, other procedures such as traffic segregation and rules-of-the-road can be invoked to complete VFR safety measures for collision avoidance.

F. Characteristics of Fluorescent Paints

Painted surfaces reflect some of the light incident upon them and absorb the rest. Reflected light gives the surface its visual appearance (color, brightness, texture), and the absorbed light is usually dissipated as heat. Fluorescent paints which have recently come into use convert some of the absorbed light energy (including some invisible ultra-violet) to light energy of different color. This transformed light is emitted along with the reflected light to give colors of higher brightness and color purity than is possible with non-fluorescent paints.

If a non-fluorescent paint is not selective (that is, if it absorbs all colors equally) its appearance will be "colorless" and may range from white through gray to black depending on how much of the incident luminous radiation it absorbs. Good quality ordinary white paints may have reflectances of the order of 70 to 85 per cent. Black paints reflect about 5 per cent of the incident luminous energy.

If a paint is selective it absorbs some colors more than others, and the light reflected from it appears colored. Thus a red paint absorbs most of the blue and green light incident on it but reflects most of the red, and thus appears red in color. Generally paints do not have sharply defined reflecting characteristics; thus, a red-painted surface will reflect, in addition to long wave lengths at the red end of the spectrum, some orange, a little yellow, and perhaps even a small amount of green or blue. Paints of relatively high color purity tend to have low reflectance. Red paints may have reflectances of the order of 10 to 20 per cent, orange paints of the order of 15 to 30 per cent.

As noted, fluorescent paints not only have a high apparent reflectance, but also can achieve a high degree of color purity. The component of the light which is directly reflected from a fluorescent paint (that part not involved in the fluorescent conversion process) is broad in wave length as is the light reflected from ordinary paint. However, the light emitted as the result of the fluorescent conversion of ultra-violet and visible short-wave light (violet and blue) can be much narrower in spectral range. The combination of the directly reflected light and the light contributed by fluorescent conversion can have a very high degree of color purity as well as a high brightness, to an extent not possible with non-fluorescent paints. Effectiveness of high-brightness high-color-purity coating of visual targets has been established, at least for maritime floats and buoys viewed from an aircraft in flight (Farnsworth, 1956; Halsey, et al, 1955).

The high apparent reflectance of fluorescent paint, of the order of two to four times that of non-fluorescent paint of similar color, puts such paints in the class of white or other very light color paints. Thus, if it is desired to make a pattern using two colors, one light and the other dark, one such pair might be white and non-fluorescent red-orange. If, however, one of the colors desired has already been determined to be fluorescent red-orange, then the second color should not be white but a dark color, say dark gray or green (non-fluorescent). If viewing conditions are good--large areas, high illumination, little atmospheric attenuation--then the fluorescent red-orange might provide good color contrast with a light background even though brightness contrast would be low. In less favorable viewing conditions, color contrast might be less helpful, but the dark alternating color might provide better brightness contrast against a light background.

III. RESEARCH ACTIVITIES AND FINDINGS

The contractor has utilized laboratory tests, field tests, and flight tests to the fullest practicable extent, and has reviewed the work of other investigators. In addition, the usefulness of paints has been discussed with pilots, operators, and maintenance organizations to obtain the benefit of their practical experience.

A. Laboratory Studies

The contractor's laboratory studies accomplished under the contract are summarized hereinunder. Brief accounts of pertinent work of other investigators are presented in Section D.

Conspicuity of paint patterns. Five laboratory experiments using simulated viewing conditions and 21 paint patterns applied to scale-model aircraft were carried out to obtain a preliminary conspicuity value of these patterns for further testing. Details of these experiments are set forth in Technical Report No. 2 of this contract (Applied Psychology Corporation, 1961b). Patterns were based on present practice, on concepts contained in aviation literature, and on other concepts considered to have possible value.

They were grouped as follows:

1. Officially specified patterns which at the time of the experiment were being used by the Air Force, Navy, Coast Guard, and Federal Aviation Agency.

2. External contrast patterns intended to maximize color and brightness contrast between the aircraft and its predominant background.

3. Internal contrast patterns intended to present different amounts of brightness contrast between portions of the aircraft surface.

4. "Point-coded" patterns utilizing paint on one, two, three, and four extremities of the aircraft (Fig. 2).

5. Sector-coded patterns providing quadrantal color coding of the aircraft (front, rear, left, right).

Each test group of models included four different paint patterns, plus a control (painted entirely aluminum).

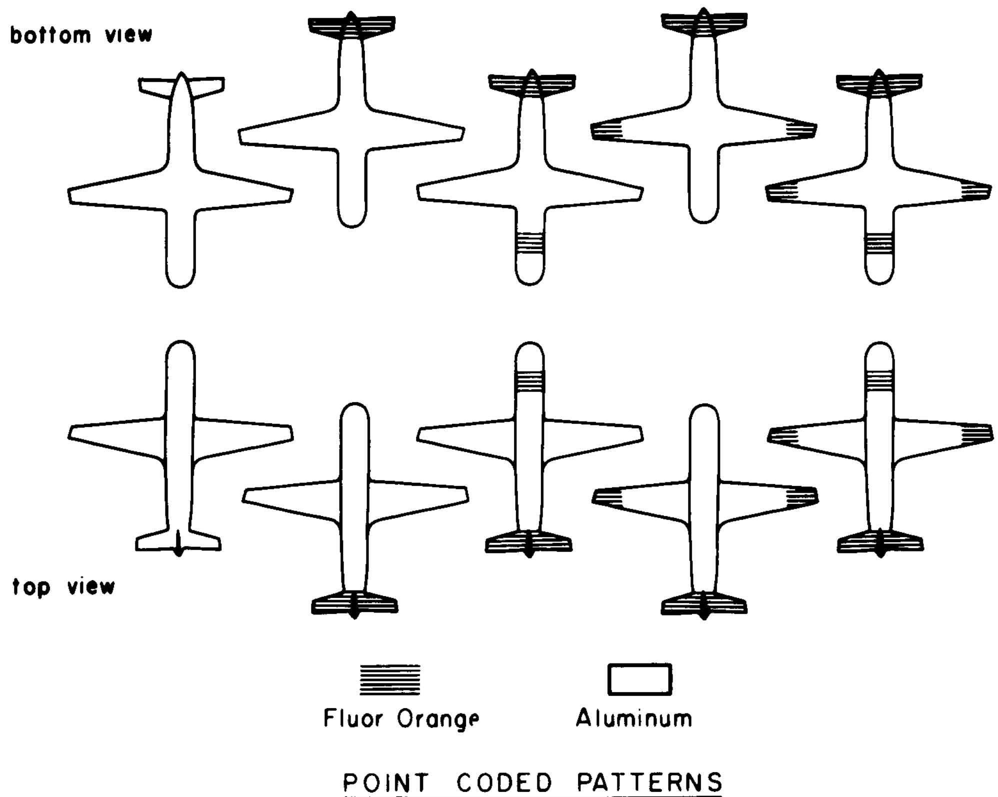

Fig. 2. Diagram of experimental patterns utilizing paint on one, two, three, and four extremities of the test models.

Pairs of scale models of both piston-engine and jet-prop transports, each painted with one of the patterns under study, were presented to the subjects in one of five flight attitudes. Backgrounds were provided by color slides projected through a translucent screen behind the models (Fig. 3). Skylight and sunlight were simulated by arrangements of incandescent lamps. Sequence of presentation was randomized. Five licensed and experienced pilots served as subjects in each experiment. They were given two seconds to observe each pair of models and decide which was more conspicuous. Each subject viewed all possible pairs. A total of 2500 observations was completed.

The experiments yielded a number of results to be tested further under more realistic conditions. These were:

1. Painting the top of the aircraft with high-brightness (high-reflectance) paints and the underside with low-brightness (low-reflectance) paints is advantageous;

2. In four of the five studies, there was some positive correlation between the amount of red-orange fluorescent paint and conspicuity scores--as the areas covered by fluorescent paint increased, so did the conspicuity score for the pattern;

3. Breaking up the areas of paint coverage so as to provide side-by-side, maximum brightness contrast areas within different portions of the aircraft surface did not aid conspicuity;

4. Massing of paint is better for conspicuity purposes than applying the same total amount of paint to different portions of the aircraft; and

5. Conspicuity scores for different paint patterns were not affected by differences in flight attitudes, backgrounds, or subjects.

Information value of paint patterns. Each pattern tested for conspicuity was also tested for its value in indicating flight attitude information. As mentioned in Chapter II, pilots and other aviation experts have suggested that aircraft aspect is one of the important visual cues used in evaluating collision threats. If the attitude of an intruder aircraft can be correctly determined, some judgment of its maneuver or direction of movement is possible.

Details of these studies are set forth in Technical Report No. 3 of this contract (Applied Psychology Corporation, 1961c). Experimental methodology was slightly different from that of the conspicuity tests. Instead of being presented in pairs, the models were presented singly, in one of 15 flight attitudes. Thus, each subject saw only one paint pattern at a

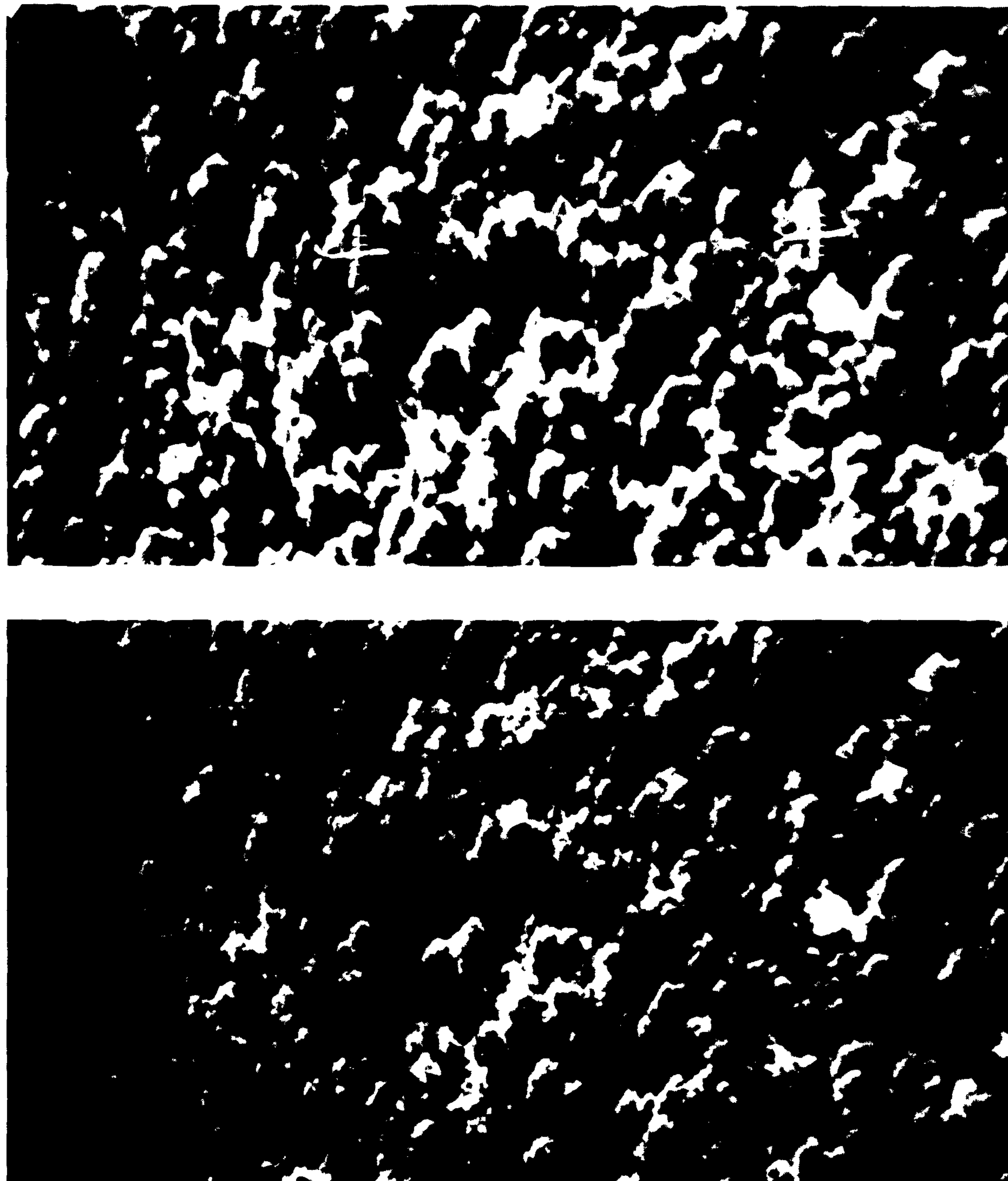

Fig. 3. Sample conspicuity test problems using painted scale models and projected color-slide backgrounds.

time. In front of him was a small display on which 15 unpainted models were mounted in attitudes corresponding to those presented by the stimulus models. He responded by matching the attitude of the stimulus model with the attitude of one of the response models.

As in the conspicuity studies, five licensed pilots served as subjects in each experiment, projected color slides served as backgrounds, and incandescent lamps were used to simulate skylight and sunlight. A total of 1875 determinations of flight attitude was made.

The major finding was that paint patterns do not greatly affect pilot judgments of aircraft attitude, at least in this simulated situation. Subjects appear to have depended largely upon aircraft aspect as the cue for attitude determination. However, even when aspect indication was enhanced by distinctive coding of right and left wings, nose, and tail, subjects did not find it significantly easier to judge the attitude. Similarly, individual backgrounds, lighting conditions, and subjects had no statistically significant effect on accuracy scores assigned to attitude perceptions.

Both for the conspicuity and the flight attitude studies, the indoor situation did not provide for the contrast attenuation effects of the atmosphere. Thus, the results represent evaluation when both the selected paint patterns and the apparent aircraft shapes could be seen clearly (with relatively high color and brightness contrast), although briefly.

Another laboratory study (Applied Psychology Corporation, 1961e) utilized the F-100/151 flight simulator at the National Aviation Facilities Experimental Center to introduce relative motion with a high degree of visual realism, yet short of the expense and hazard of actual flight testing. This simulator used a closed-circuit black-and-white television system to project images of intruder aircraft. Collision and non-collision flight paths were programmed, and the six pilot-subjects were asked to indicate throughout each problem whether they thought the intruder was on a collision course with them. A continuous record was made of the pilots' judgments throughout each problem. The principal question investigated was whether sector information distinguishing one half of the aircraft from the other half would aid pilots in making collision-or-miss decisions.

Four scale models of B-47 aircraft were used. Coding (or differentiation) was accomplished by use of white paint and black paint. One scheme differentiated front and rear, another, left and right, and a third, top and bottom. Effectiveness of these two-tone models was compared to an uncoded all-white control model. Pilots were thoroughly familiarized with the codings. A total of 144 practice problems was run and test data were collected on 288 simulated collisions and misses.

Data indicate there is no improvement in collision judgment scores obtained with sector-coded targets over scores obtained with uncoded targets.

Accuracy data show that earliest judgments were correct in 70 per cent, and final judgments in 91 per cent of the problems. Response time data show pilots spent 12 per cent of the time searching for the image, 31 per cent of the time "undecided," 15 per cent of the time indicating incorrect responses, and 42 per cent of the time indicating correct responses.

This experiment was designed to test our hypothesis that certain two-tone codings would provide helpful information--a belief which the data do not bear out. Post-experiment interviews were conducted in the interest of identifying any other factors which served the pilots in achieving quite high accuracy. These interviews revealed the pilots believed they had relied to a large extent on apparent fixity--or lack of it--in arriving at their judgments.[1]

B. Field Studies

Based on results of the above indoor studies, six paint patterns were devised to test three general principles of paint patterning (Fig. 4). These were: first, the effect of different brightness treatment of the top and the bottom of the aircraft; second, the effect of different amounts of red-orange fluorescent paint; and third, the effect of splitting up given total areas of paint coverage into several separated and, hence, smaller areas. An all-aluminum model was included in the series as a base against which to compare the six patterns.

Experimental facilities at the Warren Grove Visibility Test Range were used to collect nearly 10,000 observations.[2] Eleven observers, all experienced pilots, viewed each pattern

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[1] This tends to confirm the usefulness of the "fixity-of-bearing" criterion: when both aircraft are in straight-line constant-speed flight and one of the two aircraft appears to the pilot of the other aircraft to be motionless in his field of view, then the two aircraft are on a collision course.

[2] A detailed report of this study will be published as Applied Psychology Corporation Technical Report No. 7 on Contract FAA/BRD-127: Outdoor test range evaluation of aircraft paint patterns.

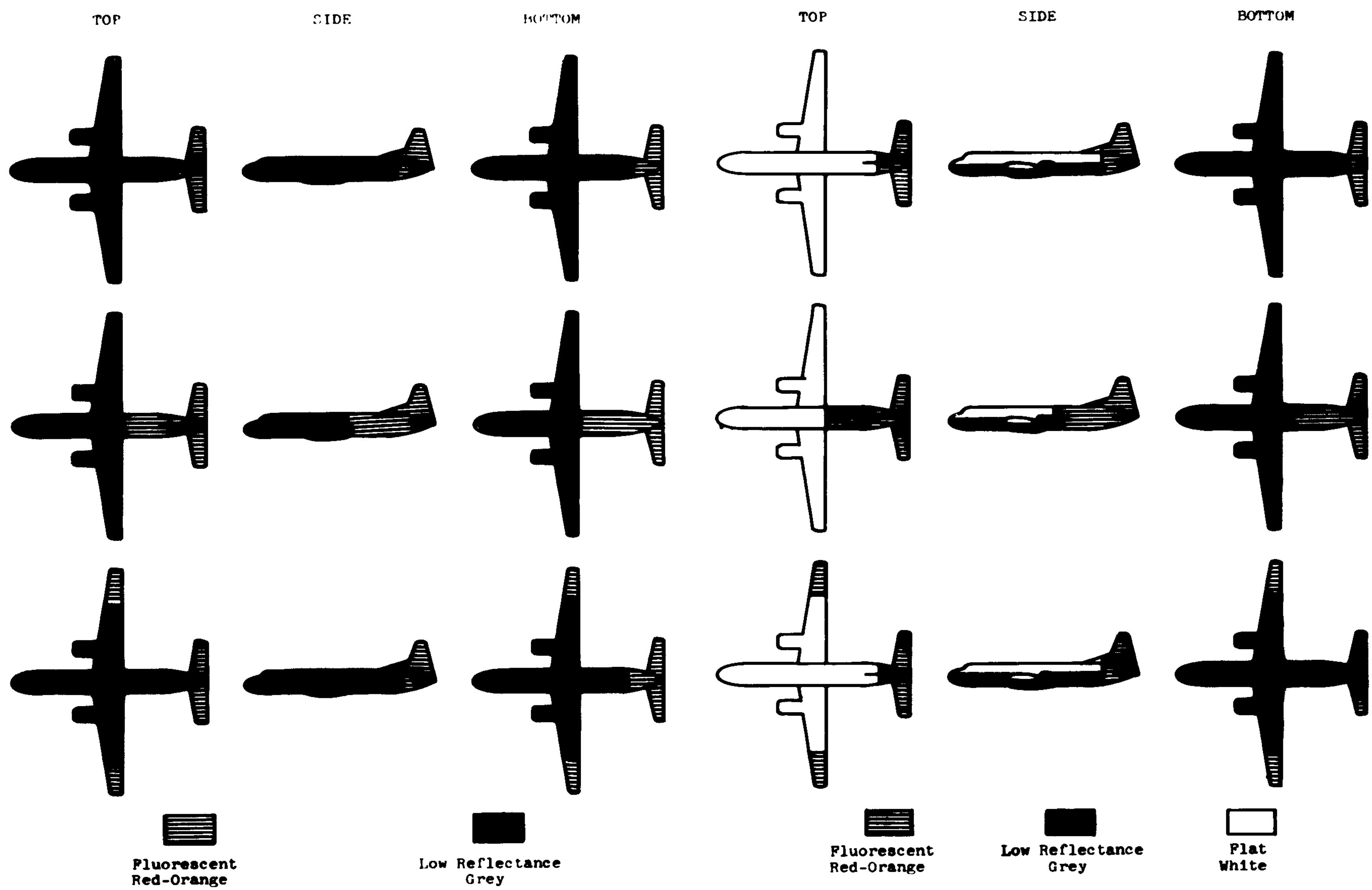

Fig. 4. Diagrams of patterns evaluated at the Warren Grove Visibility Test Range.

against each of four artificial backgrounds. Models of four sizes simulated four different ranges from about three to ten nautical miles, the models representing aircraft with a wingspan of 100 feet. Half of the observations were made during clear cloudless weather and the other half under an overcast sky. Observers were allowed three seconds to view a single model in one of 108 possible flight attitudes. They then indicated whether they saw the model, and if they did, attempted to specify its flight attitude by positioning a small model in front of them to match the attitude they believed the target had displayed. An electrical indicating system provided remote and rapid readout of the observers' judgments.

Two scores were obtained for all observing conditions: the number of times each model was detected, and a score reflecting the accuracy with which observers had perceived the flight attitude of the painted model.

Analysis of the detection scores reveals very little difference among any of the six patterns and three principles of patterning tested. However, the all-aluminum model was detected only 82 per cent of the time, while the models with paint patterns averaged about 90 per cent. Detection scores for each pattern and principle are shown in Table 2. Extending the area of red-orange fluorescent paint produced less than a one per cent increase in number of detections, and splitting the extended area out to the wings produced only a 2 per cent increase in detections.

There was no meaningful difference between the all-gray and the split white-and-gray patterns (both had areas of red-orange fluorescent). No differences were found between detections under clear and under overcast weather conditions.

Accuracy scores for perception of flight attitude were influenced very little by the six paint patterns (Table 2). However, all patterns produced higher accuracy scores than the "unpainted" aluminum treatment. None of the three principles of patterning tested held any large advantage. Providing different brightness contrasts for top and bottom of the aircraft did not produce higher scores than did patterns without this differentiation. Extending the area of fluorescent coverage did not increase accuracy of attitude determination scores, nor did splitting up of the area of fluorescent coverage.

In general, these results verify the laboratory studies. Two exceptions were noted. First, all of the paint patterns in this study held an advantage over the unpainted aluminum model. Second, although there was no clearly superior pattern,

Table 2

Detection and Accuracy Mean Scores

for the Paint Patterns Tested

at Warren Grove Visibility Test Range

Dependent variable	Paint Coverage[a]				Average of fluorescent treatments
	On fuselage and wings	Fluorescent Area			
		Empennage only	Empennage and tail section to trailing edge of wing	Empennage and wing tips	
Per cent detections	All gray	89	91	93	91
	White top & gray bottom	90	90	92	90
	Average of fuselage treatments	90	90	92	
Mean Attitude Scores[b]	All gray	21.9	23.9	23.7	23.2
	White top & gray bottom	24.5	22.1	23.5	23.4
	Average of fuselage treatments	23.2	23.0	23.6	

a The aluminum model was detected 82% of the time and its average accuracy was 18.7.

b Highest possible attitude score was 36 points.

the pattern with the top and bottom differentiated (white-and-gray), and only the empennage painted (small fluorescent area) yielded some favorable results. Figure 5 shows that other patterns either had a greater spread of mean scores, or lower actual mean scores, with respect to the four backgrounds. This may be interpreted as an indication of unreliability of these patterns. On the other hand, the pattern mentioned above yielded generally high mean scores that did not exhibit much spread. It thus might be presumed to be relatively consistent against a variety of backgrounds.

The expected decreases in accuracy of attitude determination as size of aircraft decreased were found. As in the laboratory studies, no differences were found among the several backgrounds. Finally, overcast skies did not yield any differences in accuracy scores.

C. <u>Flight Studies</u>

Flight tests of visual factors in collision avoidance are extremely troublesome to design and carry out because important parameters are difficult to control or measure. It is nevertheless essential to confirm or support the results of laboratory and field tests by obtaining data under conditions more closely approximating operational situations. To this end a program of ground-to-air and air-to-air tests was designed.

One ground-to-air test was carried out by the contractor at Washington National Airport. Two additional tests, one ground-to-air and one air-to-air, were carry-over tasks from the CAA Technical Development Center program. In these cases, the contractor designed the test procedures, and FAA personnel at the National Aviation Facilities Experimental Center (Aircraft Components Section, Experimentation and Evaluation Branch, Test and Experimentation Division) conducted the data collection. All three studies were concerned with ascertaining the visual detection threshold of various aircraft and the useful visual range of certain paint patterns.

In the Washington National Airport study (Applied Psychology Corporation, 1961d), data were collected to determine the range at which paint color could be reliably recognized, and the maximum detection range of the aircraft comprising traffic at National Airport.

The airport's tower facilities were used to conduct this study. National Airport provides a variety of types of civil and military aircraft, high traffic volume, and radar equipment for measuring aircraft ranges. Six members of the Applied Psychology Corporation staff, representing a variety of flying experience, served as observers.

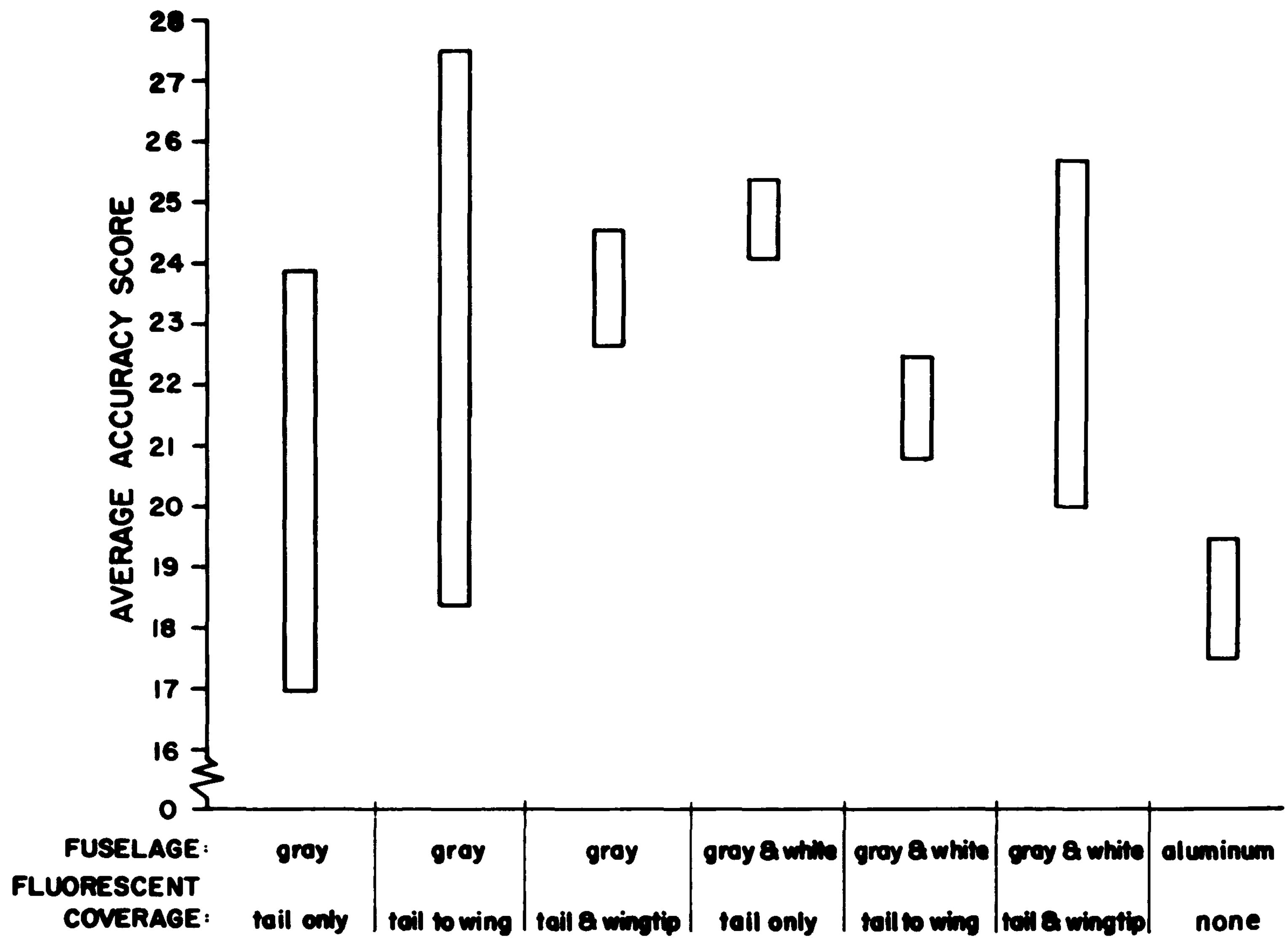

Fig. 5. Range of scores in judging aircraft attitude when different paint patterns were viewed against four representative backgrounds.

In the case of departing traffic, an observer selected a target aircraft at the beginning of its takeoff, recording its type and paint treatment. He tracked it visually and signaled the test director when he could no longer distinguish the color of the paint. Range of the aircraft at that moment was indicated by approach control radar. The observer continued tracking the aircraft until it disappeared, at which time he again signaled the test director. Range of the aircraft at this moment was taken at its maximum visual range, or detection threshold.

In the case of arriving traffic, the approach control radar operator identified a blip at approximately 18 to 20 miles range. The observer was told only that an aircraft was approaching from a certain direction: he scanned this sector and reported as soon as he detected the aircraft, then continued tracking the aircraft until he could see the predominant color of its paint treatment, then recorded what that color was. Approach control radar furnished ranges in nautical miles for both aircraft detection and color identification. All told, 541 aircraft were observed in this study.

The form used to record the many factors affecting each observation appears as Fig. 6. All items were recorded on the spot, except Weather Bureau records which were obtained later to afford official data for cloud cover, ceiling, and ground visibility.

An effort was made to examine each variable possibly associated with detection range and color-identification range. These include such things as reported meteorological range, aircraft size, aircraft aspect at time of detection, predominant color on the aircraft, presence or absence of fluorescent paint, sky background condition, brightness contrast of plane against background, and relative angle of the sun to observer and airplane.

There were no essential differences between average threshold detection ranges (maximum distance seen) for aircraft with fluorescent paint and those without it (Fig. 7). For aircraft classified as large, average detection range was slightly more than eight miles; for medium-sized aircraft it was slightly less than eight miles; and for small aircraft approximately six miles. For each size category, no more than half a mile separated the average detection threshold for aircraft having fluorescent paint from that of aircraft lacking fluorescent paint.

When color is to be identified, however, the advantage of certain fluorescent paints is evident: average identification range for fluorescent colors, predominantly red-orange, orange, and yellow-orange, was 2.3 miles, as compared to average

DAYLIGHT OBSERVER RECORD AIRPORT TOWER APPROACH	DAYLIGHT OBSERVER RECORD AIRPORT TOWER DEPARTURE
Contrast: P___ N x B___ S___	Sun azimuth 165
Range 8	Airline Private
Bearing 180^{o}	A/C Type Twin Beechcraft
O'clock 2	Color:
Color: Color Location Range 1 red tail	Pattern — empennage: white & green; fuselage: white over dark green; wings: dark green
Bearing 120^{o}	Range ½ Color green Location fuselage
Heading 330^{o}	Bearing 10^{o}
O'clock 10	O'clock 6
Pattern — empennage / fuselage / wings: Eastern Air Lines	Contrast: P___ N x B___ S___
Airline Eastern	Range 5½
A/C Type Electra	Bearing 70^{o}
Sun azimuth 165	O'clock 6
Time: EST 1100 GMT ______	Time: EST 1112 GMT ______
Date 11 April '61	Date 11 April '61
Observer LOP Radar Opr. VM	Observer LOP Radar Opr. VM
Unusual atmosphere Haze -- scattered to broken cloud.	Unusual atmosphere Haze -- scattered to broken cloud.
Ceiling M55 ⦶	Ceiling M55 ⦶
Ground visibility 15+	Ground visibility 15+
Sun elevation 55	Sun elevation 57

Pattern tables:

	empennage	fuselage	wings
Pattern (Approach)	Eastern Air Lines		
Pattern (Departure)	white & green	white over dark green	dark green

Fig. 6. Sample observation records for aircraft detection and color identification ranges.

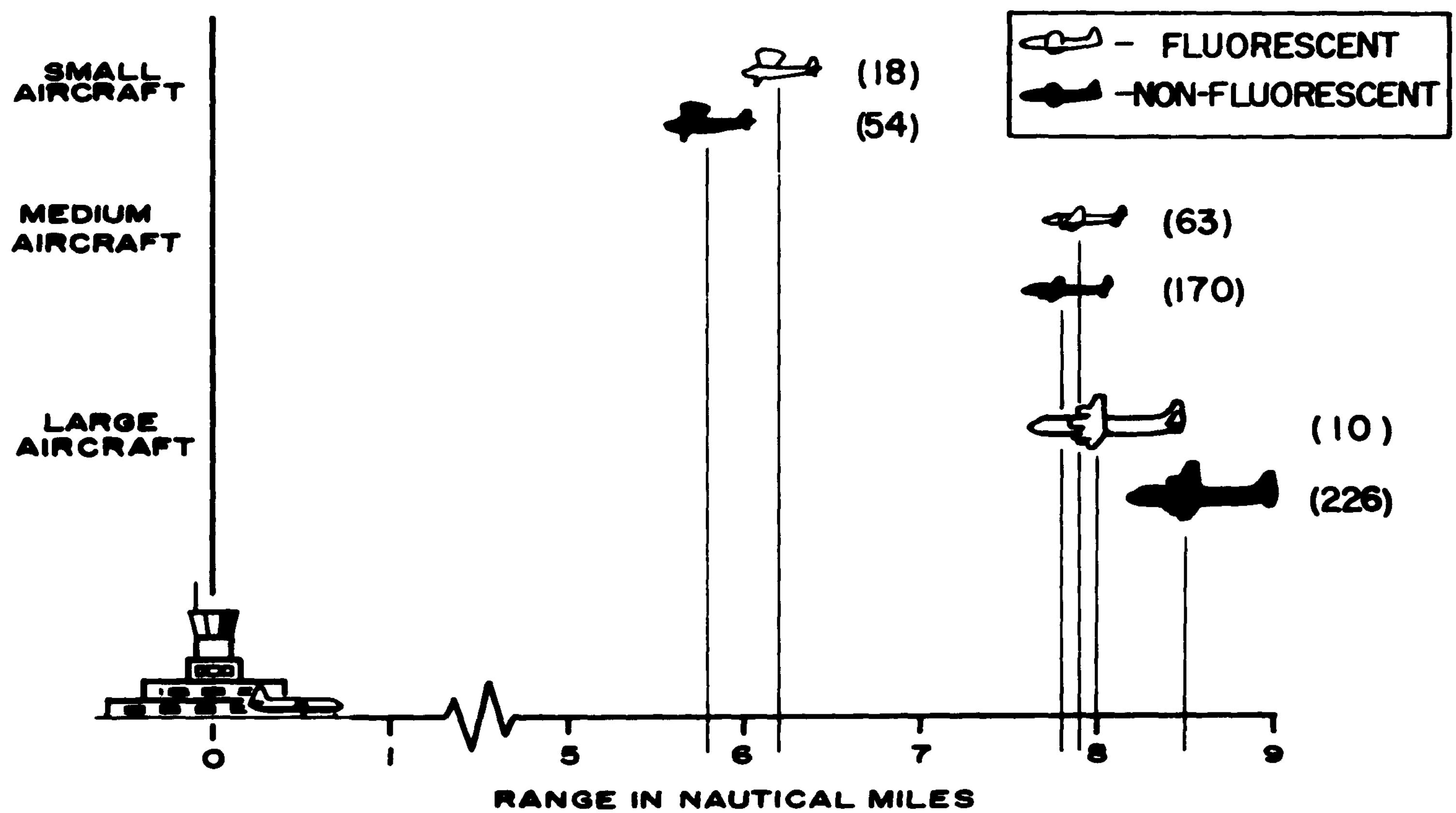

Fig. 7. Average threshold ranges for fluorescent painted and non-fluorescent painted aircraft as a function of aircraft size.

identification range of 1.0 mile for non-fluorescent reds and oranges. This same advantage in favor of the fluorescent paints existed with respect to enamels of other color (Fig. 8). Furthermore, 60 per cent of fluorescent-painted aircraft had color identified at two miles or more, as contrasted with about 12 per cent of the aircraft having no fluorescent paint.

While on rare occasions certain observers saw aircraft at ranges greater than reported meteorological visibility, the bulk of detections were made at considerably shorter range than the reported visibility (Fig. 9). When reported visibilities were between 8 and 10 miles, aircraft were detected (or lost), on the average, at about 5-3/4 miles, while with "over 13 nautical miles" reported visibility, aircraft were detected (or lost) at an average distance of 8-1/2 miles.

A ground-to-air test involving more rigid control over observation conditions was designed by the contractor to be conducted by NAFEC personnel.[1] The objective was again to determine the ranges at which aircraft with fluorescent paint patterns could be detected, as opposed to aircraft without such paint, and to determine color-identification range. The pattern tested was a standard Navy transport pattern on a DC-3 aircraft. Another DC-3, used for comparison, was painted with the same pattern except that where red-orange fluorescent paint was applied to the first aircraft, surfaces of the comparison aircraft were untreated aluminum or aluminum-painted. Observations were originally planned to be taken in two sets of conditions: clear sky and overcast. Weather conditions during the period of the experiment were such that collection of data under overcast conditions was not possible.

Several observers were tested at a time. They looked through a box-like arrangement that framed their view. The two DC-3 target aircraft flew individual patterns controlled by a combination of visual contact flying and radio voice communication. When the aircraft were at each of five visual check points located 1.3 miles to 7.3 miles from the observers, the shutters on the viewing boxes were opened for four seconds. Observers indicated whether they saw an airplane, and if so, whether it had fluorescent paint. Flight paths provided a random sequence of three views of the aircraft in successive exposures--a rear quarter view, a 30° bank, and a side profile.

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1 The basic task requirement had been transferred to NAFEC from the program of the Technical Development Center, Indianapolis, Indiana. The final report is in preparation by NAFEC personnel.

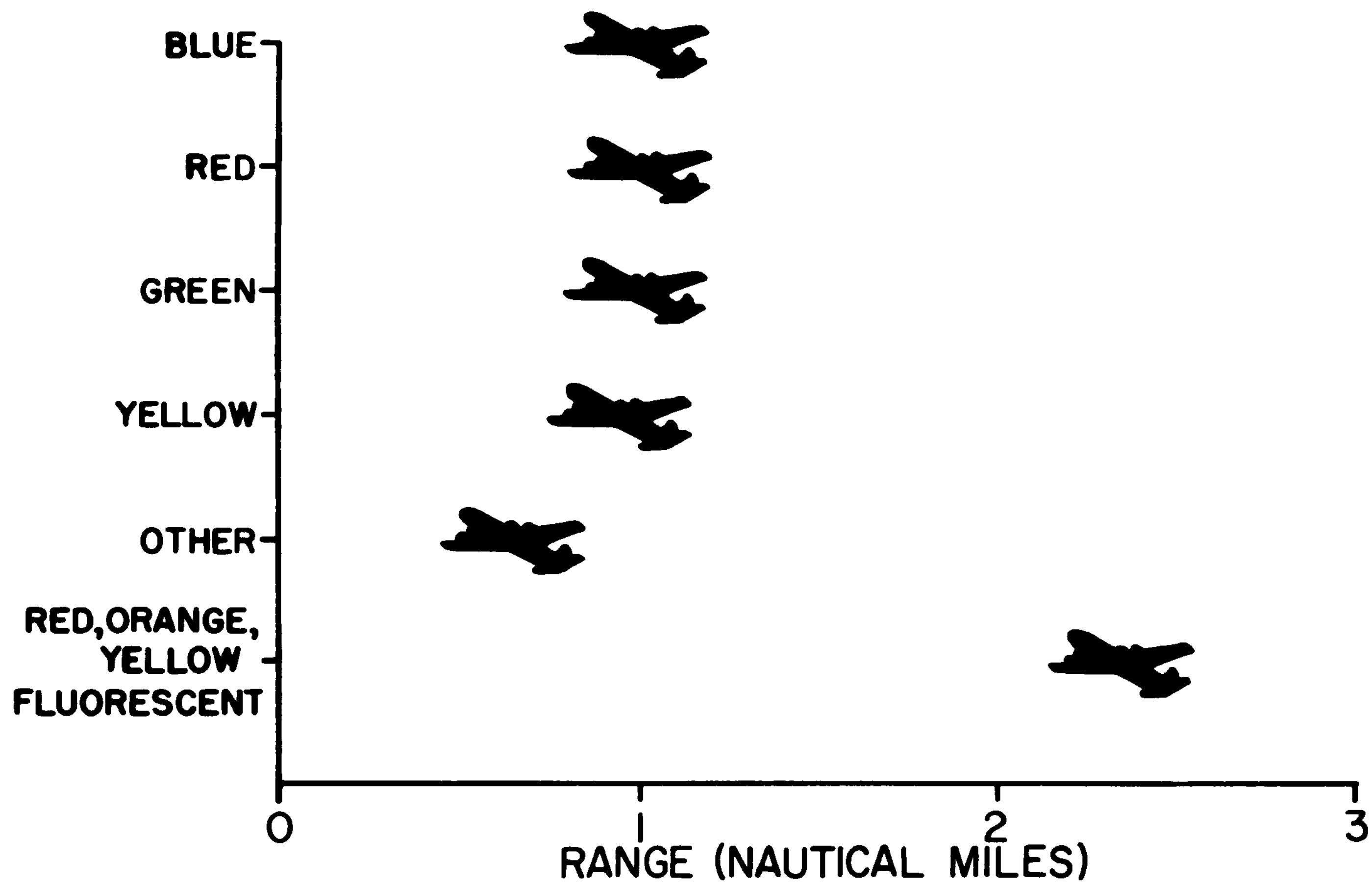

Fig. 8. Average distance at which aircraft predominant color was identified from a control tower.

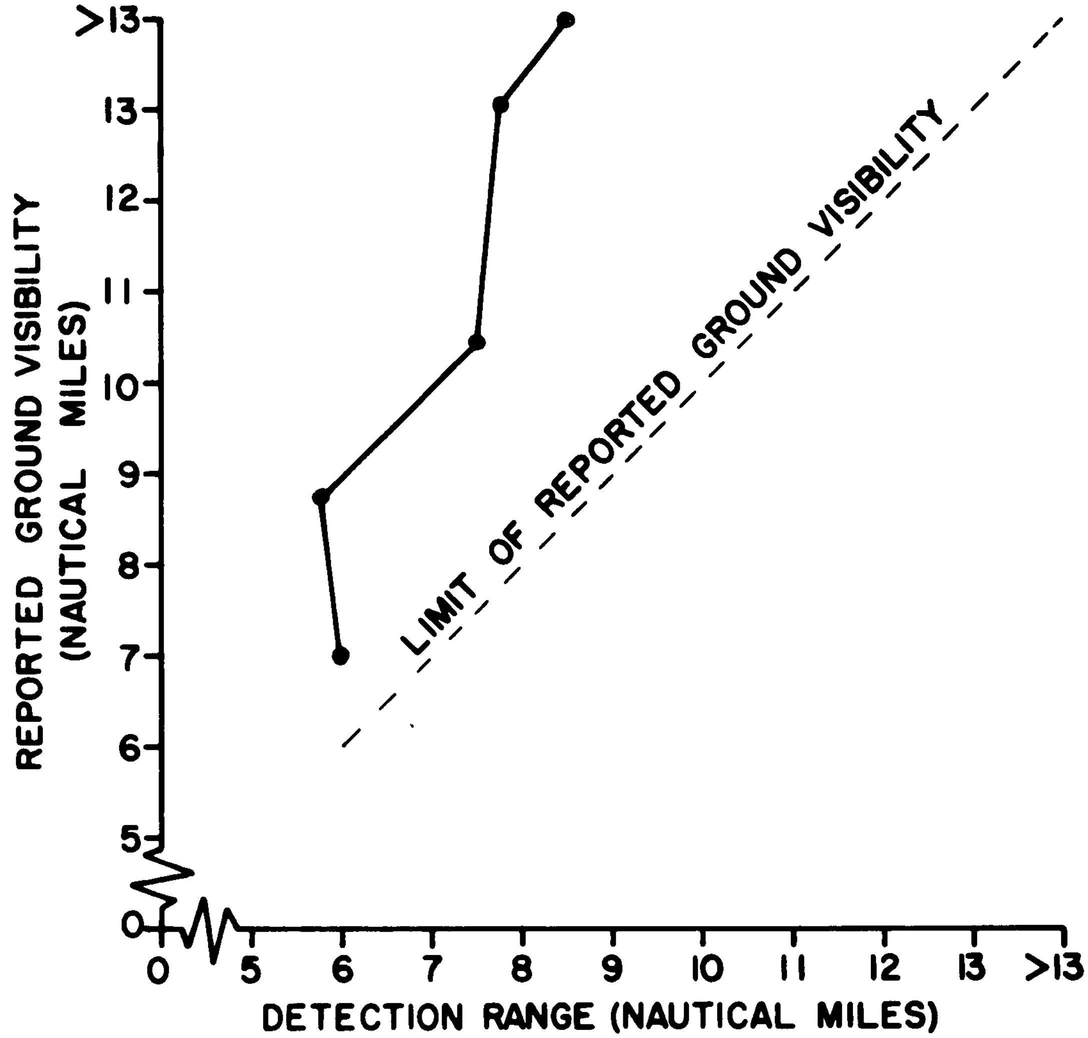

Fig. 9. Effect of meteorological visibility on aircraft detection range for a sample of routine traffic at Washington National Airport.

Data were collected for 20 observers, 10 of them pilots and 10 non-pilots. Since there was no statistically significant difference between mean scores for the two groups, data for both were analyzed together. Six hundred observations were made.

An analysis of variance reveals there was no statistically significant or practical difference in total number of detections between the fluorescent-painted aircraft and the aircraft with no fluorescent paint. Missed detections showed a significant increase as distance from the observer increased, and there were statistically significant differences among the three aspects, and among the individual observers. Analysis also revealed significant differences in missed detections or target aspect presented. The side profile data favored the non-fluorescent target; the 30-degree bank results favored the fluorescent target; and the rear quarter tallies produced a stand-off. Table 3 contains a summary of the missed detection data.

The number of correct identifications of the aircraft having fluorescent paint was variable, depending on the distance of the check points and the aspect of the aircraft being viewed. Table 4 indicates that identification of the red-orange fluorescent paint was best at close range and for aspects presenting the largest visible areas.

NAFEC had previously assumed the task of determining whether fluorescent paint in the red-orange band of the spectrum improves the conspicuity of small aircraft in terminal areas.[1] The present contractor designed experimental procedures for conducting the test.

A triangular flight pattern, with two-minute legs and with standard-rate turns at the two base corners, was devised (Fig. 10). Two Beech Bonanza aircraft, one with a selected fluorescent paint pattern (Fig. 11) and one without special treatment, served as targets. These aircraft proceeded around the test flight path in a counter-clockwise direction.

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1 Transferred from the program of the Technical Development Center, Indianapolis, Indiana. The final report is in preparation by NAFEC personnel.

Table 3

Per Cent of <u>Missed Detections</u>[a] for Fluorescent (F) and Non-Fluorescent (N) Patterned Aircraft at Stated Ranges and in Specified Flight Attitudes

Check point range (NM)	Target aspect presented						Total	
	Side profile		Rear quarter		30-deg. bank			
	F	N	F	N	F	N	F	N
1.3	0	0	0	0	0	0	0	0
2.6	0	0	0	0	0	0	0	0
4.7	40	15	40	20	5	10	28	18
6.0	35	30	45	55	10	15	30	33
7.3	80	60	65	70	10	40	52	57
Total per cent all check points	31	21	30	31	5	13	22[b]	22[b]

a Note that a low per cent indicates superior performance.

b Total number of observations in the test was 600; 300 were of the fluorescent painted aircraft, and 300 were of the aircraft lacking fluorescent paint.

Table 4

Per Cent of Correct Color Identifications of

Red-Orange Fluorescent Paint in

Ground-to-Air Observations

Check point range (NM)	Target aspect presented		
	Side profile	Rear quarter	30-degree bank
1.3	100	100	100
2.6	100	100	100
4.7	100	66	100
6.0	78	70	100
7.3	25	14	88

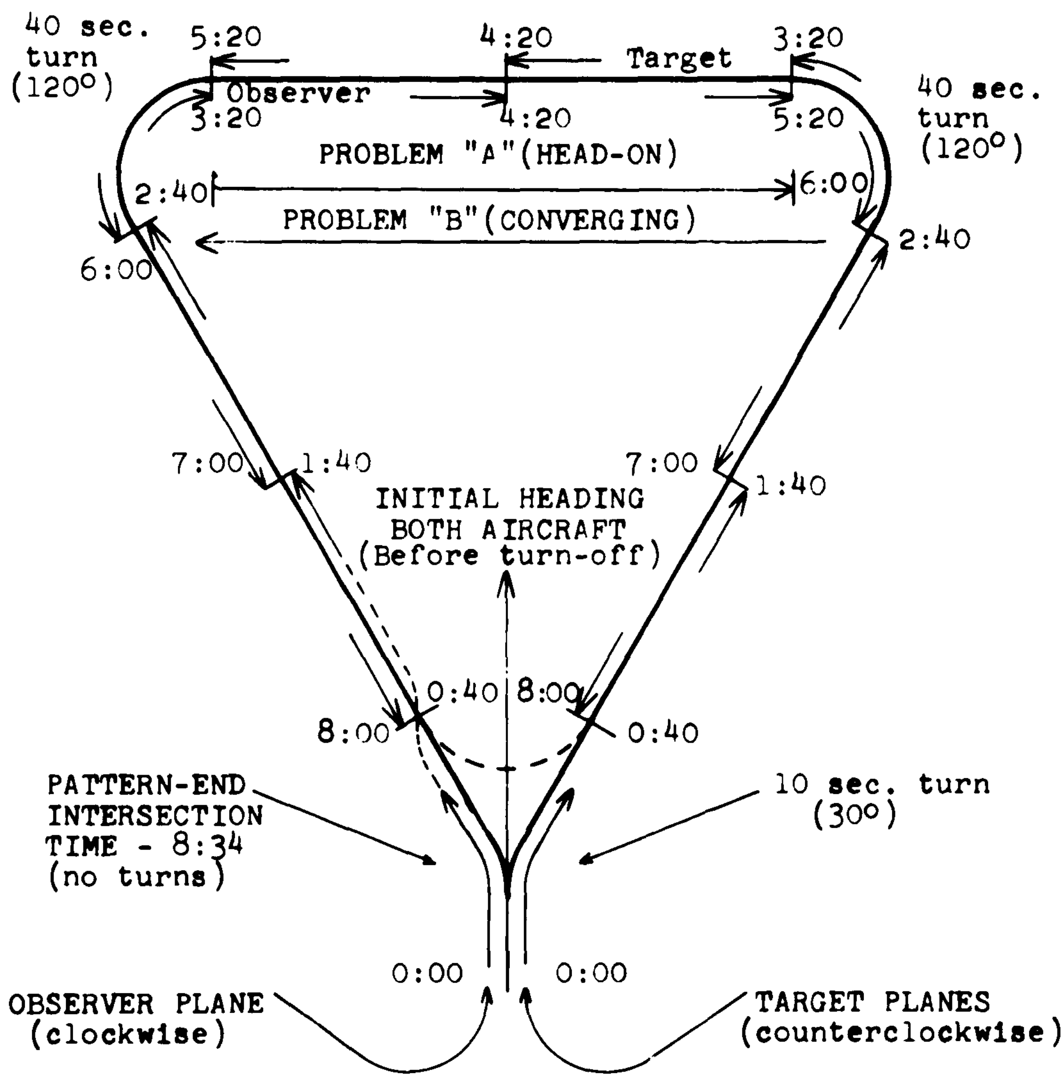

Fig. 10. Flight test pattern for air-to-air observations of small aircraft.

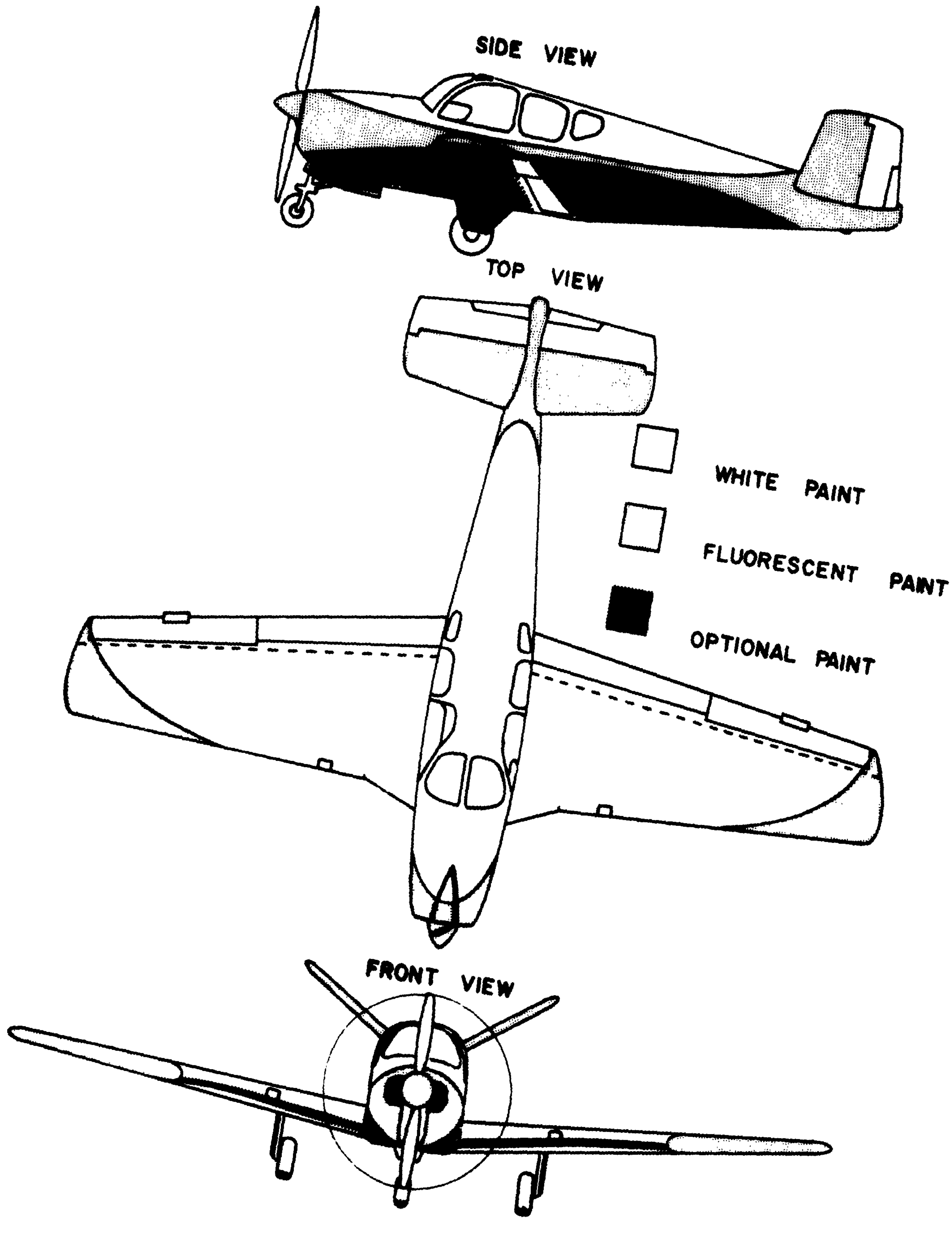

Fig. 11. Diagram of fluorescent-patterned target aircraft used in flight tests of visibility.

A third aircraft, carrying an observer, was flown clockwise around the triangle. To present the observer with an unpredictable sequence of problems, relative positions of the two target aircraft were varied as they proceeded around the triangle. The triangular pattern was flown in several different localities in order to encompass a variety of background conditions (city, open terrain, sea, sky). Observers indicated when they first detected the target aircraft, and when they could first identify fluorescent color.

Analysis of 144 observations by eight pilot observers (Table 5) reveals no significant difference between the number of detections (Part I, Frequency) for the fluorescent-painted and the non-fluorescent-painted aircraft. Average detection ranges for the two aircraft were identical within the limits of measurement precision possible: 1.3 nautical miles for head-on approaches, 2.1 nautical miles for the 60-degree converging course situation.

As would be expected from general data on visibility, average detection ranges were greater for homogeneous backgrounds (sky, sea) than for textured backgrounds (city, open terrain). Fluorescent paint provided no substantial advantage against either type of background.

D. Selected Relevant Studies

Laboratory investigations into the intricacies of visual functions are numerous, many bearing on a variety of visual tasks required of pilots. One encyclopedic volume (Wulfeck, Weisz, & Raben, 1958) lists nearly 2300 references in support of its analysis of the importance of vision in military aviation. A literature review directed toward aircraft detectability and conspicuity (Kulp & Rowland, 1959) lists more than 400 references. Several papers on contrast and atmospheric topics have been noted in Chapter II.

The most elaborate and pertinent laboratory study of aircraft paint patterns was conducted by the Bureau of Aeronautics,[1] Department of the Navy (Wagner and Blasdel, 1948). Scale-model aircraft were painted in many variations of pattern using glossy sea blue enamel on aluminum. A single problem consisted of displaying one patterned model in front of a white, gray, or black background; the observer had to indicate which of four headings the model presented. The basis for evaluating the various paint patterns was a weighted score reflecting the accuracy with which observers could identify aircraft heading. The results of more than 22,000 observations involving more than 100 observers and 37 different paint

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1 Now part of the Bureau of Naval Weapons.

Table 5

Detection Frequency and Average Detection Range Obtained in Air-to-Air Observations

	Flight situation	
	Head-on approach*	60-degree converging courses*
I. Frequency (detections)		
A. Fluorescent patterned aircraft detected first	20	28
B. Non-fluorescent patterned aircraft detected first	27	25
C. Both target aircraft detected simultaneously	19	16
D. Both target aircraft never detected	6	3
	72	72
II. Detection Range (nautical miles)		
A. Fluorescent patterned aircraft	1.3	2.1
B. Non-fluorescent patterned aircraft	1.3	2.1
C. Identification of fluorescent color	0.9	1.9

* Closing speed for the head-on situation was approximately 230 knots; for the converging situation, approximately 120 knots.

patterns indicated that glossy sea blue enamel applied to the trailing halves of the empennage and wing surfaces of an aluminum aircraft model yielded the highest heading-accuracy scores.

More recently the same Navy unit has sponsored laboratory research comparing the visibility of fluorescent paints and "ordinary" paints (Crain & Siegel, 1960; Siegel, 1961; Siegel & Crain, 1960, 1961). The chief methods were retinal perimetry (mapping the areas of the retina within which individual colors can be seen), and tachistoscopic threshold measurements (determining the shortest time a particular stimulus can be exposed to view and still be correctly identified). A variety of stimuli were used, and the results generally are in the expected directions: high contrast situations are most favorable, large areas are more visible than small areas, and compact stimuli are more visible than broken-up stimuli of equivalent area. The advantage achieved by fluorescent paints in this study appears to be explainable in terms of contrast, and may have resulted partially from the particular backgrounds and ambient illuminations used during the observations.

A well-known field study conducted jointly by the U. S. Army, the Massachusetts Division of Fisheries and Game, and the American Optical Company (Richards, Woolner & Panjian, 1960) was designed to determine the best color for hunters to wear so as not to be mistaken for a deer. Test procedures involved painted targets located at intervals in woodland, and colored vests worn by military personnel moving along prescribed pathways in the forest. The outcome of more than 13,000 individual sightings was favorable to an orange fluorescent paint having a dominant wave length between 595 and 605 millimicrons, a luminance factor of not less than 50%, and an excitation purity of not less than 90%. The authors caution that no single color can be superior for all viewers and all kinds of terrain during all seasons of the year and for all brightnesses encountered from dawn to dusk.

The problem of obtaining adequate conspicuity throughout a variety of target-background conditions led to a field study by the Sandia Corporation (Anders & Lenz, 1957). The standard practice had been to paint airdrop test vehicles in alternate quarters of orange and white. For photographic purposes the white areas frequently blended with clouds or contrails and made photographic interpretation of test drops very difficult. After extensive field observation and photography, a pattern comprised of specified areas of white, flat black, and fluorescent orange paint was identified as most useful. With respect to the discussion in Chapter II of the present report, it will be noted that the components of the Sandia pattern can provide either positive or negative brightness contrast as well as color contrast. Although some combinations of background and atmosphere can render this type of pattern invisible, the combination of a light (high-reflectance) area and a dark (low-reflectance) area and a "non-natural" color area appears to offer the greatest over-all possibility of detectability in outdoor observations.

A field study bearing on the effect of distance on the conspicuity of various colors was recently reported (Fitzpatrick & Wilcox, 1960). Recognizing that "under daylight conditions, brightness contrast is the important factor in maximum distance sighting of objects, and color or shape distinction is generally necessary for positive identification" of a target, the authors devised procedures to obtain objective data under controlled or measured circumstances.

> "A series of observations, over 700 in total, were made.... Targets of selected color were viewed on measured courses by two observers. Observation was begun from a distance at which no targets were detectable. As the observers slowly approached the targets, distances at which targets were detected as objects, detection range, and distances at which targets could be identified by chromatic color or hue, recognition range, were separately recorded. Targets used were circular and had an area of ... .01 square foot.... Backgrounds included dead grass, snow, forest, sky, and black panels.... Observations were made under varying atmospheric conditions: bright clear sky, cloudy bright, and a heavy overcast, with a complete range of solar altitudes from noon through twilight. In addition, identical observations were made with targets facing the four points of the compass.... A limited number of target colors was chosen ... international orange, yellow, white, and yellow-orange ... fluorescent."

Results were consistent with general expectations, and produced quantitative values for a number of specific conditions. For distant (maximum) detection[1] there was no universal superiority for any single-color stimulus or for white stimuli; for recognition there was nearly universal superiority for a yellow-orange fluorescent having among other characteristics, a dominant wavelength of 605 millimicrons. The size of the recognition advantage, of course, differed under different viewing conditions.

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[1] Actual distances were 1600 feet or less, therefore the atmospheric attenuation effects of most VFR situations were not present.

A flight test yielding important findings concerning maximum detection range and operational detection range was conducted at the CAA Technical Development Center, Indianapolis (Howell, 1957). Using a DC-3 aircraft as a target,

> "Two separate collision-course conditions were investigated: the uninformed phase and the informed phase. In the uninformed phase the subject pilot was unaware that he was flying a collision course.... In the informed phase the subject pilot was aware that he was flying a collision course but did not know from which direction the other aircraft was approaching.... The subject pilots' average detection distance ... obtained at the four angles of approach varied from 3.4 to 5.4 miles. The data showed no significant difference between the average detection distances obtained from the uninformed and the informed pilots. Average threshold distances ... [determined by an experimenter whose gaze was directed toward the target aircraft] ... varied from 10.8 to 12.4 miles."

Howell analyzed photographs taken of the pilots' eye movements. One indication was that the cockpit visual workload was too great to permit adequate search for intruders, and that the comparatively short detection ranges resulted both from the low frequency of search and from individual habits of search. Substantial variability among individual observers was noted.

Another well-known flight test (Skeen, 1958) compared fluorescent and conventional paints as aids in detecting or "spotting" aircraft. The right and left sides of a Convair 340 (called the Test Aircraft) were painted with different fluorescent paint patterns for comparison with another Convair 340 (called the Standard Aircraft) carrying the conventional United Air Lines pattern (white enamel fuselage top, blue stripe insignia pattern along side midlines). Fifteen observers participated in the tests, which included seven different operational conditions.

> "Considering the test as a whole, the paint on the Test Aircraft did not particularly aid in the <u>initial spotting</u> of the airplane. This was especially true at distances over about 3 miles and when the lighting and background were other than ideal. Under a wide variety of conditions, the white top of the Standard Aircraft was felt to be at least as effective, if not more effective than the orange paint on the Test Aircraft. This was

particularly true at distances greater than 3 miles. The Test Aircraft was easier to pick up than the Standard Aircraft when they were in direct sunlight and against a brilliant white background of clouds. The Test Aircraft was more visible in the late evening with a low overcast."

The report of the test also suggested that, to be effective at all, a large mass of fluorescent paint must be visible.

A flight test involving both ground-to-air and air-to-air observations was conducted at the Air Force's Wright Air Development Center[1] (Baker, 1960).

> "Under the limited conditions of the test, the distance at which an aircraft was first detected was shown to be independent of the existence or non-existence of orange fluorescent markings on the aircraft. Both the unpainted and the painted aircraft were clearly visible at distances far greater than those at which it was still possible to discern the presence of the orange markings. However, most observers felt that the painted aircraft were much more conspicuous at nearer distances than were the unpainted aircraft."

Another flight study at the Technical Development Center, Indianapolis (Howell, 1958) involved examination of several means to improve the daytime conspicuity of aircraft (lights, solar reflectors, and fluorescent paints). Results of observing a small aircraft (an Ercoupe) which was covered almost entirely with fluorescent orange paint indicated that fluorescent paint improved the daytime conspicuity appreciably and helped the pilot detect aircraft at low altitudes in the proximity of airports, particularly when the aircraft were viewed at short distances and with the ground as a background.

A more exacting flight procedure was devised by TDC for further evaluation of the conspicuity of fluorescent paint on small aircraft (Marshall and Fisher, 1959).

> "Each [of the 25 participating] pilot[s] was required to fly three collision courses.... Each collision course consisted of a different terminal area maneuver: departure and climb-out, straight-in approach, and a right turn-in approach. During each maneuver, the target airplane was on a 90° converging course with the subject's airplane,

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[1] Now the Wright Air Development Division.

requiring a 45° left visual angle for the subject to detect the approaching target.

> "Eleven pilots failed to detect the target aircraft[1] when flying the departure and climb maneuver.... Ten pilots failed to detect the target when flying the straight-in approach maneuver, and five pilots failed to detect the target aircraft when flying the right turn-in approach maneuver."

Average detection distances for those times when the target was seen were: departure and climb-out, 0.85 mile; straight-in approach, 1.30 miles; right turn-in approach, 1.05 miles. Experimenters who knew exactly where to look achieved much better detection ranges (2.8, 4.0, and 4.3 miles, respectively).

A flight study performed for the U. S. Coast Guard (Hodgson, 1959) used a "high-visibility" aircraft paint design to test the basic roles of color and luminance contrast in detection and recognition against normal backgrounds from all directions of view. It was found that optimum visibility and quick recognition were achieved by: (1) the use of black paint in shadow areas and undersurfaces; (2) the use of white paint on upper surfaces that are sunlit and normally viewed at a downward angle; and (3) fluorescent red or orange on one or two large sunlit areas.

It is tempting (and perhaps worthwhile) to mention a few cautions about this last study. It selected a "high-visibility" paint scheme and then found it a valuable one; data are said to have been obtained universally ("from all directions of view"), although no listing or tabulation is provided; and so on.

But precautions of this nature must be sounded to a greater or lesser degree with respect to all flight tests described herein, including those performed by this contractor. As was pointed out, flight tests of visual factors in collision

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1 The pilots were briefed so that they were uninformed about the true nature of the situation. One sentence in the instructions stated: "Please point out all aircraft you detect in the area and take any appropriate action necessary as four eyes watching are better than two." It is impossible to determine how this affected the intensity of the subjects' searching and reporting, if at all.

avoidance are extremely troublesome to design and carry out because important parameters are difficult to control or measure. They nevertheless more closely approximate operational conditions and are therefore essential to support the results of laboratory and field tests. The inescapable duty of researchers, pilots, aviation management, and the regulatory agencies, is to weigh each flight test objectively, and to refrain from universal inferences drawn from (necessarily) limited test conditions.

IV. ECONOMIC CONSIDERATIONS

Fluorescent paint costs considerably more than non-fluorescent paint, and applying it to an aircraft is somewhat more exacting and time consuming. Therefore, whatever conspicuity advantage it offers must be appraised, in part, in terms of economic impact. Primary factors include: initial conversion cost, down time for conversion and maintenance, weight (whenever extensive amounts are used), material and labor costs, and durability or expected life.

Initial conversion costs may range from $50.00 for a small, single engine private aircraft to $5000 for large aircraft with complex patterns.[1] How much maintenance cost will be required to keep the fluorescent coating effective will depend on the amount used, to what surfaces it is applied, kind of exposure and climatic conditions, air speeds, and kind of hangaring.

A. Requirements for Application of Fluorescent Paint

For proper application, adhesion, and maximum brilliance the following steps are prescribed by manufacturers:

1. Clean and degrease all metallic surfaces to be coated;
2. Chemically etch the metallic surfaces;
3. Wash off etching material;
4. Apply a pretreatment solution and rinse off with water;
5. Mask surrounding area surfaces not to be coated;
6. Spray one or more coats of properly thinned white primer to a 1.5 mil maximum thickness;[2]

1 See Section C, Costs.

2 A wash coat primer, zinc chromate primer may precede the white primer. The use of an epoxy base primer does not require the use of additional primers.

7. Spray two or more coats of properly thinned fluorescent paint to a 3.0 mil maximum thickness;

8. Spray one or more coats of transparent protective overcoat to a 1 to 1.5 mil thickness;

9. Remove masking materials from adjacent surfaces; and

10. Remove any overspray.[1]

In the above process sufficient drying time must be allowed between each coat, and prescribed thicknesses must be controlled according to manufacturers' specifications. For large aircraft the process, properly applied, may take an entire week.

B. Requirements for Application of Fluorescent Films and Tapes

Fluorescent films and tapes are also available. They are composed of a durable plastic sheet on which white undercoat, fluorescent paint, and clear protective overcoat have been applied under quality-controlled conditions. These sheets and tapes may be obtained with either a pressure-sensitive adhesive backing, or a dry adhesive backing which is activated by heat or solvents. Claimed advantages of these films over paint are: Factory-controlled coating thickness (an important factor for maximum effectiveness), fewer tools, hand application, and less stripping time.

Metallic surfaces to which fluorescent films are to be applied must be cleaned and degreased. The films are cut to fit the surfaces; the paper backing is removed; the film is applied to the aircraft surface. The tapes or films should be applied at surface and ambient temperatures above 50° F for maximum pliability. Any trapped air must be removed by puncturing the film and working the air out by use of hand pressure or plastic scraper. The film is usually edge-sealed to prevent the entrance of air under the sheets.

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[1] The steps required for enamel painting are similar, except that step 8 (protective overcoat) is not necessary and step 6 (primer or undercoat) is optional.

For large-area coverage, painting is reported to be slightly cheaper than tape applications, because of the maximum tape width of 6 inches (required to keep wrinkles to a minimum). For small areas or narrow stripes, tape is cheaper than paint.

C. Costs

Materials. Primer-undercoats and sealer-overcoats may cost from $7.00 to $13.00 a gallon and the fluorescent paint about $20.00 a gallon. Enamels of good quality presently cost about $10.00 a gallon.

The area which a gallon of paint will cover depends upon how it is applied, the type of surface, how much waste there is, and so forth. However, advertising literature of fluorescent paint manufacturers indicates that coverage of fluorescent paints is approximately 250 to 400 square feet per gallon.[1] Coverage of enamels is at least this much.[2] The Air Force experience has been that the materials cost for painting was approximately 4 to 9 cents per square foot (including masking tape, paper, etching materials, primer coats, etc.); for fluorescent tape, materials cost has been from 39 to 60 cents per square foot.[3]

Initial application. In 1958 the Engineering Department of United Air Lines conducted a ground and air test to evaluate the effectiveness of fluorescent paint as an aid to aircraft visibility (Skeen, 1958). A Convair 340, painted with a selected pattern and used for the tests, served as the basis for estimating the cost of painting 199 aircraft then in the UAL fleet. Estimates were made for two procedures: applying fluorescent paint over existing paint (Table 6), and applying fluorescent paint after existing paint had been removed (Table 7).

The fluorescent pattern tried out by United Air Lines was a simple design requiring little or no complicated masking.

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1 Lawter Chemicals, Inc., Radiant Color Co., Switzer Brothers, Inc.

2 E. I. duPont de Nemours.

3 According to data supplied by the Wright Air Development Center, 1960.

Table 6

Estimated Cost of Painting United Air Lines' Aircraft with Fluorescent Paint Over the Existing Pattern[1]

Item	Cost
Material per A/C[2] (Primer, Paint, Overcoat)	$200.00
Direct Labor per A/C	350.00
Labor Overhead @ 138% of Direct Labor	483.00
Total cost per aircraft	$1,033.00

1 From Skeen, 1958.

2 Fleet included DC-6s, DC-7s, and Convair 340s. See text for description of pattern.

Table 7

Estimated Cost of Painting United Air Lines' Aircraft with Fluorescent Paint After Stripping Old Pattern Completely[1]

Item	Type of Aircraft	
	DC-6 and 7	CV-340
Material per A/C[2]	$600.00	$500.00
Direct Labor per A/C	1300.00	700.00
Labor Overhead	1800.00	970.00
Total cost per A/C	$3700.00	$2170.00

1 From Skeen, 1958.

2 See text for description of pattern.

Fluorescent paint was used on the following locations: the whole tail section beginning just aft of the last passenger window (but excluding control surfaces); a three-foot band around the fuselage just aft of the cockpit window; and the outermost six feet of the wingtips. The pattern selected by the Federal Aviation Agency (December 1958) shortly after it was constituted was more complicated. Costs to FAA for representative aircraft types are shown in Table 8.

Using labor costs approaching $6.00 per hour, Butler Aviation (Washington, D. C. shop) estimated that a very simple fluorescent pattern applied to a small two-place single-engine private aircraft might cost as little as $50, while cost of a complicated custom pattern for a DC-3 executive aircraft could be as much as $5000.

Much of the total cost is labor. Initial application of the Air Force fluorescent paint pattern to some 8800 aircraft required more than 367,000 man-hours--nearly 42 man-hours per aircraft.[1]

Maintenance and renovation. Fluorescent paints are subject to several maintenance difficulties. Inadequate preparation of metal surfaces before the primer was applied, together with less than optimal undercoat compositions and ineffective sealer coatings, has resulted in much cracking and peeling and a great deal of premature weathering and fading. Some undercoatings have proven deleterious to fabrics on rudders, elevators, and ailerons. Revised formulas and improved techniques, particularly in initial preparation of surfaces to be painted, have to some extent eliminated peeling and extended the life of the paint.

Maintenance costs also are attributable mainly to labor. Data from an Air Force survey[2] indicate that the 8800 USAF aircraft painted with fluorescent patterns annually require 451,000 man-hours for maintenance, including retouching and renovating. This averages about 51 hours per aircraft per year. The fluorescent paint pattern on the average Air Force

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1 Information supplied in personal interview with a member of the Aircraft and Missile Division, Directorate of Maintenance Engineering, D/C of S, Systems and Logistics, 1961.

2 Information supplied by the Aircraft and Missile Division, Directorate of Maintenance Engineering, 1961.

Table 8

Actual Cost Figures for a

Federal Aviation Agency Fluorescent Paint Pattern[1]

Type of Aircraft	Cost
Cessna 180	$350.00
Beechcraft	600.00
DC-3	1100.00
DC-4	3084.00
Fairchild C-123	4646.00

1 Figures supplied by the Federal Aviation Agency, 1960.

aircraft had to be removed and reapplied within a year; such repainting has required 561,000 man-hours per year or over 60 man-hours per aircraft per year.

D. Life Expectancy

Life expectancy of fluorescent paint has varied among aircraft and among users. In the Air Force, average life of the paint has varied between 4 and 12 months among 27 types of aircraft in its inventory, as well as for the same type of aircraft in different commands. It has been FAA's practice to repaint annually. Butler Aviation reports the life of fluorescent paint to be short compared to conventional paint.[1] Generally, non-fluorescent type lacquers and enamels used on aircraft have a life expectancy of four or five years, while fluorescent paints generally seem to last closer to one year.

Fluorescent tape has been found to have about the same life expectancy as the fluorescent paint. Such tape was tested by the Air Force on five Boeing KC-135 aircraft operating from bases in three different climatic areas of the United States (Stout, 1960). After nine months, inspectors judged the tapes to be in serviceable condition, and forecasted that they would probably remain so for three more months. While close inspection revealed cracks, blisters, and patches, only the patches were noticeable as defects when the aircraft were viewed from a distance of 100 feet. As a result of these tests, the Air Force in October, 1961, authorized optional use of fluorescent tape instead of fluorescent paint.[2]

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1 Information supplied by a representative of the Washington, D. C. shop, 1960 and 1961.

2 Information supplied in personal interview with a member of the Aircraft and Missile Division, Directorate of Maintenance Engineering, D/C of S, Systems and Logistics, 1961.

V. CONCLUSIONS

On the basis of the foregoing material, the role of paint in preventing mid-air collisions during Visual Flight Rules operations can be delineated within the following framework:

A. FOR CONSPICUITY PURPOSES, SOME PAINT ON THE EXTERIOR SURFACES OF AN AIRCRAFT IS MEASURABLY BETTER THAN NO PAINT.

1. Unpainted metal surfaces often promote visual blending of an aircraft with the background against which it is viewed. Furthermore, specular reflections from such surfaces occur too infrequently to be relied on as general-purpose visibility aids.

2. Unpainted fabric surfaces (gray or preservative-coated only) generally do not provide sufficient brightness or texture to afford noticeable target-background contrast.

3. In most of the laboratory, field, and flight tests described in this report, aircraft or models having predominantly aluminum surfaces or aluminum paint were detected less often and perceived less accurately than aircraft or models having designated paint patterns.

B. THE OPTIMUM FUNCTION OF PAINT (IN TERMS OF COLLISION AVOIDANCE) IS TO PROVIDE USABLE VISUAL INFORMATION AT INTERMEDIATE OR CLOSE RANGES (FOUR MILES OR LESS).

1. Atmospheric attenuation of the color of reflective surfaces is severe. Long-range sighting of aircraft is not significantly helped or hindered by the nature of the paint pattern they carry. In these situations, the visual angle subtense of the target is so small, and the atmospheric attenuation is so great, that the color or brightness of parts of its paint pattern are not distinguishable.

2. Since closer range situations do not generally permit extended decision periods, an optimum paint pattern should involve only simple, unambiguous elements that can be perceived quickly.

C. FOR OBTAINING OPTIMUM VISUAL INFORMATION ABOUT AN INTRUDER AIRCRAFT, STANDARDIZED PAINT PATTERNING PRINCIPLES ARE ESSENTIAL.

1. In many close-range or intermediate-range observations, pilots can discern some structural aspects of the target aircraft, then, making use of past experience, can

make some rough judgments about the flight attitude or the maneuver of the intruder.

2. In other instances the appearance of the aircraft at these ranges can be ambiguous. In many flight situations, an aircraft seen nearly head-on looks almost exactly like an aircraft seen nearly tail-on.

3. In both of the above cases, the use of standardized paint patterns may provide information of value to a pilot, either by reinforcing his perception when aircraft structural characteristics are clearly visible, or by helping him to interpret visual situations in which the target image is ambiguous.

D. FOR PURPOSES OF COLOR RECOGNITION, THE PRESENTLY AVAILABLE FLUORESCENT PAINTS IN THE ORANGE AND RED PORTIONS OF THE SPECTRUM ARE TO BE PREFERRED OVER OTHER FLUORESCENT COLORS, AND OVER ENAMELS OF ALL COLORS.

1. Data supporting this statement appear in numerous field studies, the most comprehensive of which was conducted at Washington National Airport as part of this contract.

2. These paints, within close ranges, are identifiable at greater distances than all colors of enamels. They also have the advantage of color contrast with a majority of the natural backgrounds encountered during visual flight.

E. ALTHOUGH NO SINGLE PATTERN OF PAINT WILL GUARANTEE CONSPICUITY IN ALL VFR CONDITIONS, AN OPTIMUM STANDARDIZED PATTERN WILL HAVE TO INCLUDE ELEMENTS FOR POSITIVE BRIGHTNESS CONTRAST, NEGATIVE BRIGHTNESS CONTRAST, AND COLOR CONTRAST.

1. The bottom half of the fuselage, and optionally the under surfaces of wings, should be painted partially or completely with a dark color. In most illumination conditions these surfaces are likely to be shadowed and thus to be seen with negative contrast against lighter backgrounds. "Dark" in this context means any moderately dark color--black, green, maroon, etc.--whose reflectance is of the order of 10 to 15 per cent or less.

2. The upper half of the fuselage, and optionally the upper surfaces of wings, should be painted partially or completely with a light color. In most conditions these surfaces tend to be relatively bright and thus to be seen with positive contrast against darker backgrounds of the earth's surface. "Light" in this context means white or any bright pastel color whose reflectance is of the order of 50 to 60 per cent or more.

3. All fixed surfaces of the empennage should be colored orange or red, preferably fluorescent paint or film. This will provide color contrast against almost every natural background; it will also be effective against snow-covered terrain, when the white-top fuselage pattern might be hard to distinguish.

4. Identification markings and special insignia, intended for operational or aesthetic reasons to be discernible on the ground or within very short flight ranges, need not be restricted except to avoid violating the safety effectiveness of the basic pattern described above.

F. PRESENT METHODS FOR APPLYING AND MAINTAINING FLUORESCENT COATINGS ARE RELATIVELY EXPENSIVE AND COMPLICATED, AND THEIR DURABILITY VARIABLE AND RELATIVELY SHORT.

1. The present cost of fluorescent coatings would appear to be burdensome for many owners and operators. Undoubtedly, some would consider the gain in visibility and collision-preventing information worth the present price; but a nationwide requirement appears inappropriate until technological advances and cost reductions are achieved.

G. THE CONTRACTOR FEELS THAT, ALL THINGS CONSIDERED, THE FEDERAL AVIATION AGENCY SHOULD ENCOURAGE THE USE OF FLUORESCENT PAINT OR FILMS, FOR THEIR CONSPICUITY VALUE IN CLOSE-RANGE AND INTERMEDIATE-RANGE SITUATIONS, BUT AT THE OPTION OF THE AIRCRAFT OWNER OR OPERATOR; REGARDLESS OF WHETHER ENAMELS OR FLUORESCENT COATINGS ARE USED, STANDARDIZED PATTERNS CONFORMING TO THE PRINCIPLES STATED ABOVE IN PARAGRAPH E SHOULD BE FOLLOWED.

1. This stipulation is necessary to prevent ambiguity of interpretation in those situations when the paints are visually identifiable.

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