ASD-TR-77-33

ASD STROBE LIGHT EVALUATION

DEPUTY FOR ENGINEERING
WRIGHT-PATTERSON AFB, OH 45433

JUNE 1977

TECHNICAL REPORT ASD-TR-77-33
Final Report for Period 3 June 1975 -- 22 October 1976

Approved for public release; distribution unlimited.

GENERAL OFFICER PANEL FOR SAFETY MATTERS
USAF DEPUTY INSPECTOR GENERAL
WASHINGTON, DC 20330

AVIONICS AND AIRCRAFT ACCESSORIES SPO
DEPUTY FOR AERONAUTICAL EQUIPMENT
WRIGHT-PATTERSON AFB, OH 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

PAUL E. BECK
Technical Director, Equipment Engrg
Directorate of Equipment Engineering

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

AIR FORCE/56780/17 October 1977 — 500

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ASD-TR-77-33	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ASD STROBE LIGHT EVALUATION		5. TYPE OF REPORT & PERIOD COVERED Final 3 June 1975 to 22 October 1976
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Phillip L. Schmidlapp		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Deputy for Engineering (ASD/ENEGE) Wright-Patterson AFB, OH 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PROG ELEMENT: 64212F PROJECT: 2713 TASK: 45
11. CONTROLLING OFFICE NAME AND ADDRESS Avionics and Aircraft Accessories SPO (ASD/AEAI) Deputy for Aeronautical Equipment Wright-Patterson AFB, OH 45433		12. REPORT DATE June 1977
		13. NUMBER OF PAGES 209
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 211 p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

DDC
OCT 26 1977
B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Anticollision lights
Mid-air collisions
Strobe anticollision lights
Visibility
Collision avoidance

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents a synopsis of the literature search and testing conducted by ASD from 3 June 1975 to 22 October 1976 in an attempt to determine the specification requirements for strobe anticollision lights. The literature search resulted in a draft military specification for aircraft anticollision strobe lights which was circulated to the using commands and industry for comments 27 February 1976. Since the literature search had not provided quantative data relative to required intensity, further investigation was deemed necessary. Testing was designed to generate data which could be extrapolated to

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

008 800

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

(Block 20 Continued)

determine intensity requirements for the specification. Test results indicate that strobe lights of intensities far exceeding those practical for aircraft installation would be required. The total effort resulted in the ASD recommendation that the proposed strobe light specification not be published as the visibility enhancement characteristics of the strobe lights when compared to the midair threat environment, offer very little, if any, added protection against midair collisions. ASD also recommended that the "Force Wide Retrofit" action item of the General Officer Panel for Safety Matters be deleted. Any future strobe light activity should be based upon potential Life Cycle Cost advantages when they are used as functional replacements for the present rotating beacons. It was also recommended that the Midair Prevention System program, which was an outgrowth of early ASD proposals and provides a systematic approach to the midair collision problem, be continued.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

SUMMARY

This Technical Report describes the work effort conducted in pursuance of improved aircraft anticollision protection through the use of High Intensity Xenon lighting (commonly referred to as Strobe Lights). The study upon which this report is based was initiated by the Air Force Systems Command (AFSC) upon receipt of a letter dated 3 June 1975, from the Air Force Logistics Command (AFLC), entitled "Specification for Strobe Lights on USAF Aircraft." An evaluation [1] conducted by the Deputy Inspector General for Inspection and Safety (IGD) recommended that high intensity strobe lights be procured for present and future USAF aircraft. Acting on this recommendation, AFLC then requested AFSC develop an Air Force specification for standardization and procurement purposes. The Avionics and Aircraft Accessories SPO under the Deputy for Aeronautical Equipment, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, directed the work effort with technical support from the Deputy for Engineering (ASD/EN), Aeronautical Systems Division, Wright-Patterson AFB, Ohio. Major Donald Drinnon served as the project manager. A draft specification (see Appendix 1) was prepared and then circulated to all Air Force Major Commands and industry for comments. This "strawman" specification had several undetermined parameters. A testing program was initiated to identify and quantify these unknown parameters. ASD/EN was not able to substantiate the IGD findings and, therefore, recommended strobe lights not be procured on the basis of improving conspicuity. The work described herein was performed during the period 3 June 1975 to 22 October 1976. It consisted of the following.

a. A literature search

b. Preparation of initial draft Strobe Light Specification

c. A testing program attempting to quantify unknown parameters in the draft specification

d. Presentation of recommendations

e. Preparation of this report.

PREFACE

This study has resulted in the birth of a new program called MAPS (Mid-Air Prevention Systems) which will hopefully be able to do what strobe lights are unable to do, significantly reduce the potential for midair collisions. Special thanks is in order for MSgt Lloyd F. Woodhouse for his work in the follow-up measurements of the T-43 system and his able-bodied assistance during the ASD tower test. Also to Dr. C. Thomas Goldsmith of Decilog Inc., whose technical report on the ASD tower test was only slightly edited and appears herein as section 3.5. Finally, the pilots who served as subjects for the ASD tower test and who performed diligently under adverse circumstances.

CONTENTS

FIGURES

TABLES

1.0 ANTICOLLISION LIGHTING HISTORY

1.1 NAVIGATION LIGHTING

The first lighting system used as a collision avoidance device was navigation lights. These lights had been in use on vessels traveling on the surface of the sea and were copied (as was the name "navigation lights") to aid air navigation. The simple three color system seemed a logical extension from the water to the air. A red light on the left wing tip shows forward and to the left side. A green light on the right wing tip does the same thing for that side. The White light on the tail can be seen from the rear and from either rear quadrant. Just as is the case with ships, if red and green are seen simultaneously, the other aircraft is approaching head-on. A red and white or green and white combination indicates the other aircraft to be about broadside. White only means that the other aircraft is headed away from the observer.

Very little thought was given to the special problems of air navigation that might call for a different system of lights. The lookout duty on board ship is generally much easier than the pilot's airborne problem. Most obvious, of course, is that ships on the surface of the water are all at the same elevation. Shipboard lookouts do not have to scan both above and below their own altitude. Nor are shipboard lookouts tasked with the other duties levied on a pilot related to aircraft control and navigation. A major part of the problem is to see and recognize another aircraft as soon as possible.

In an attempt to improve the conspicuity of the navigation lights flashers were added. Aircraft of the 1930s began to flash wing tip lights and some added a yellow light to the tail alternating with the white. While it has been shown that a flashing light will attract attention and be seen before a steady light, the flashing of the position lights increases the time required by the observer to interpret what is seen.

1.2 ROTATING BEACONS

The next major improvement in collision avoidance lighting was the use of rotating beacons. These beacons are known as "anticollision lights" and took over the function of calling attention to the aircraft. After anticollision lights were adopted, the requirementfor flashing position lights was discontinued. The first Federal Aviation Regulations covering anticollision light intensities and flash rates were issued in 1957. The minimum flash rate was 40 per minute and the maximum was 100 flashes per minute with a minimum intensity in the horizontal plane of

100 effective candela (E.Cd.). The first anticollision lights tested were white but were changed to red after flight evaluation, primarily because of backscatter problems when operating in any perceptible haze or clouds (not as is popularly believed that red indicates danger). From the time anticollision lights were first used, the choice of color has been the subject of much discussion. Proponents of the use of red have contended that it provides easier recognition against an urban background, that it is less distracting to the pilot in hazy and cloudy atmospheric conditions, and that it has less effect on the pilot's dark adaption. Proponents of white cite the loss of light in the red filter (upwards of 80% absorption), and contend that the brighter white light is visible against urban backgrounds. They also note that the eye is more sensitive to white light in the periphery. The problem was summed up by one expert who noted that if he were a pilot he would want a red light on his aircraft and white lights on all other aircraft.

In order to demonstrate the increased intensity of white lights as compared with red lights of the same wattage, Grimes Manufacturing Company (a major manufacturing company of aircraft lighting systems located in Urbana, Ohio) arranged a demonstration at the old Civil Aviation Administration's Technical Development Center in Indianapolis, Indiana. Two Bonanza aircraft were equipped with identical anticollision lights on the top and bottom of the fuselage, except that one aircraft was fitted with clear covers and the other with red covers. These anti-collision lights were developed by Grimes to reduce the size of the original light to allow installation on single engine aircraft. This design was based on two small reflectorized 40 watt lamps rotating back-to-back about a common axis and provided 6000 candela on the lamp central axis. Both aircraft were viewed from other aircraft against the city lights of downtown Indianapolis, dark country side, and starlit sky. Viewing distances ranges from one-half mile to ten miles. From this evaluation by airline, military, and general aviation pilots, it was determined that the red cover was preferred by both the observing pilots and the pilots of the Bonanza aircraft. Tests on the lights used in this evaluation showed that the photometric intensity of the white lights was approximately four times that of the red lights. However, the observing pilots were in agreement that there was no significant difference in the apparent intensities of the red and white lights.

Other configurations of anticollision lights have been developed providing essentially the same capability as described above. For example, improving the aerodynamic characteristics resulted in the same two 40 watt reflectorized lamps used above mounted one in front of the other, each pivoted on its own axis and was known as the tandem oscillating light. In other common rotating or oscillating beam type anticollision lights single lamps are mounted stationary at the center of rotation of a moving reflector or lens. Rotating the reflector or lens rather than the bulb has the obvious advantage of dispensing with the need for slip rings to carry lamp power.

1.3 WHY STROBES?

It is important to note that the development of lighting systems for collision avoidance purposes has historically examined a nighttime problem. The development of high intensity lighting as exemplified by strobe anticollision lights is an attempt to expand the useful range of the lighting aided "see-and-avoid" concept into dawn-dusk and even the daytime problem.

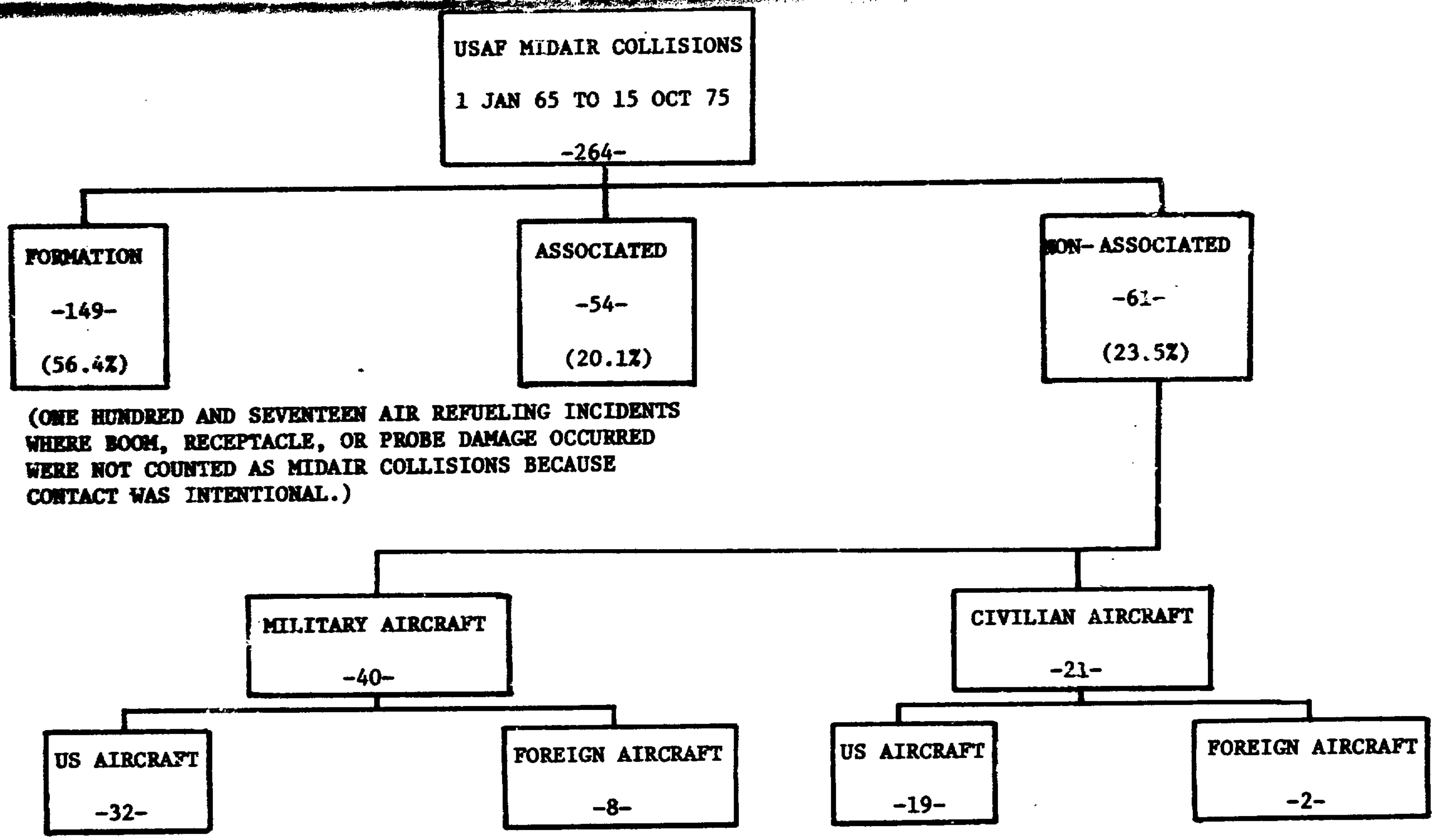
2.0 THE MIDAIR COLLISION POTENTIAL

The task of publishing a specification for strobe lights resulted primarily from high level concern that the development of aircraft painting schemes to reduce aircraft visibility (a tactical consideration) could result in an increase in the midair collision potential during peacetime. Analyses were initiated which would hopefully identify those conditions which influence the potential for midair collisions. These data would then be used to determine parameters such as required intensity and distribution pattern for the strobe light specification.

2.1 USAF STATISTICS [2]

The Air Force Inspection and Safety Center provided an analysis of Air Force midair collisions occurring in the period 1 January 1965 to 15 October 1975. During this period the Air Force experienced 264 midair collisions involving 530 aircraft (213 of which were destroyed) and 222 military and 111 civilian fatalities. Unlike civilian aircraft the Air Force purposely flies aircraft in close proximity (fighter formation) and comes in contact intentionally during refueling operations. The midair collisions were categorized as follows; formation, associated, and non-associated. For this analysis: (a) Formation was defined as flight in which flight members are attempting to maintain or attain a fixed position relative to a leader with whom they have visual contact. (b) Associated flying involving two or more aircraft operating in a limited airspace where each is aware of the presence of, but not necessarily the exact location of, the other aircraft. (c) Non-associated collisions are those in which the aircraft involved are not both aware of each other's presence. Figure 1 consolidates the numerical data from the analysis.

Since the task was to examine those midair collisions which would identify the conditions influencing strobe light specification parameters, formation and associated midair collisions were eliminated from the data base. While these two flying relationships accounted for 76.5% of the midair collisions over the study period, strobe anticollision lights would not affect these types of midairs. (While some associated flying may belong in the group where anticollision lights would be an aid the majority of the associated collisions in this data could not be prevented by any visual means. Associated collision data must be carefully considered analysis by analysis.) Formation flying pilots do not normally use their rotating beacons during formation flights due to the spatial disorienting and distracting effects. There is no reason to suspect that increasing the intensity of these lights 20 to 50 times (as with high intensity strobes) would reduce these effects. Associated collisions



VFR VS IFR

35 (57.4%) - BOTH AIRCRAFT VFR
26 (42.6%) - ONE AIRCRAFT VFR
0 (0%) - BOTH AIRCRAFT IFR

DAY VS NIGHT

8 (13.1%) - AT NIGHT (NONE IN WEATHER)
53 (86.9%) - DAY (4 IN WEATHER - 3 CIVILIAN - 1 ARMY HELICOPTER)

FIGURE 1 - USAF MIDAIR STATISTICS

were eliminated as virtually all resulted during some form of military operation where one does not wish to be seen by the enemy (i.e., FAC operations, air combat maneuvering, intercept, etc.). The breakdown of the non-associated midair collisions can also be seen in Figure 1. It is interesting to note that over the 11 year period the Air Force experienced an average of one midair collision every 245,208 flying hours. This is a rate of 0.41 per 100,000 hours.

As can be seen in Figure 1, non-associated flying accounted for 23.5% (61) of the total Air Force midair collisions. Using these as our data base we find 34.4% (21) involved civilian aircraft, two of which were foreign while 65.6% (40) involved other military aircraft, eight of which were foreign.

2.1.1 VFR vs IFR

Examining the non-associated collisions relative to flight plan we find 57.4% occurred when both aircraft were flying Visual Flight Rules (VFR) and 42.6% occurred when one aircraft was VFR and the other flying Instrument Flight Rules (IFR). The Air Force was not involved in any midair collisions over this 11 year period when both aircraft were flying IFR.

It is not the type flight plan filed which increases the midair potential but the metrological conditions which exist (requiring the filing of an IFR or VFR plan) that affect the midair potential. The conditions at the time of collision are found to be far more significant than the flight plan filed. For example, an aircraft flying under positive radar control, in weather, reduces the probability of a midair collision significantly, even if it took off on a VFR flight plan in VMC.

Flying in weather reduces the probability of a midair collision if all aircraft doing so are under radar control. All four non-associated collisions that occurred in weather involved a VFR aircraft violating visual flight rules.

2.1.2 DAY vs NIGHT

Thirteen and one-tenth percent (8) of the non-associated collisions occurred at night, none of which were in weather. Seven and one-half percent (4) of the 53 daytime non-associated collisions involved aircraft flying VFR in IFR conditions. The reduced number of this type collision at night is largely due to the reduced flying activity, rather than the lack of sunlight. However, increased conspicuity due to aircraft lighting, the probable higher experience level of civilian pilots flying at night, and reduced light aircraft traffic are significant in reducing the collision potential.

Of the total number of midair collisions,in the eleven year period, eighty-three and eight-tenths percent (221) occurred during day flight, two and six-tenths percent (7) occurred during dawn-dusk conditions and thirteen and six-tenths percent (36) occurred at night. From this data it appears that expanding the anticollision lighting system into the dawn-dusk area from a nighttime only system will not significantly reduce the Air Force midair statistics, especially when one considers that only eight of the night collisions were the non-associated type possibly preventable by strobe lights.

2.1.3 OTHER FACTORS

Type of Aircraft. Although fighter aircraft were involved in 60% of all collisions, this is attributable to the fact that they fly close together more often, not simply because they are fighters. Actually fighter aircraft were only involved in 33% of the non-associated collisions. Better visibility and maneuverability make a fighter more able to avoid the collision once an impending collision is recognized. Type of aircraft was found to have little influence on midair collision probability.

Geographical Location. Midair collisions occur wherever flying activity is concentrated. No particular geographical area was identified as being inherently conducive to midair collisions. Flying activity tends to concentrate in the vicinity of airfields and depends on both size and number of airfields in a given area. Traffic funnel points, pattern entry points and departure routes for multiple airfields in a given area further increase the probability of a collision.

Phase of Flight. Takeoffs and landings have higher potential for midair collisions. The major influence during these phases is the close proximity to concentrated flying activity. Contributing elements are the degraded aircraft response at slower airspeeds during takeoffs and landings and the increased cockpit workload during visual conditions.

Altitude. Fifty-eight percent (12) of the 21 midairs involving civilian aircraft occurred below 5000 feet. Decreasing altitude increases the probability of a collision with a light aircraft due to increased traffic density and the reduced likelihood of being under positive control.

2.1.4 CONCLUSIONS FROM AIR FORCE DATA

Non-associated flying accounted for approximately one-fourth of the total number of midair collisions. Non-associated collisions are the only type of the three defined categories which might be reduced through the use of high intensity anticollision lights (strobes being one type).

Half of all midair collisions occurred at or below 3000 feet above ground level (AGL). Two-thirds of the non-associated midair collisions occurred with other military aircraft during takeoff, initial climb, descent, or landing.

Eighty-seven percent of the non-associated midair collisions occurred during the day.

All Air Force midair collisions occurred with at least one aircraft flying under VFR.

2.2 FEDERAL AVIATION ADMINISTRATION (FAA) STATISTICS [3]

The FAA published a report in 1973 entitled "Civil Aviation Midair Collision Analysis January 1964 to December 1971." Supplement 1 to this report added 1972 statistics but did not result in any change to the statistics other than an increase in the data base. This study was examined in hopes of gaining further insight into the non-associated type midair collisions. Almost all civil midair collisions are of the non-associated type except for a small number (primarily crop dusters).

During the nine year period of the report, civil aviation experienced 296 midair collisions. These collisions were divided into two major categories; "Airport Collisions" and "Enroute and Terminal Area Collisions." Airport Collisions were defined as those collisions which occurred local to a specific airport (those within a radius of five statute miles of the airport and at or below 2000 feet AGL). Airport collisions were divided into two sub sets; "Uncontrolled Airports," an airport without an active FAA manned control tower at the time of the collisions, and "Controlled Airports," an airport with an active FAA manned control tower at the time of the collision. Enroute and Terminal Area Collisions were defined as those collisions which occurred away from the airport, either while enroute or while crossing the terminal area which services one or more airports. The basic numerical statistics are presented in Figure 2.

2.2.1 AIRPORT COLLISIONS

Airport collisions accounted for 66% (195) of the total civil collisions. Eighty-two percent (160) of these were at airports without an active FAA manned control tower while 18% (35) occurred at FAA

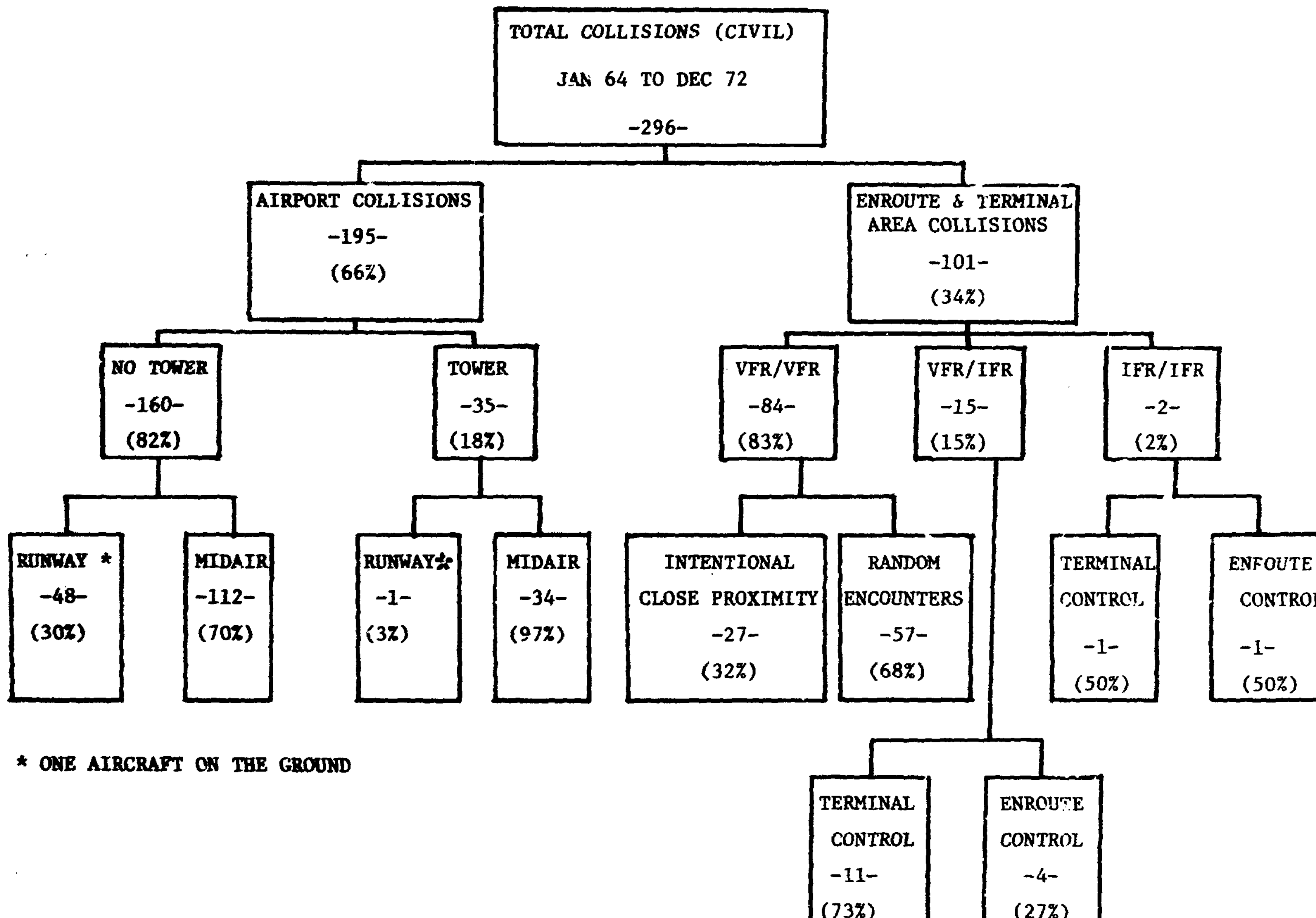


FIGURE 2 - FAA MIDAIR STATISTICS

manned facilities. It is significant to note that almost one in three (30%) of the collisions at uncontrolled airports were "runway" collisions (i.e., they occurred with one aircraft on the ground), but only one runway collision occurred at controlled airports. The one exceptional case was a runway collision at Chicago O'Hare Airport in December 1972. This collision was attributed to the failure of a ground controller to establish where the taxiing aircraft was positioned and to provide the crew with an unambiguous taxiing clearance from that position.

The FAA study takes special note in the fact that general aviation involvement in airport collisions predominates; 99.5% (194) of the collisions at both controlled and uncontrolled airports involved at least one general aviation aircraft. The O'Hare runway collision described above is the only collision between two commercial aircraft.

2.2.1.1 WHERE AIRPORT MIDAIRS OCCUR

At uncontrolled airports 68% of the midair collisions occurred while both aircraft were in the final phases of landing (57% final approach, 11% touching down). At controlled airports on the other hand 61% occurred when both aircraft were beyond or attempting to join the VFR traffic pattern but before final approach. As a function of altitude, the distinction between collisions for uncontrolled and controlled airports is quite pronounced. Taking the nominal altitude of 400 feet AGL at which base leg traffic turns on the final approach centerline, 80% of the midairs at uncontrolled airports occur below this altitude, while 80% at controlled airports occur above this altitude.

2.2.1.2 CLOSING VELOCITIES IN AIRPORT MIDAIRS

Figure 3 shows the horizontal convergence angle for all civil airport collisions when the angles are known. In both the uncontrolled and controlled airport cases, the predominant collision mode is the overtake. Taking both cases together 90% were from behind. These then are relatively slow (generally well below 200 knots) closing velocities.

2.2.1.3 AIRPORT COLLISIONS BY TIME OF DAY

Figure 4 graphically presents data on collisions at uncontrolled airports by time of day. The figure shows that 89% of the collisions at uncontrolled airports occurred during the daylight hours. The reduced number of collisions during non daylight hours is probably more related to reduced flying activity rather than the lack of sunlight. Strong contributing factors are, increased conspicuity due to the increased effectiveness of aircraft lighting and the probable higher experience level of pilots flying at night.

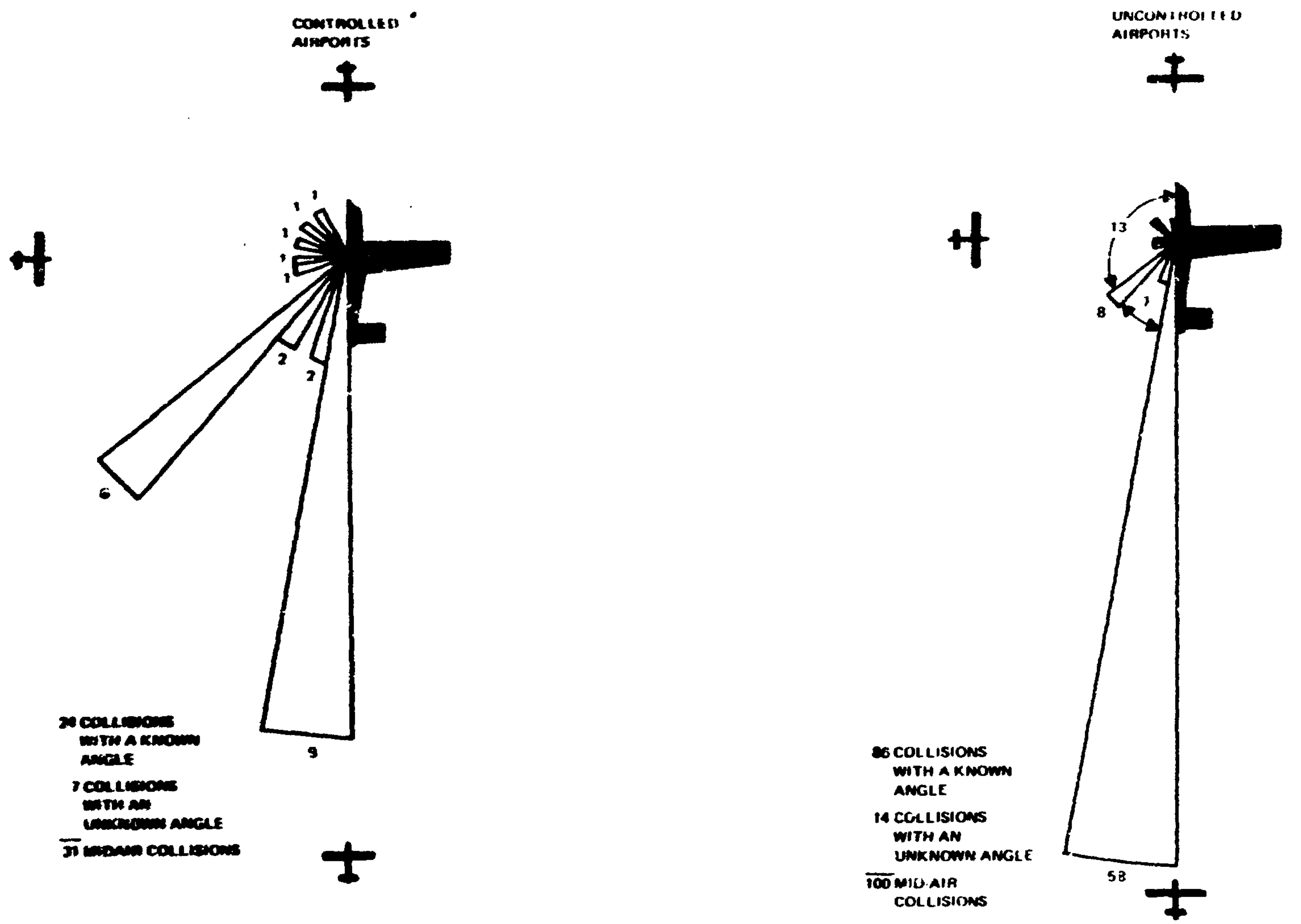


FIGURE 3 [3:3-10]
HORIZONTAL CONVERGENCE ANGLES OF AIRPORT MIDAIRS
JANUARY 1964—DECEMBER 1971

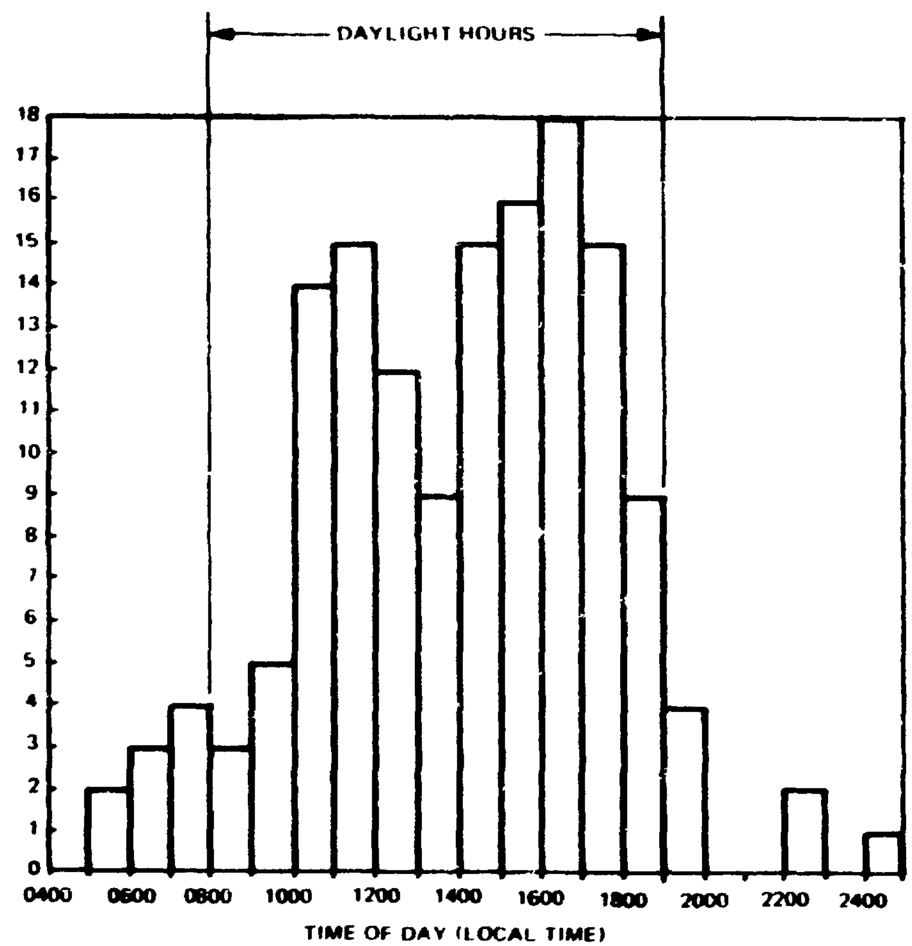


FIGURE 4 [3:3-26]
TIME OF DAY OF UNCONTROLLED AIRPORT COLLISIONS
JANUARY 1964–DECEMBER 1971

2.2.2 ENROUTE & TERMINAL AREA COLLISIONS

Enroute and terminal area collisions accounted for 34% (101) of the total civil collisions. Of these 98% (99) occurred with one of the involved aircraft flying on a VFR clearance. The two percent (2) that occurred when both aircraft were flying IFR clearance involved one of the aircraft knowingly violating an IFR clearance. Military aircraft were involved in 18% of the enroute and terminal area collisions.

2.2.2.1 WHERE TERMINAL AREA AND ENROUTE COLLISIONS OCCUR

Most terminal area and enroute collisions were within 30 statute miles of a primary airport and above 2000 feet. The FAA points out in this report that the majority of these collisions occurred within existing or planned radar/beacon coverage and that no collisions have occurred in positively controlled airspace.

2.2.2.2 CLOSING VELOCITIES IN TERMINAL AREA AND ENROUTE COLLISIONS

Closing velocities are determined by the angle between the paths of two converging aircraft and the individual velocities. Figure 5 shows the horizontal convergence angles for all collisions involving IFR aircraft and all random VFR - VFR collisions for which the angles are known. As in the airport case (paragraph 2.2.1.2) VFR - VFR collisions are predominantly overtakes. Except for the eight collisions involving military aircraft, these collisions were between piston aircraft operating at 250 knots or below. In the collisions where IFR aircraft were involved, the distribution is more uniform. Three of these collisions involved high performance military fighters (one head-on collision involving an F-101, and two collisions crossing courses involving an F-4 and an F-102). In all but two of the collisions shown in Figure 5, the IFR aircraft was a turbojet and the other a piston aircraft.

2.2.3 CONCLUSIONS FROM FAA COLLISION DATA

No midair collisions occurred over the nine year period when both aircraft were:

a. identified and under radar/beacon surveillance,

b. under positive control, and

c. both pilots conformed to their ATC clearance.

Thus, the IFR system worked effectively to prevent collisions.

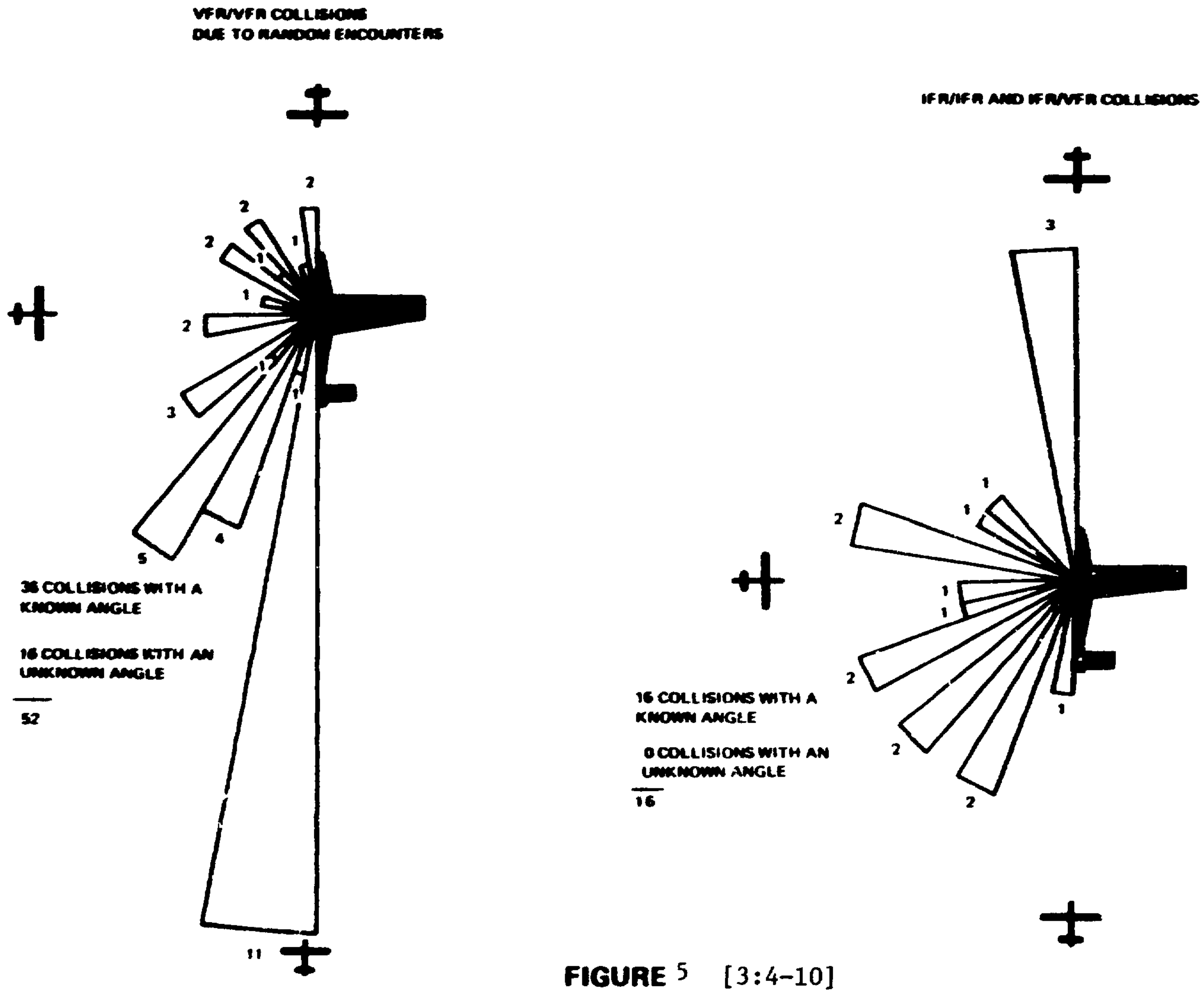


FIGURE 5 [3:4-10]
HORIZONTAL CONVERGENCE ANGLES OF TERMINAL AREA AND EN ROUTE MIDAIRS
JANUARY 1964—DECEMBER 1971

Most collisions occurred within five miles of an airport (66%). Of these, most occurred at uncontrolled airports (83%). At uncontrolled airports, most midair collisions occurred while the aircraft were below 400 feet (68%). Most runway collisions involved at least one landing aircraft (89%). One runway collision occurred over the nine year period at controlled airports while one out of three collisions at uncontrolled airports were runway collisions.

Airport collisions as a function of annual aircraft operations were related as follows:

a. Midair collisions at uncontrolled airports were nearly linearly related to operations. That is, when operations doubled, then the number of collisions doubled.

b. Midair collisions at all controlled airports were non-linearly related to operations. That is, when operations doubled, then the number of collisions more than doubled.

The annual risk of midair collision per aircraft operation or flight hour did not change significantly, despite constantly increasing annual levels of aviation activity which effectively doubled between January 1964 and December 1971.

Eighty-nine percent of the collisions were between two general aviation aircraft. General aviation aircraft were involved in 99.5% of all collisions.

2.3 NEAR MIDAIR COLLISION REPORT OF 1968 [4]

The Near Midair Collision Report of 1968 is the result of a year long study conducted by the FAA. This study was supported by a major segment of the aviation community because of the potential of the "near miss" becoming an actual midair collision. It was an attempt to determine the true nature and extent of the "near miss" danger and to develop further insight in the midair collision problem.

An FAA Advisory Circular AC 00-23 issued effective 1 January 1968 provided information on the study, including a reporting form, and outlined the procedures to be followed for reporting near midair collisions. The circular was mailed to about 523,000 pilots who had current medical certificates on file and to military distribution points.

In the past, pilots have contended that "near misses" were not reported because the FAA enforcement program discouraged such reports by subjecting the reporting pilot to possible sanctions for his own actions. Pilots believed that an objective analysis of the situation would be possible only when immunity against enforcement action was given to pilots who were involved in near midair collisions. The FAA therefore granted anonymity, confidentiality, and immunity from FAA enforcement or other adverse action to any pilot of a aircraft, an air traffic controller, or any other persons involved in a near midair collision where the facts, conditions, and circumstances of such a near midair collision were reported to the FAA.

2.3.1 STUDY OBJECTIVES

The objectives of this study were set forth as follows:

a. To describe the near midair collision problem areas existing in the National Airspace System and to identify specific causal factors which separately or in combination lead to a near midair collision.

b. To clearly identify the circumstances surrounding near midair collision incidents in order to develop procedures, regulations, and techniques for increasing aviation safety in connection with the near midair collision hazard.

2.3.2 NEAR MIDAIR COLLISION CLASSIFICATION

In this study all occurrences reported as near midair collisions were considered for data collection. The severity or danger of a collision in flight was determined and each occurrence was then classified as "Hazardous (Critical or Potential)" or "No Hazard" based on the following guidelines:

HAZARDOUS

Critical - A situation where collision avoidance was due to chance rather than an act on the part of the pilot.

Potential - An incident which might have resulted in a collision if no action had been taken by either pilot.

NO HAZARD

An occurrence which does not meet the hazardous classification.

The technical and statistical analyses were performed on the hazardous group since the characteristics of this group were considered similar to those of the midair collisions that actually occur. Many things can affect how a near midair collision is viewed. For example, the "frame of mind" of the reporting pilot (i.e., the degree of his being startled by the sudden appearance of the other aircraft) and various other subjective factors may have resulted in the submission of a near midair collision report, whether or not the encounter actually warranted a report.

Some significant factors which contribute to the identification of a near miss are:

a. distance at first sighting

b. distance at closest proximity

c. closure rate

d. relative position

e. evasive action involved

It should be recognized that in busy airspaces such as control zones, aircraft often do pass in close proximity to each other where a near miss situation does not actually exist. While one pilot might believe he had a "near miss" the other pilot was at all times fully aware of the presence of the other aircraft and was acting accordingly. It must be noted that without each being aware of the other's intentions there is a potential danger to flight safety and a valid near midair collision situation does exist.

2.3.3 FINDINGS

While near midair collision reports are received from geographical locations throughout the nation, it was found that certain locations generated more reports than others. The analysis of the near midair collisions resulted in a clustering around large air transportation hubs and the remainder along the published airways with very few "off" airways.

Thirty general area locations were selected from different sections of the country including large, medium, and low activity hub areas to obtain a representative nationwide sampling of both enroute and terminal airspace. A circular boundary with a 50 nautical mile radius was established around each of the 30 selected hubs and all near midair collisions within that radius were recorded. Fifty-two percent (594) of the 1,128 hazardous incidents occurred in the 30 areas identified. Terminal incidents accounted for 70% (417) of these. The study of these

30 areas resulted in the identification of factors which can be shown to affect significantly the near midair collision statistics. These factors were the terrain effect, airport proximity, published information showing patterns of traffic, certain air traffic control services, and type of aircraft and operations involved. These factors affect near midair collisions to different degrees at the different hubs depending on the magnitude of each of these factors.

As might be expected, the large metropolitan areas reflected the heavy concentration of reported near midair collisions. Just as in the midair collision data, increased traffic density results in increased near midair collisions. At locations where the main airport has surrounding airports generating different kinds of traffic, reported near midair collisions were numerous. The flow of traffic to and from these different airports conflicted because of the proximity of traffic patterns, random arrival/departure routings, instrument approach course locations, and aircraft flying over or near airport traffic areas. Conflicts between arriving and departing aircraft occurred much more at locations having airports in close proximity than at other locations.

Military involvement in the terminal airspace was found to occur primarily around military terminals and particularly at military airports conducting training. Near midair collisions reported by the military most often involved "light aircraft" (12,500 pounds or under). These aircraft were usually operating in or in close proximity to the military terminal traffic areas, in level flight, while the military aircraft were in descent arriving or in climb departing modes. The descent arriving mode is particularly dangerous as Air Force fighter aircraft have very restricted visibility down and to the front. The altitudes ranges from 2000 ft to 1000 ft AGL and closure rates from 300 to 400 knots.

The majority of terminal near midair collisions reported occurred in good VFR weather, well above VFR minimums (visibility more than five miles). As the following table shows, most occurred on bright days.

PILOT REPORTED	NUMBER
Bright Day	406
Haze	164
Smoke	43
Precipitation	28

The principal problems identified in the terminal airspace are:

a. The uncontrolled mixture of VFR and IFR traffic (i.e., exposure of known IFR and VFR traffic to unknown VFR traffic).

b. The difficulty experienced by the pilots to "see and avoid" soon enough to prevent a near midair.

Ninety-three percent of the 1,128 hazardous incidents took place during the day. Eighty-six percent occurred during good VFR conditions (flight visibility better than five miles). Table 1 shows the visibility limitations encountered.

The following figures (6 through 10) and tables (2 and 3) provide data of interest to the military midair collision study published by the FAA in the Near Midair Collision Report of 1968.

2.4 A COMPARISON OF FAA MIDAIR COLLISION AND NEAR MIDAIR COLLISION STUDY FINDINGS [3:App F]

The results of the Near Midair Collision Report of 1963 (paragraph 2.3) parallel the results of the FAA Midair Collision Study (paragraph 2.2) in many respects. The FAA's Near Midair Collision Report made the assumption that actual midair collisions are a sub set of near midair collisions where the miss distance is zero. There were some significant differences however.

The near midair collision data does not statistically parallel the midair collision data. As shown in Figure 11 general aviation's involvement in reported near midair collisions is nowhere near its involvement in actual midair collisions. This results in gross over-emphasis of the involvement of air carrier and military aircraft in any midair collision prediction model based on the near midair collision data. The difference in the data collection system most likely accounts for the observed data bias. Every midair collision occurring within the United States must be reported to the National Transportation and Safety Board. In contrast, near midair collision reporting was voluntary. The observation is that while near midair collisions may represent, in theory, a large set of data points with midair collisions as a sub set of those points, it does not follow that the actual data collected is an unbiased set. This is not to imply that the data does not produce useful information relative to the midair collision problem. While the near midair collision data cannot be interpreted as an unbiased substitute for actual collision data, it should be a leading indicator in system improvements (i.e., improvements toward the reduction of midair collisions should first be reflected in significant reductions in near midair collision reports).

TABLE 1. [4.55] REPORTED ATMOSPHERIC AND CLOUD CONDITIONS
HAZARDOUS INCIDENTS

	ENROUTE	TERMINAL	TOTAL
BRIGHT DAY	288	406	794
GLARING SUN	10	29	39
BRIGHT NIGHT	16	33	49
DUSK	23	61	84
DAWN	0	3	3
THUNDERSTORMS	3	6	9
PRECIPITATION	13	28	41
TURBULENCE	5	7	12
HAZE	60	164	224
ICING	2	0	2
SMOKE	12	43	55
SNOW	0	1	1
OVERCAST	13%	15%	14%
BROKEN	10%	14%	12%
SCATTERED	14%	14%	14%
CLEAR	63%	57%	60%

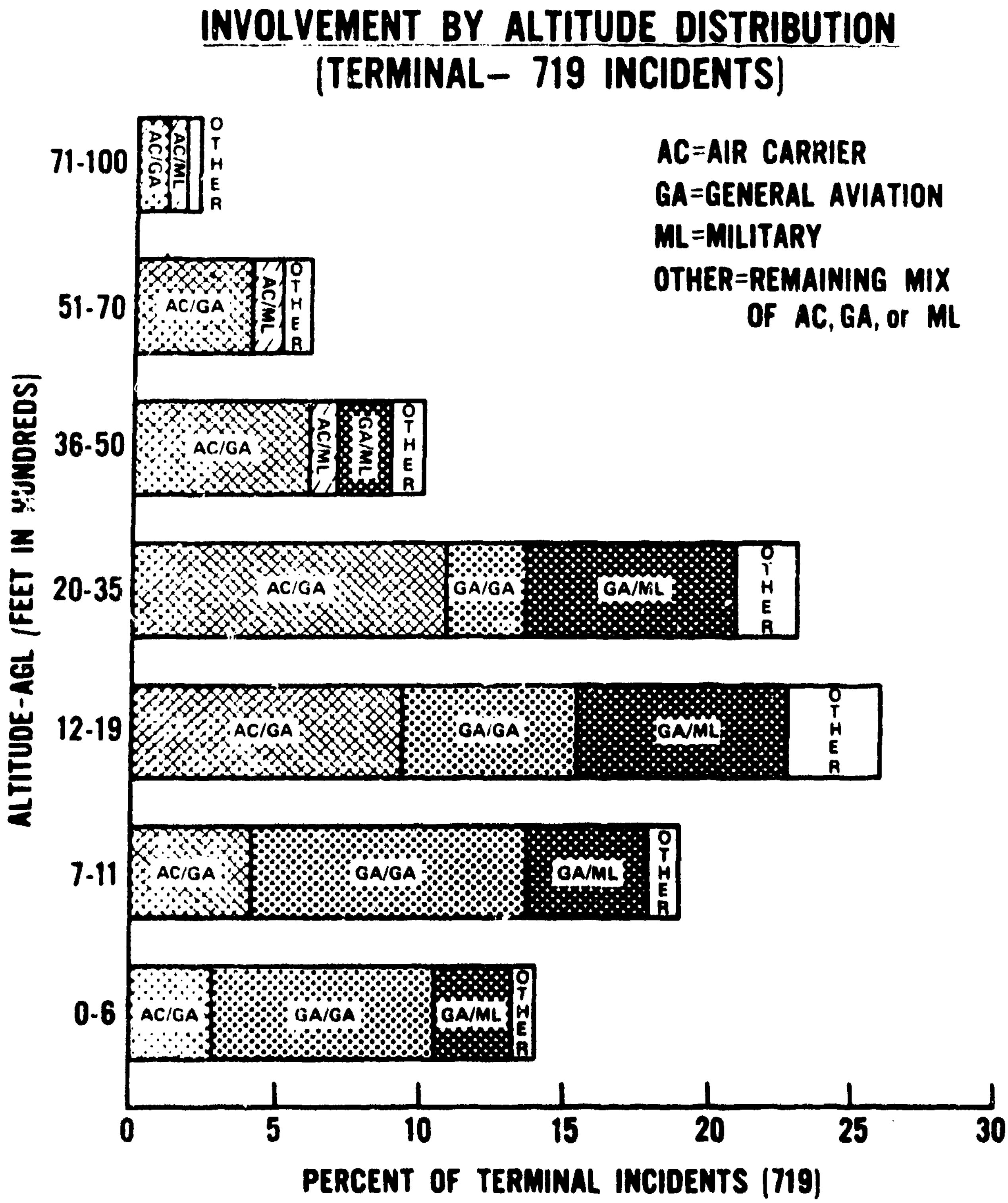


FIGURE 6. [4:125]

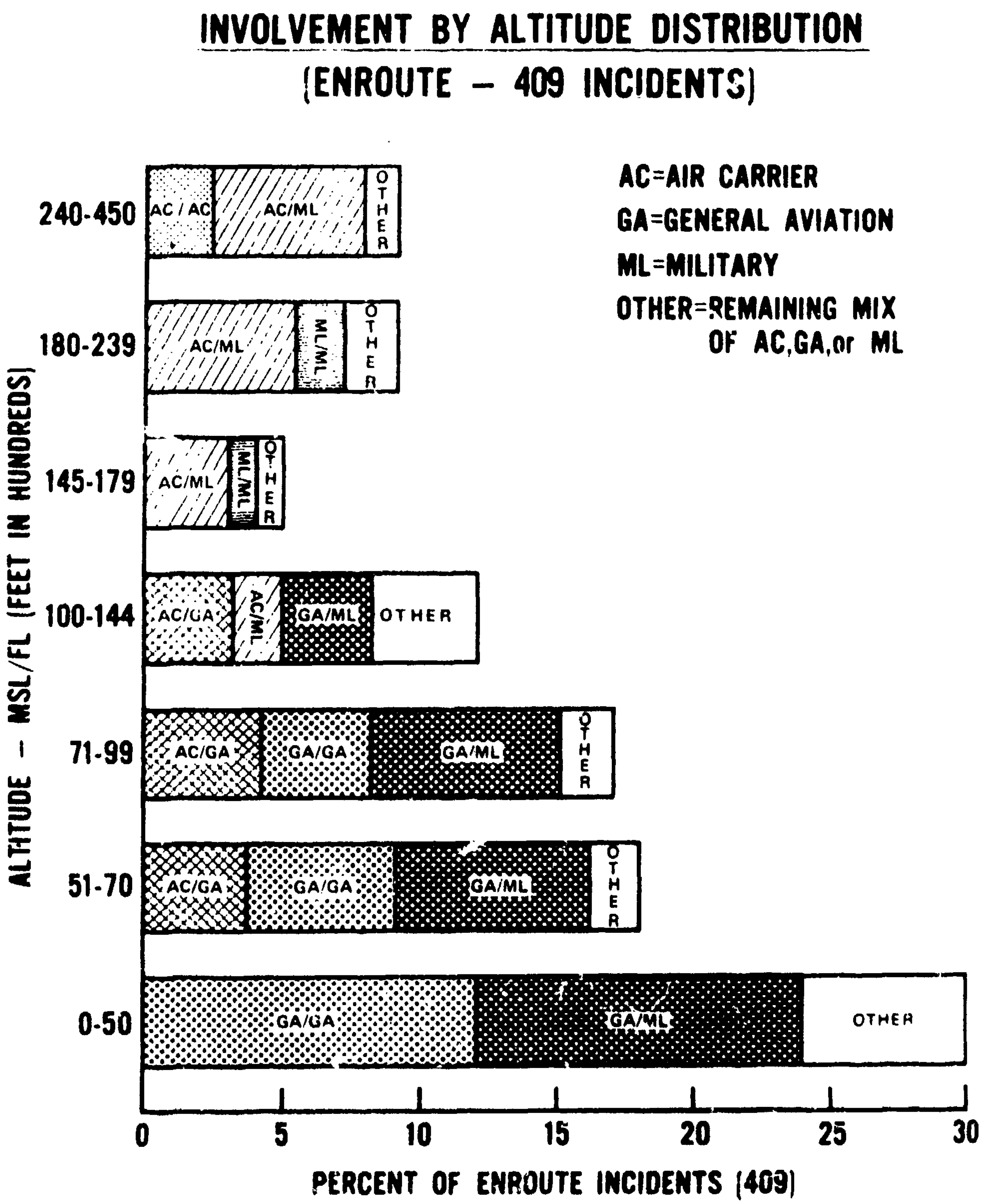
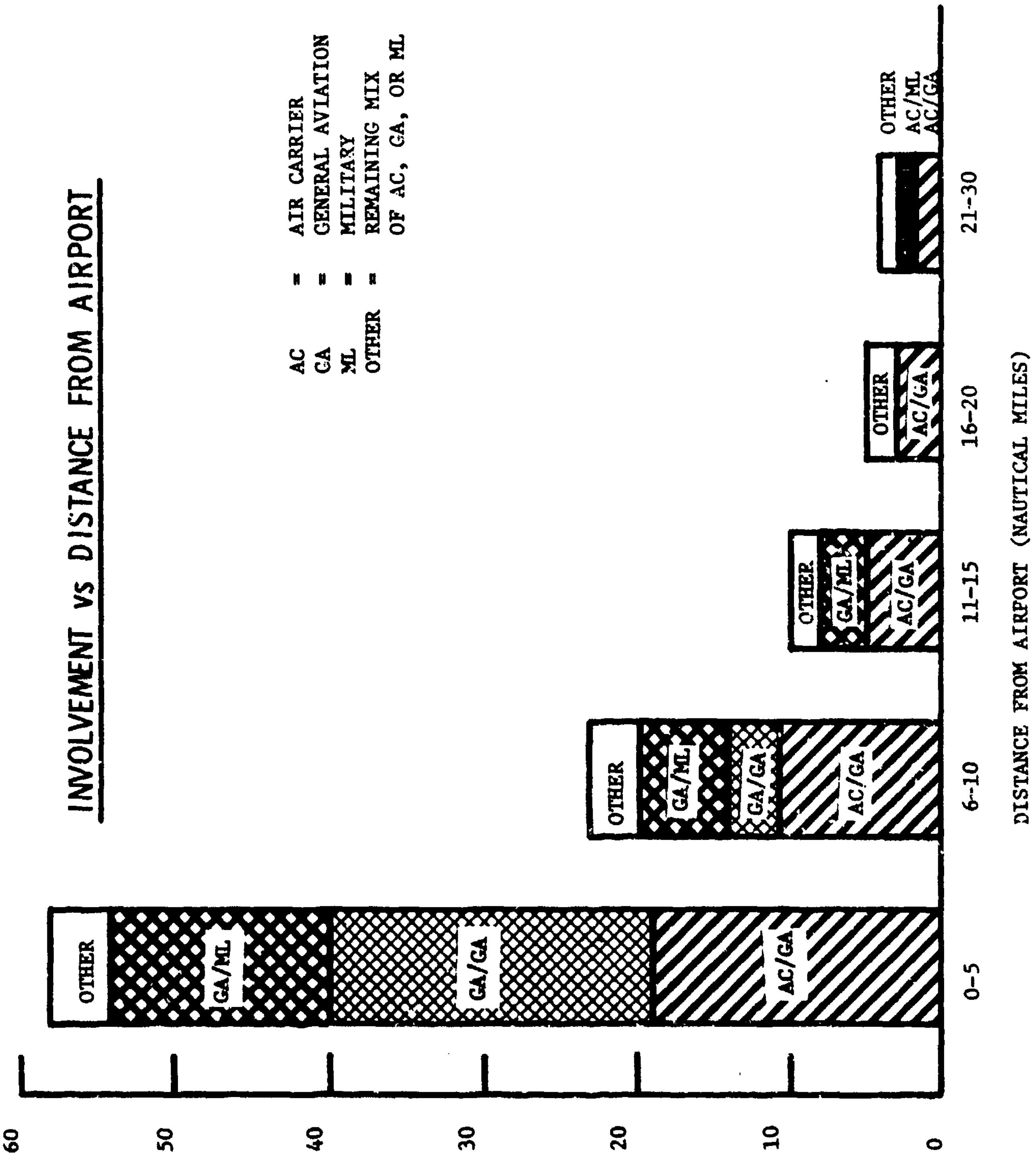


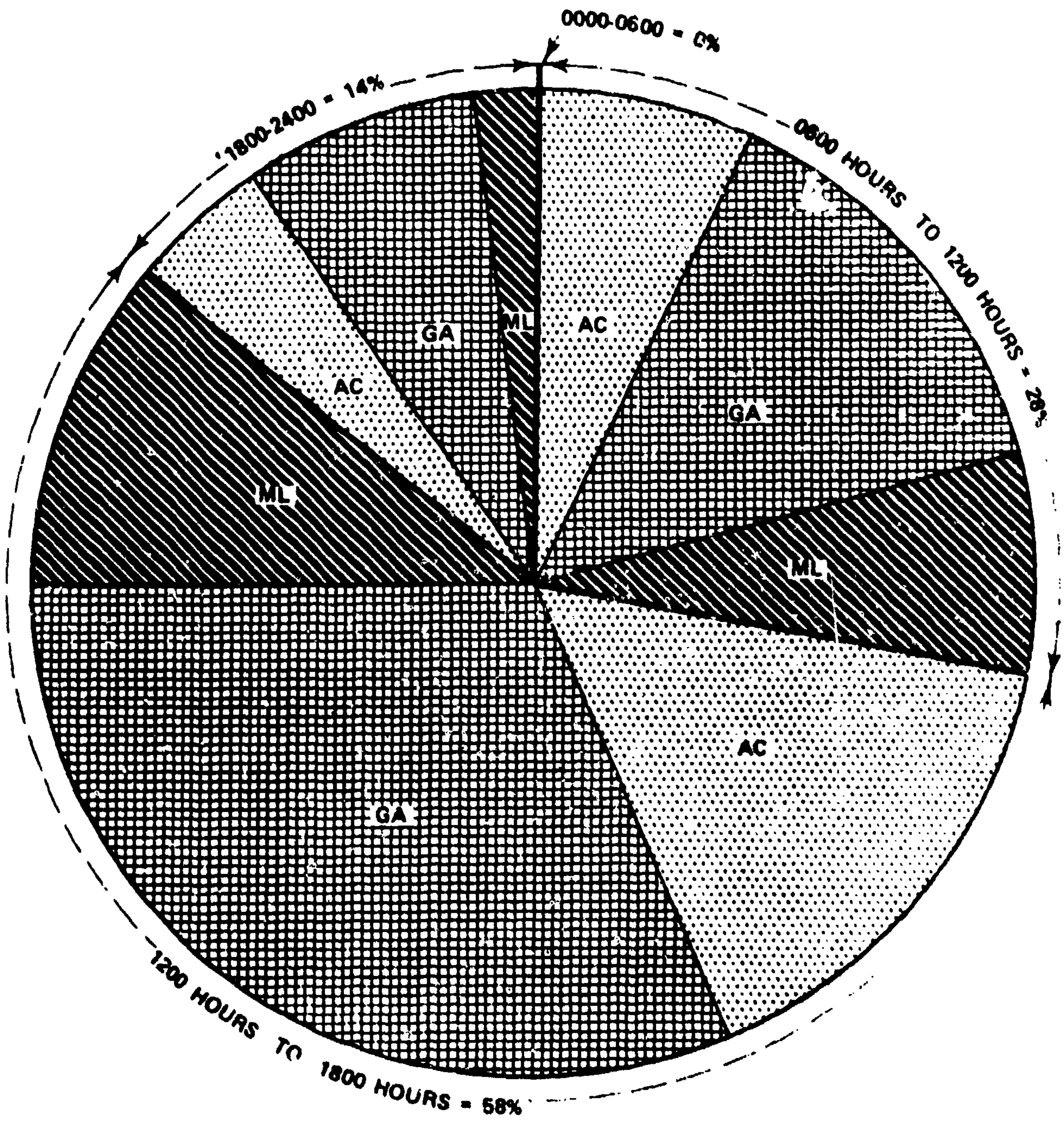
FIGURE 7. [4:126]



PERCENT OF TERMINAL INCIDENTS (719)

FIGURE 8. [4:127]

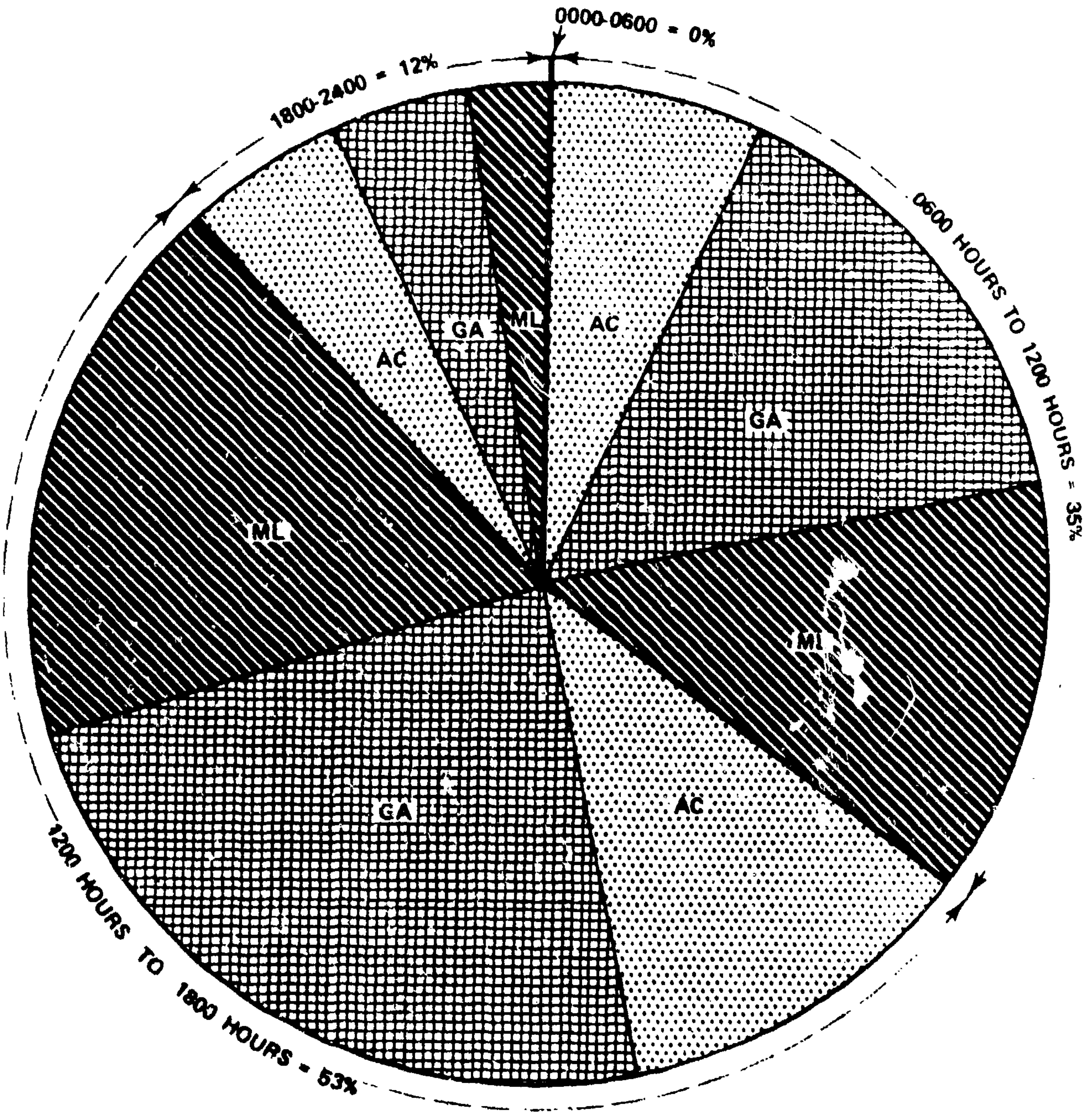
OPERATOR INVOLVEMENT VS LOCAL TIME (TERMINAL)



TOTAL = 719 INCIDENTS

FIGURE 9. [4:131]

OPERATOR INVOLVEMENT VS LOCAL TIME
(ENROUTE)



TOTAL = 409 INCIDENTS

FIGURE 10. [4:132]

REPRESENTATIVE AIRCRAFT INVOLVEMENT

AIRCRAFT MODEL	REPORTING AIRCRAFT			OTHER AIRCRAFT		
	EN	TE	TOTAL	EN	TE	TOTAL
Single-Engine						
C-150	32	69	101	5	62	67
C-172	17	36	53	13	55	68
C-182	8	11	19	11	21	32
PA-28	18	40	58	14	66	80
BE-35	11	11	22	9	44	53
Light Twin						
C-310	2	2	4	2	4	6
BE-55	4	3	7	1	5	6
BE-18	6	5	11	5	7	12
2 & 3-Engine Transport						
B-727	23	61	84	19	17	36
B-737	0	8	8	1	0	1
DC-9	16	56	72	11	8	19
4-Engine Transport						
B-707	10	18	28	14	11	25
DC-8	11	18	29	3	4	7
DC-6	2	13	15	2	4	6
Military						
B-52	6	1	7	3	1	4
F-4	7	12	19	24	9	33
A-4	11	5	16	6	6	12
T-33	3	7	10	3	12	15
T-38	4	22	26	2	1	3

NOTE: **Number of times each model involved in 1,128 Hazardous Incidents**

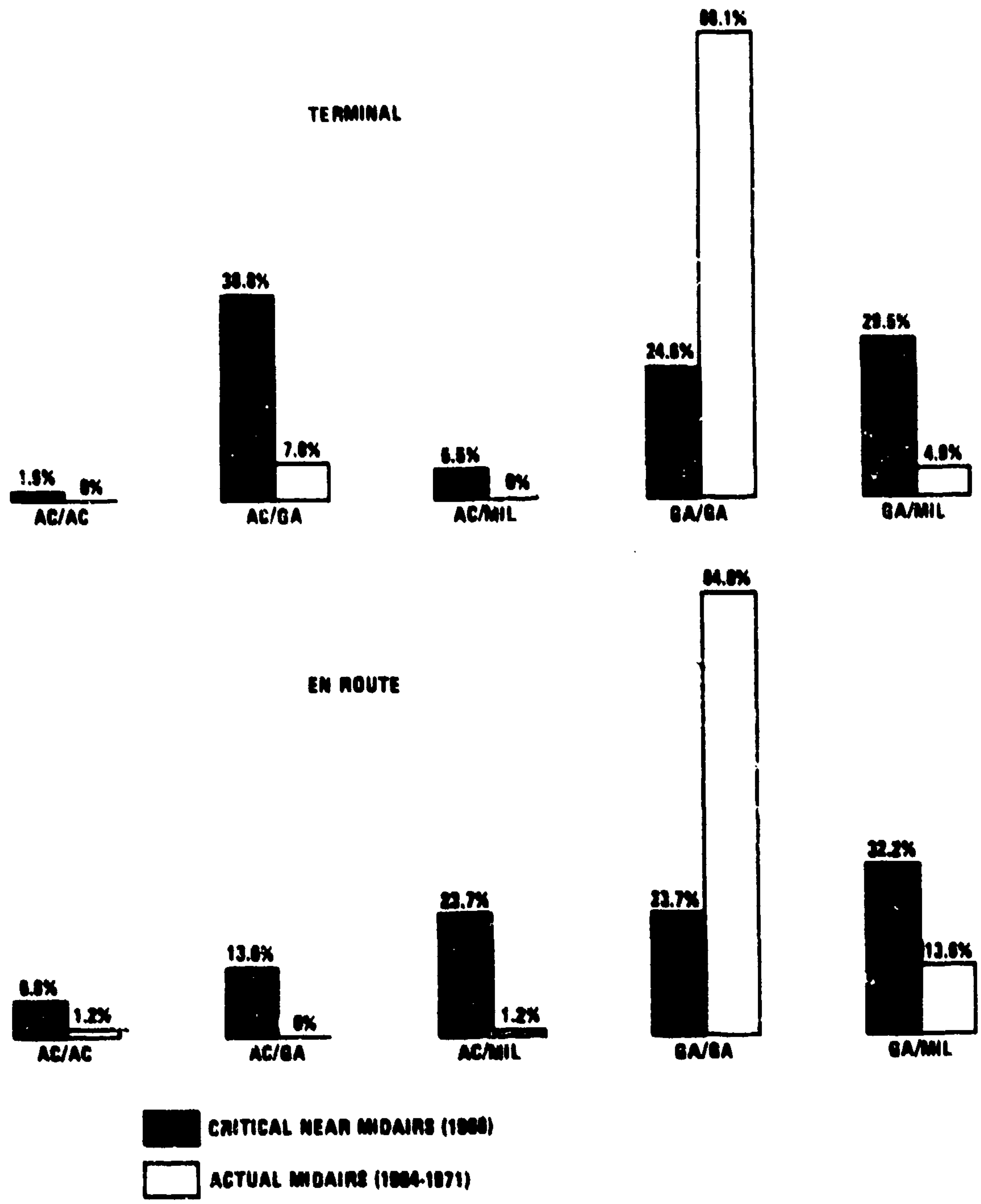
TABLE 2. [4:130]

TYPE OF MISSION CONDUCTED*

MISSION	AIR CARRIER		GEN. AVIATION		MILITARY		TOTAL
	EN	TE	EN	TE	EN	TE	
SCHEDULED	153	308					461
TRAINING	3	11	37	135	75	133	394
CROSS-COUNTRY	2	0	35	27	32	12	108
TEST	2	0	2	10	4	4	22
AIR TAXI			15	29			44
BUSINESS			57	51			108
PRIVATE			65	135			200
AGRICULTURAL			3	1			4
PATROL			0	4			4
FORMATION			3	2	27	15	47
MILITARY	0	2			45	41	88
TACTICAL					8	6	14
UNKNOWN	13	13	163	430	74	69	762

* Includes mission reported for both reporting <u>and</u> other aircraft for 1,128 Hazardous Incidents.

TABLE 3.



AC = Air Carrier
GA = General Aviation
MIL = Military

COMPARISON OF CRITICAL NMAC DATA AND MAC DATA BY USER CLASS

FIGURE 11. [3:F-2]

2.5 AIRCRAFT VISIBILITY

Every aircraft pilot has the responsibility to maintain a vigilant lookout so as to maintain a safe separation distance from other aircraft regardless of the type aircraft being flown or whether operating on an IFR flight plan or under VFR. The inability of a pilot to see other aircraft on a collision course can be caused by:

a. preoccupation (in which the pilot attends to other flight relevant tasks such as radio calls, navigation, etc.)

b. fatigue (retarding muscular action of the eyes)

c. glare (causing a loss of visual sensitivity)

d. visual deterioration (e.g., myopia - nearsightedness; hypoxia - resulting in a constriction of visual field)

e. lack of sufficient contrast between an intruding aircraft and its background

f. fixation (gazing into space without vertical or horizontal scanning)

g. poor illumination

h. visual field blockage (due to canopy bows, visors, etc.)

i. backscatter (in the surrounding atmosphere)

just to mention a few.

Detectability of an aircraft depends on many factors, but the more important appear to be its size, its shape and aspect, its distance from the observer, its contrast with its background and on the atmosphere.

While many experiments have examined the visibility of simple targets (uniformly bright circles, squares, or rectangles) viewed against homogeneous background [5:624, 6:237, 7:500, 8:531] very little data has been obtained on visibility of complex targets seen against complex background. Examining the simple target-and-background situations will give an idea of how complex situations affect aircraft visibility and will be done here before some actual complex situation data is examined.

2.5.1 BRIGHTNESS CONTRAST

The contrast between target and background is the primary determinant of target visibility in the simple target-and-background situation when the target is seen large (those subtending visual angles of one degree or more) in the field of view. Brightness contrast is defined by the equation

$$C = \frac{B_t - B_b}{B_b}$$

where C = the Brightness Contrast
B_t = the Target Brightness
B_b = the Background Brightness

When the target appears brighter than the background the contrast is positive ($B_t > B_b$), and when the target appears darker than the backgtound ($B_b > B_t$) the contrast is negative. If $B_t = 0$, a perfectly black target, then the contrast $C = -1$. This is the maximum negative contrast possible. Positive contrast, on the other hand, is mathematically limitless, but values higher than two to five are unusual unless the aircraft should happen to reflect the sunlight specularly. Threshold contrast (the contrast when the target becomes detectable) under field conditions is generally accepted to be 0.05 [9:94] for large targets. This contrast is obtained when the target brightness is approximately five percent greater (or smaller) than the background.

When the target is small (those subtending visual angles of less than one degree), the required threshold contrast for visibility is higher [5]. As an example, when the target subtends only four minutes of visual arc, the contrast threshold is about ten times as high as the threshold for a large target (i.e., C = 0.5). For a contrast of 0.5, the target brightness must be at least one and one-half 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.

Thus it becomes apparent that at the same visual range small aircraft must present a much higher brightness contrast than do large aircraft for equal detectability.

2.5.2 TARGET SIZE AND SHAPE

Compact targets like squares or rectangles with low aspect ratios do not differ appreciably from circles of the same area in threshold contrast (as described above). However, when the target is not compact (a long linear target such as an aircraft in certain aspects) much higher contrasts are required for threshold visibility compared to compact targets of equal area.

The shape and size of an aircraft affect the 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 overall effect of the brightness distribution.

It has been proposed that the top half of aircraft, including upper wing surfaces, be painted white and the lower half, including lower wing surfaces, be painted black. Thus the maximum contrast is obtained when the aircraft is viewed from below against the sky (in most cases the dark aircraft will appear against a light sky) and from above against the ground (in most cases a light aircraft will be seen against a dark background). But what happens when this same aircraft is viewed broadside?

Suppose the above aircraft is seen broadside. In this instance it is hoped that at least one-half of the aircraft will contrast with the background. If the brightness distribution is broken up into areas smaller than that required to be detected individually, the overall effect on visibility is sometimes determined by averaging the brightness over the whole cross section and contrasting this average brightness with the background. This averaging effect can cause problems with our half-and-half aircraft. If the top half (white half) is brighter than the background and the bottom half darker (black half), then the overall appearance would be that of two rectangles, one on top of the other, the upper having a positive contrast and the lower a negative contrast. If these contrasts are of approximately the same magnitude and the aircraft is at a distance where it would normally be just becoming visible, the two rectangles might not be resolvable and a blending would occur. The net effect would be nearly perfect camouflage and a resulting reduction in detection range.

The above discussion is intended to illustrate that improvements in visual detection can result in a worsening of the problem under the widely variable condition to be found.

2.5.3 EFFECTS OF THE ATMOSPHERE

The atmosphere works in two ways to change the appearance of objects seen through it. One is atmospheric attenuation. The other is the addition of light from the atmosphere, so that distant objects seem lighter. Atmospheric attenuation is the loss of light by absorption and scattering, so that it does not reach the observer's eye. Addition of light from the atmosphere most commonly changes the appearance of objects during the day and it is most important for objects that reflect light rather than transmit it. It comes about when light from another source, such as the sun, is reflected or refracted by the atmosphere so that it follows the same path to the eye as the light from the object. Since light from the object is being lost at the same time through atmospheric attenuation, the net result is that a dark object both appears lighter and stands out less clearly from surrounding objects (loss of contrast). This effect is most commonly seen in the appearance of distant mountain ranges, whose dark forests appear progressively lighter with increasing distance.

In the simple case of a light seen at night, atmospheric attenuation reduces the amount of light reaching the observer from the signal (see paragraph 3.21.). Affects of the atmosphere on daytime visibility of targets is far more complex, due principally to the scattering of light by atmospheric particles. As pointed out earlier, as distance to the target increases the target takes on more and more of the appearance of the sky or air background itself, until finally it disappears completely (even though its size may be well above threshold). The effect is visible generally as a reduction of both color and brightness contrast. Reduction of color contrast is generally more pronounced such that color becomes imperceptible before the brightness contrast threshold is reached and the target finally disappears [9:174].

Table 4 provides some examples of the interrelationship of target size, contrast, atmosphere, and sighting range, based on data for simple targets and backgrounds [9:110]. (For the reader interested in a detailed analysis of the manner in which the atmosphere affects the visibility of targets Reference 9 is highly recommended but is too complex for treatment here.) From Table 4 it can be concluded that (1) actual sightings are likely to be at closer ranges than the reported visual range and (2) when high contrast is provided 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. At the limit of detectability, color contrast generally has no affect on sighting range. As noted previously color contrast is reduced by the atmosphere and at the limit of detectability, the observer cannot tell whether the target has color. This conforms to theory [9:174] and has been demonstrated in flight observation [10]. Thus the detectability of aircraft for safe collision avoidance purposes can be treated as a brightness contrast problem alone (without reference to color).

TABLE 4

EXPECTED SIGHTING RANGE[1] FOR TARGETS OF VARIOUS SIZES AND CONTRASTS, SEEN IN VARIOUS ATMOSPHERES

DIAMETER OF CIRCULAR TARGET VIEWED AGAINST SKY BACKGROUND[2]	REPORTED VISUAL RANGE[3]	BRIGHTNESS CONTRAST $\frac{B_t - B_b}{B_b}$			
		2.0	1.0	0.5	0.1
36 ft	20SM	14.2SM	11.9SM	9.9SM	6.2SM
	10SM	9.0SM	7.9SM	6.8SM	4.5SM
	5SM	5.7SM	5.0SM	4.4SM	2.9SM
6 ft	20SM	6.7SM	5.3SM	4.1SM	2.2SM
	10SM	4.8SM	4.0SM	3.2SM	1.8SM
	5SM	3.3AM	2.8SM	2.4SM	1.4SM

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 ft) and a small aircraft (6 ft).

3. International Visibility Scale categories are:

5 statute miles	=	light haze
10 statute miles	=	clear
20 statute miles	=	very clear

2.5.4 COMPLEX SITUATION DATA

As pointed out earlier, predicting target visibility under a wide variety of atmospheric and target conditions is an extremely complex problem. The techniques for prediction of target visibility that have been developed are of uncertain value, for few field tests have been conducted to try them out. Two flight tests conducted by the FAA shed some light on the matter.

2.5.4.1 "LARGE" (DC-3) AIRCRAFT VISIBILITY

The first flight test [11] we will examine, conducted in 1957, studies the visibility of transport aircraft. The conspicuity of the then-present-day transport aircraft was determined by measuring, in daytime flight, the distances at which pilots of one aircraft became aware of another DC-3 aircraft, normally painted and normally equipped, as it approached from various angles on courses which would result in midair collisions. Two subject groups were used. One group was deliberately misinformed. This group was told that the study was concerned with the eye movements made with two types of instrument displays. These pilots were also told that if they should see another aircraft in the vicinity they should report it to the safety pilot. During their flights another aircraft was put on one of four different collision courses with their aircraft as shown in Figure 12 through 15. The second group of pilots, the informed group, was told that they were on a collision course with another aircraft, but they were not told from what direction it was approaching. An engineer who knew where to look also recorded where the collision aircraft was first detected. The results are shown in Table 5.

DISTANCE AT WHICH AIRCRAFT ON COLLISION COURSE WAS DETECTED

Relative Bearing To Collision A/C	Detection Distance		
	Engineer Knew Where To Look	Pilots Informed	Pilots Misinformed
0° (head-on)	11 Miles	5.00 Miles	3.50 Miles
30° left	14	4.50	5.00
60° left	12	4.50	4.50
100° left	10.5	4.75	3.50

TABLE 5

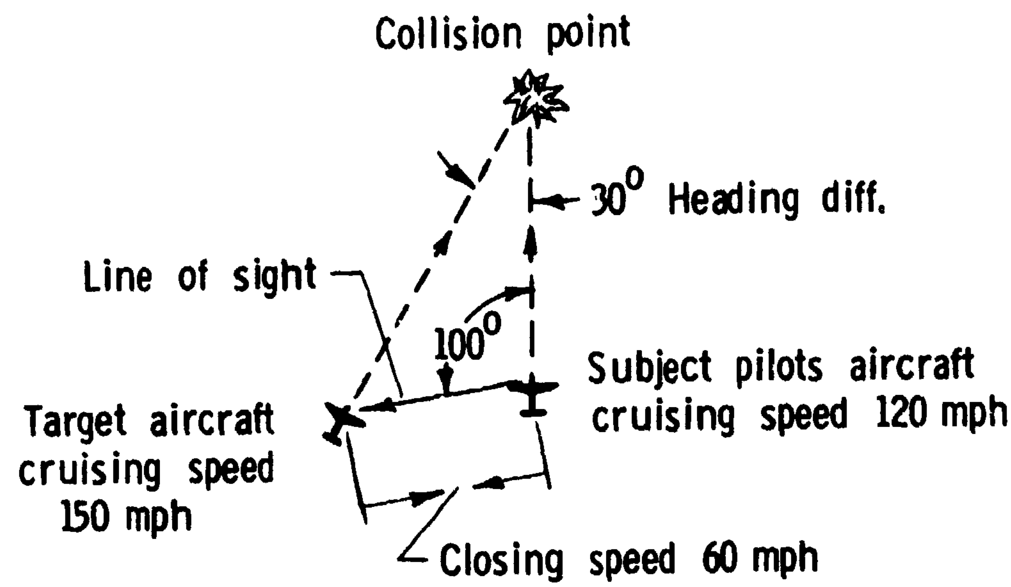


Figure 12 Collision Case I [11:3]

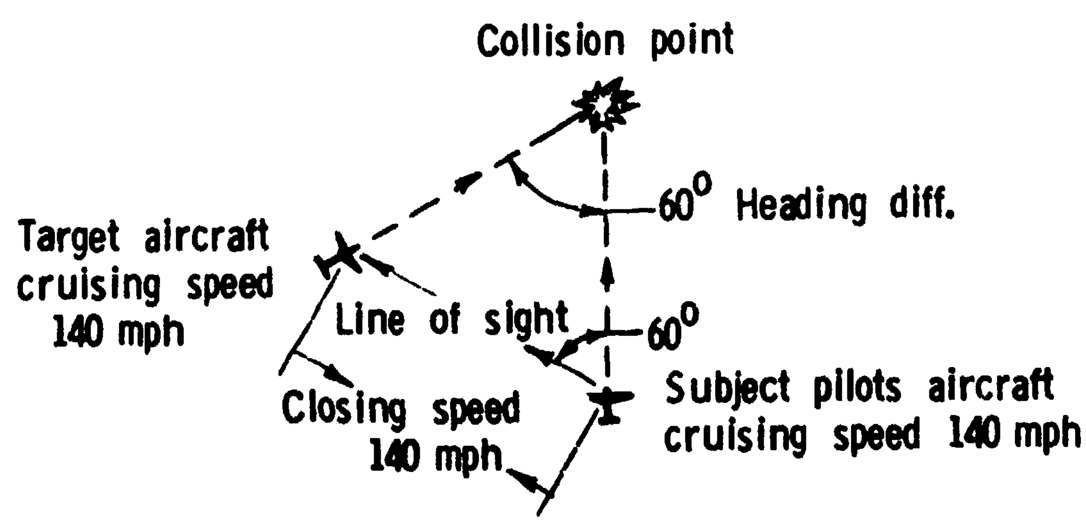


Figure 13 Collision Case II [11:3]

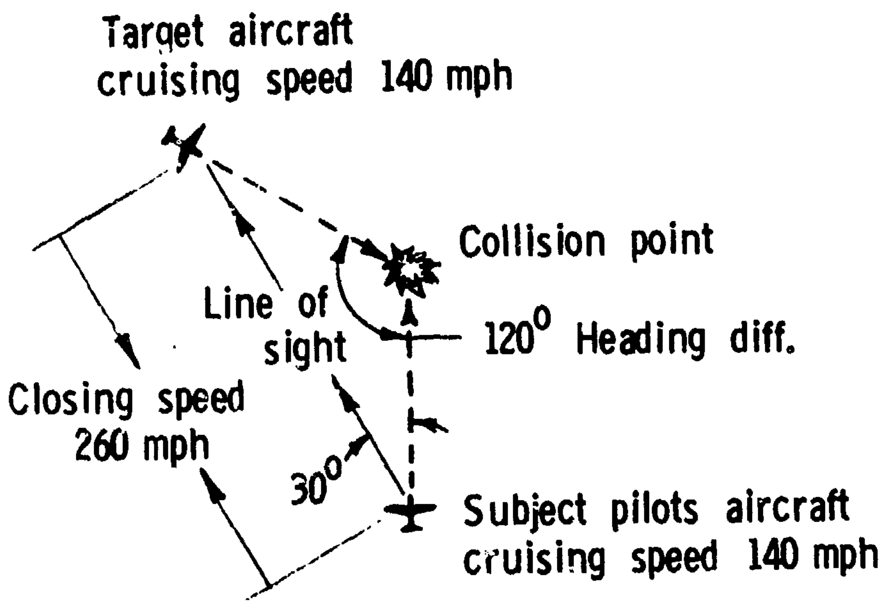


Figure 14 Collision Case III [11:4]

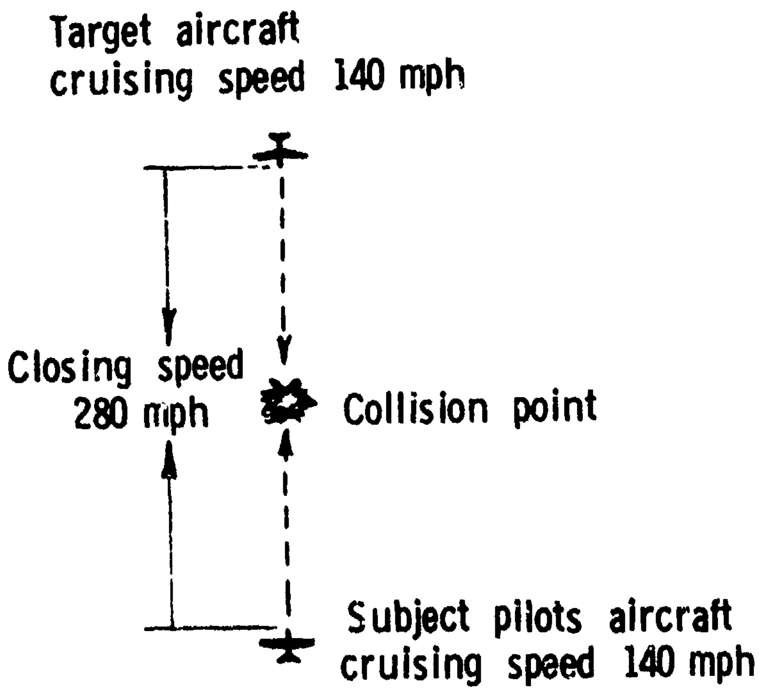


Figure 15 Collision Case IV [11:4]

The conditions for these tests were not described completely in the report, only that ceiling and visibility unlimited (CAVU) weather conditions existed. This lack of more exact data describing the atmospheric conditions makes comparison of predicted data and test data almost impossible. However, the range of detection reported by the engineer is of the same order of magnitude as would be obtained from appropriate visibility nomographs.

Two interesting points are seen in Table 5. First, both the informed and the misinformed pilots failed to pick up the target aircraft until it was three to five miles away even though the target was visible ten to twelve miles away. This discrepancy is probably due to the time required to scan large areas of the sky; the aircraft in one sector while the pilot searched others. Second, an anticollision device which would inform the pilot of the relative position of an approaching aircraft at visual threshold distance should extend threefold the average detection range of the pilot in these tests.

Figure 16 presents the daytime ranges of the DC-3 aircraft found in this study as well as presenting curves extrapolating this data to the left 100° horizontal visual angle. The long dashed line shows a maximum threshold distance of 12.4 miles at 30° visual angle, decreasing to 10.8 miles at 0° visual angle and to ten miles at 100° visual angle. The small aircraft cross sectional area presented at 0° visual angle was probably the major contributing factor lowering the threshold range in the head-on collision case. It should be noted that the cross sectional area at 0° visual angle is approximately one-half of the 30° visual angle cross sectional area.

The average uninformed pilot's detection curve, presented as the solid line, shows the average detection distance at 0° visual angle to be three and four-tenths miles, at 30° visual angle to be five and four-tenths miles, at 60° visual angle to be four and three-tenths miles, and at 100° visual angle to be three and five-tenths miles. Just as in the threshold case we see a decrease in the detection at 0° visual angle compared to the 30° visual angle due to the decreased cross sectional area. The gradual reduction in the detection distance found in the 30° to 100° sector is most likely due to the test subjects search habits which reveal a low look frequency in this sector (see Figure 17).

The average informed pilot's detection curve, presented as the short dashed line of Figure 16 shows the average detection distance at 0° visual angle to be five miles, at 30° visual angle to be four and five-tenths miles, at 60° visual angle to be four and two-tenths miles, and at 100° visual angle to be four and eight-tenths miles. Comparing these

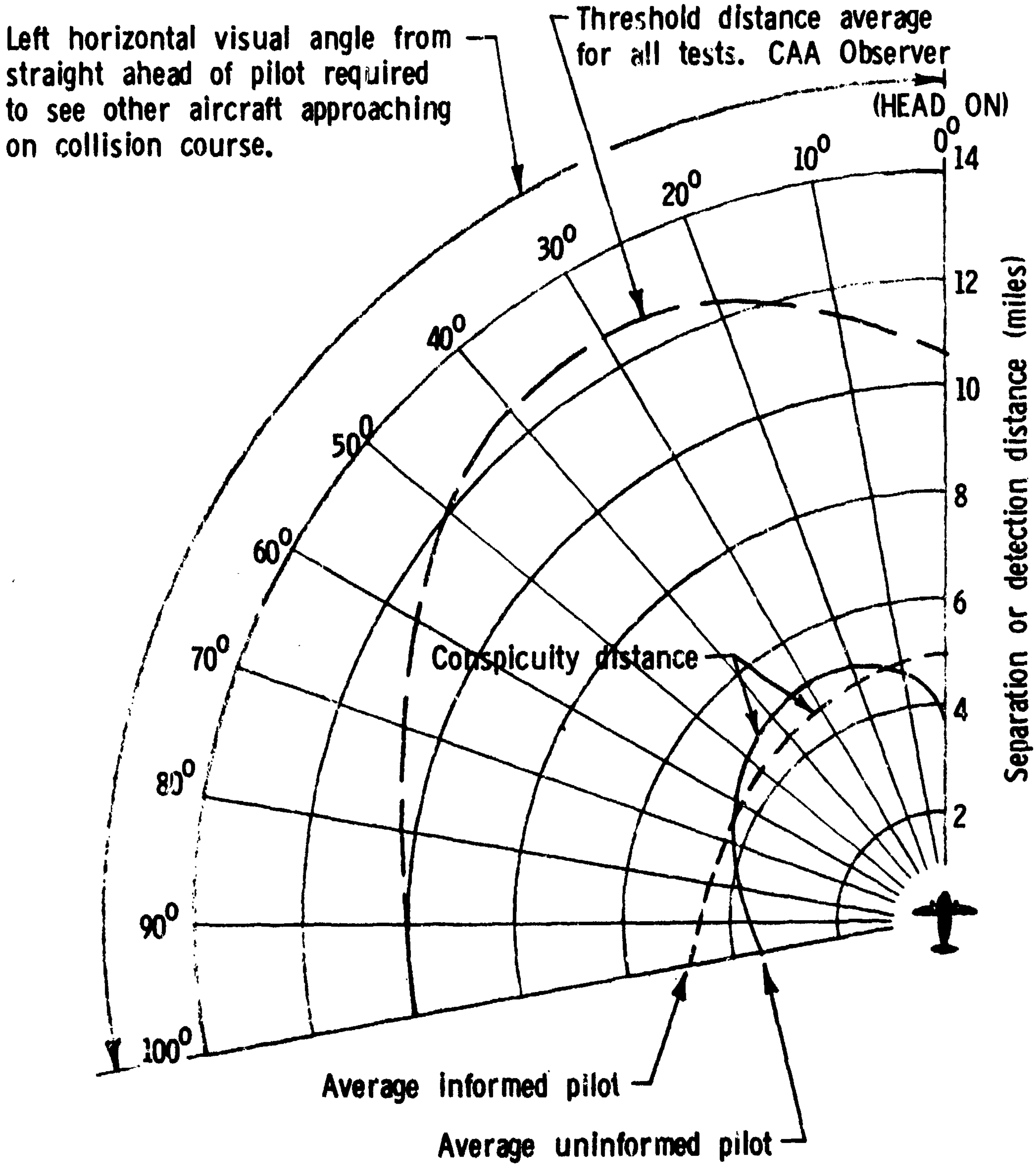


Figure 16 Conspicuity of Present-Day Aircraft [11:8]

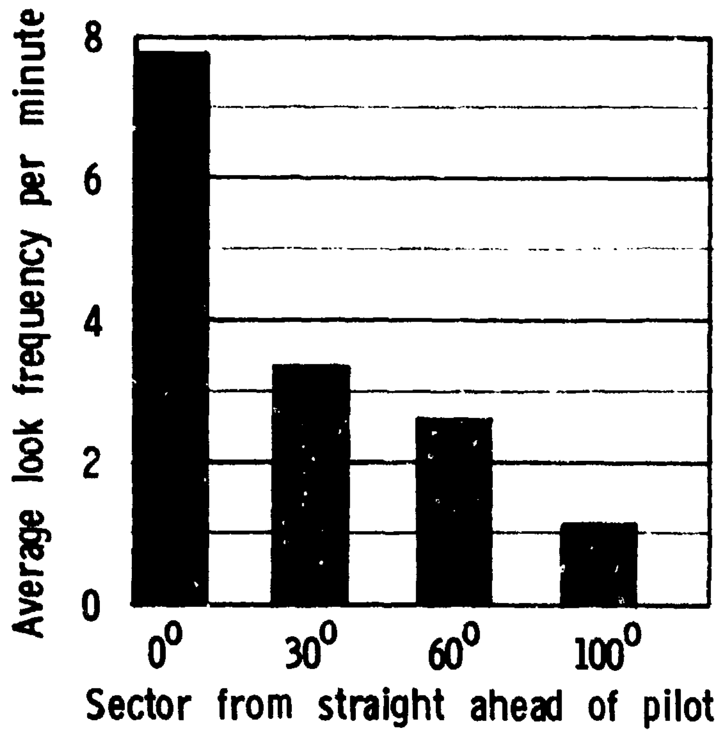


Figure 17 Look-Distribution Chart (Uninformed Phase) [11:9]

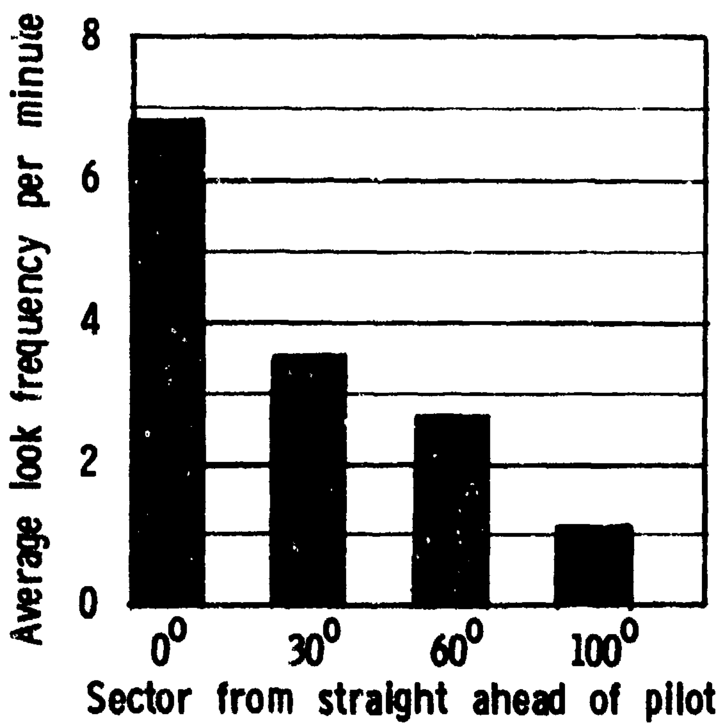


Figure 18 Look-Distribution Chart (Informed Phase) [11:16]

results with the uninformed phase we find an increase from three and four-tenths to five miles at 0°, a decrease from five and four-tenths to four and five-tenths miles at 30°, no change at 60°, and an increase from three and five-tenths miles to four and eight-tenths miles at 100°. When the look frequency for the informed pilot is reviewed (see Figure 18) we find that the informed pilot tended to distribute his looks more evenly over his visual area.

2.5.4.2 "SMALL" AIRCRAFT VISIBILITY

The second flight test [12] we will examine, conducted in 1958, studies the visibility of small aircraft in the terminal area. The average detection distance for a Beechcraft four-place Bonanza (a small single engine aircraft) was determined in a terminal area during daytime VFR conditions. These distances were determined in normally painted and normally equipped aircraft as they approached on various collision courses. Twenty-five pilots each flew three collision situations for a total of 75 test flights. Each collision course consisted of a different terminal area maneuver. The three maneuvers studied were (1) departure and climb-out, (2) straight-in approach, and (3) a right turn-in approach. During each maneuver, the intruder aircraft was on a 90° converging course with the subject pilot's aircraft, requiring a 45° left visual angle for the subject to detect the approaching target. The test subjects were unaware that they were flying collision courses and the true purpose of the flight test.

Figures 19 and 20 present the diagram of the corridors that each subject was instructed to fly and the VFR reference map used by the subjects respectively. Figures 21, 22, and 23 show the three collision courses described above. Table 6 provides the parameters and results of the test flights.

Examining collision course A (departure and climb-out) it is found that the average detection separation distance for the observers (who were aware of the intruder aircraft position) was 2.82 miles, six times greater than the average for all pilots. As in the first test (paragraph 2.5.4.1) knowing where to look moved the detection range toward threshold. On course A, the subject aircraft was climbing to the altitude at which the intruder aircraft was flying. The fact that 14 of the 25 pilots made no attempt to avoid a collision after detection and that eight of the eleven who did initiate action waited until the aircraft were within six seconds or less of the collision point is alarming and reflects an inability to make a quick decision for self-preservation or an inability to recognize a hazardous condition, or both.

Examining collision course B (straight-in approach) an average detection distance approximately twice the distance for course A is found. It must be noted that both aircraft were at the same altitude

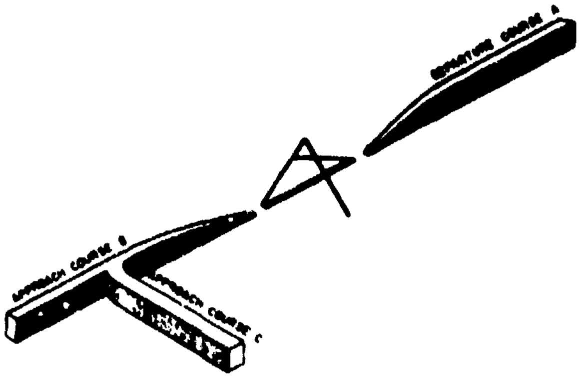


FIGURE 19

DEPARTURE AND APPROACH CORRIDORS USED BY PILOTS [12:3]

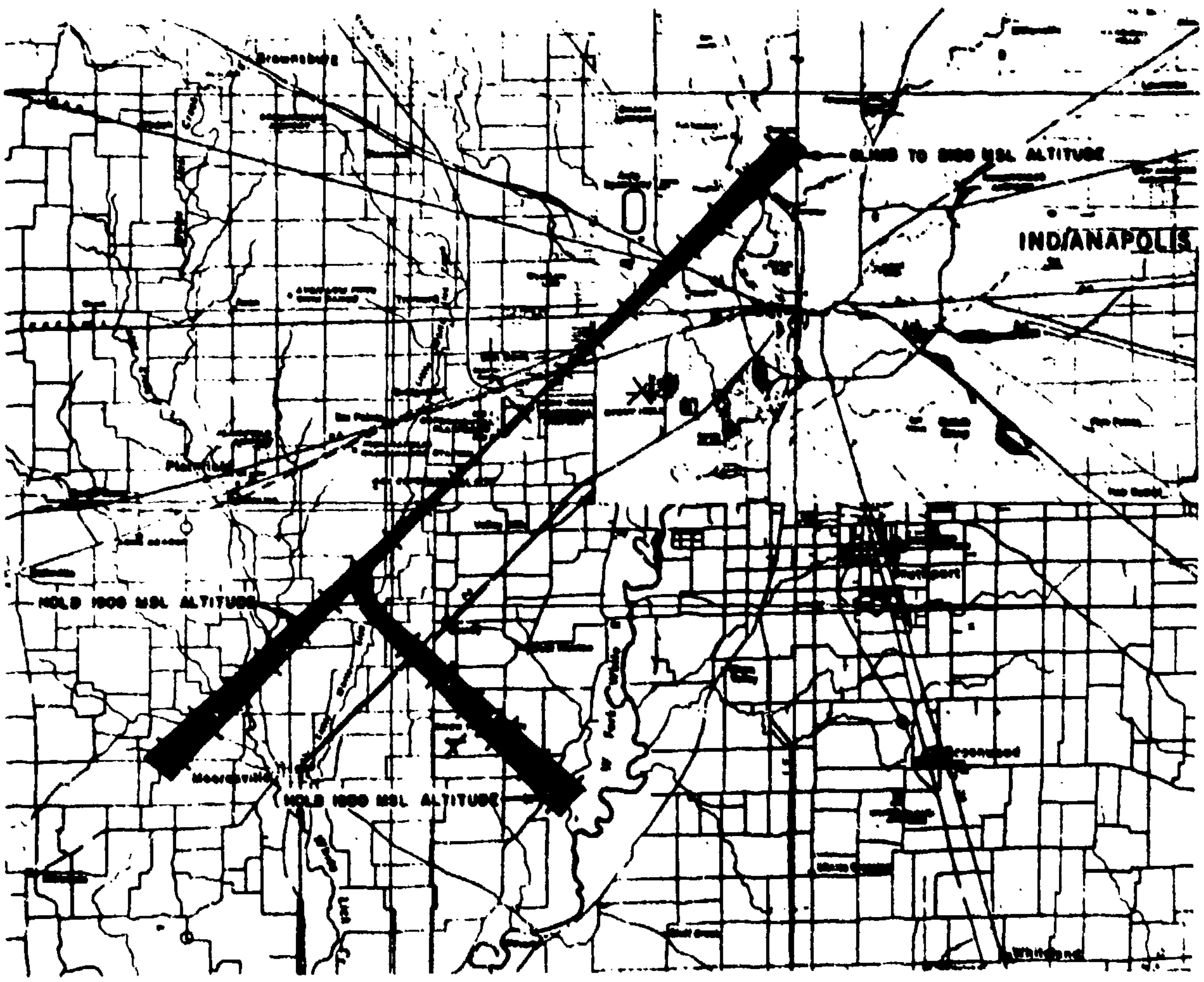


FIGURE 20

SUBJECT PILOT REFERENCE MAP [12:4]

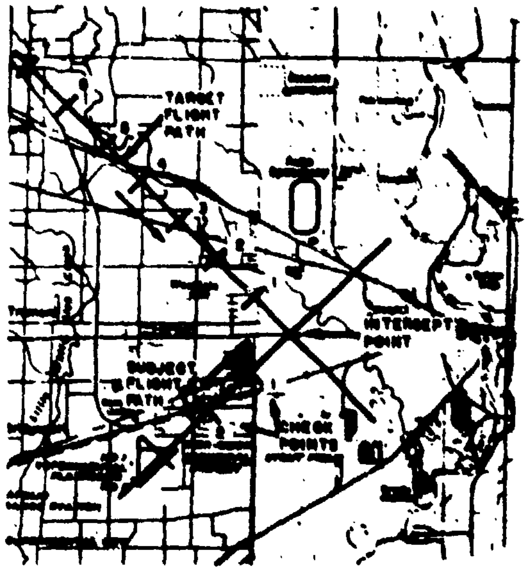


FIGURE 21

COLLISION COURSE A [12:5]

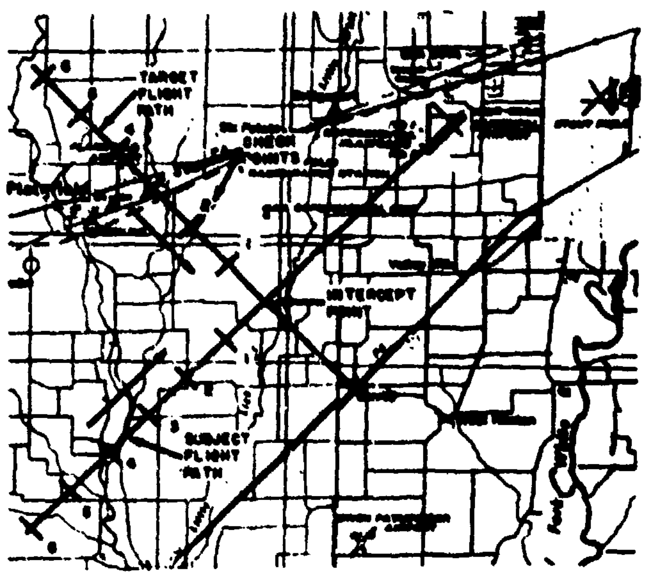


FIGURE 22

COLLISION COURSE B [12:5]

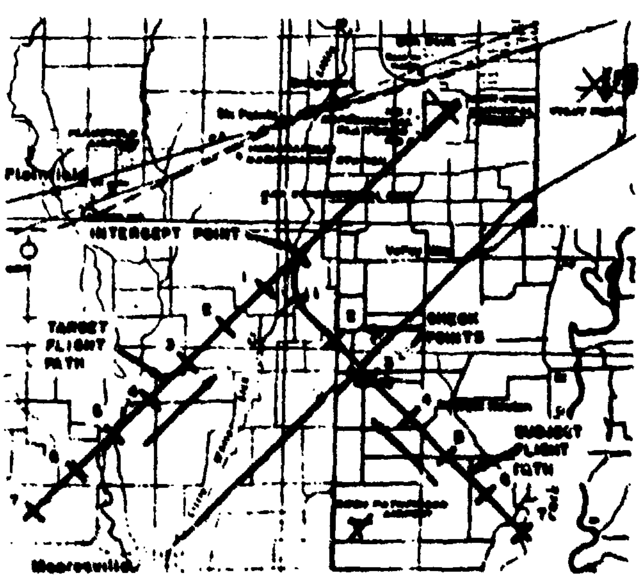


FIGURE 23

COLLISION COURSE C [12:6]

TABLE 6

PARAMETERS AND RESULTS IN SMALL AIRCRAFT VISIBILITY TEST

PARAMETER/RESULT	COLLISION COURSE		
	A	B	C
AVERAGE RATE OF CLOSURE	186.5 mph	197 mph	197 mph
TOTAL NUMBER OF PASSES	25	25	24
AVERAGE DETECTION SEPARATION DISTANCE OF THE OBSERVERS (KNOWN POSITION OF INTRUDER)	2.82 SM	4.0 SM	4.3 SM
NUMBER OF DETECTIONS	14	15	19
NUMBER OF MISSED DETECTIONS	11	10	5
AVERAGE DETECTION SEPARATION DISTANCE FOR ALL PILOTS	0.47 SM	0.78 SM	0.84 SM
TIME PRIOR TO COLLISION	9.5 sec	14.6 sec	15.3 sec
AVERAGE DETECTION SEPARATION DISTANCE FOR PILOTS DETECTING TARGET	0.85 SM	1.30 SM	1.05 SM
TIME PRIOR TO COLLISION	16.8 sec	24.5 sec	19.3 sec

in course B which was not the case in course A. Again improved performance of the informed observer is found just as in course A with the informed observer's detection distance more than five times greater than the uninformed observer. Of the 13 pilots who initiated an avoidance maneuver on course B, nine waited until six seconds or less remained to avoid the collision. When this is compared with the eight late recognitions on course A, there is further indication that a hazardous collision situation cannot be recognized nor a decision reached readily even when both aircraft are at the same altitude.

Examining collision course C (right turn-in approach) we find detection distances approximately the same as in course B. There were only five missed detections on this course, which may indicate more alertness by reason of the two previous experiences, or an awareness that radio communication increased for the copilot prior to a previous near collision experience. It is also possible that early pilot training, to always scan an area before making a turn, was influential in the increase in number of detections for this course, since a turn was necessary and since the majority of the detections were at close range. There was however, no decrease in the number of pilots who failed to initiate action until six seconds or less prior to the point of collision. This may be explained by the changing aspect of the subject aircraft as it turned relative to the target, adding a factor of difficulty to decision time.

In general it was found that:

a. In daytime VFR conditions with a minimum ten miles visibility aircraft of this size could be detected in the terminal area at distances up to four miles.

b. When not forewarned of an impending collision situation pilots could not be expected to detect an aircraft of this size at distances greater than two and eight-tenths miles.

c. Aircraft or hazardous conditions were not recognized as readily during takeoff and climb as they were during straight and level flight.

d. For every three hazardous situations, two subject pilots detected and avoided the impending collision.

e. The pilots did not recognize a hazardous collision situation in flight by the aspects of the approaching aircraft above, until both aircraft were in dangerous proximity to each other.

2.6 MIDAIR COLLISION GEOMETRIES

Investigations of midair collisions generally center around reconstruction of the two flight paths. It seems logical that analysis of midair collision geometries would allow the investigator to determine which aircraft was flying "blind" due to structural blockage, relative paths and velocities, etc., and would aid in the analysis of corrective measures. Many lists have been compiled by investigators trying to define the information "needed" by the pilot to accomplish the sensing, comparing, and decision procedure resulting in the solution of midair collision problems and their subsequent avoidance. These lists are generally not alike with some of the items being expressed in different ways. If the lists are compared, consolidated, and reduced to essentials, the remaining parameters are those necessary to allow the solution of a four-dimentional space time vector problem involving two aircraft. These parameters are: heading, airspeed, altitude, and maneuver for both aircraft, distance to the intruder at the time of detection, and bearing to the intruder at the time of detection.

2.6.1 THE RECOGNITION OF AND RESPONSE TO INTRUDER AIRCRAFT

As Calvert points out [13] the mental processes involved in recognizing a collision threat and responding to it are quite different on the ground than in the air. The driver of a ground vehicle has a fixed frame of reference on which he and all other ground vehicles move. He can see at a glance where he will be in this frame of reference during the next few seconds and can estimate where other vehicles will be in this frame of reference at the same time. Since he is seeing the two movements relative to the same fixed framework, he can arrange that the points in the framework toward which the vehicles are moving, shall not be the same at the same instant. Since each vehicle is generally restricted to a channel (the road) each driver can predict where the other will most likely go using the rules of the road.

In the air there is usually no external frame of reference, other than the structural framework of ones own aircraft, close enough to be used as described above. One can also see the aspect (to some extent) of the other aircraft by day or a light (see paragraph 1.1) by night.

Figures 24 to 28 were prepared by Calvert showing 17 different situations, seven in the vertical plane. In these diagrams V_A and V_B are the velocities of A and B relative to the air and are constant during pilot A's observation of B. Each diagram includes a triangle of

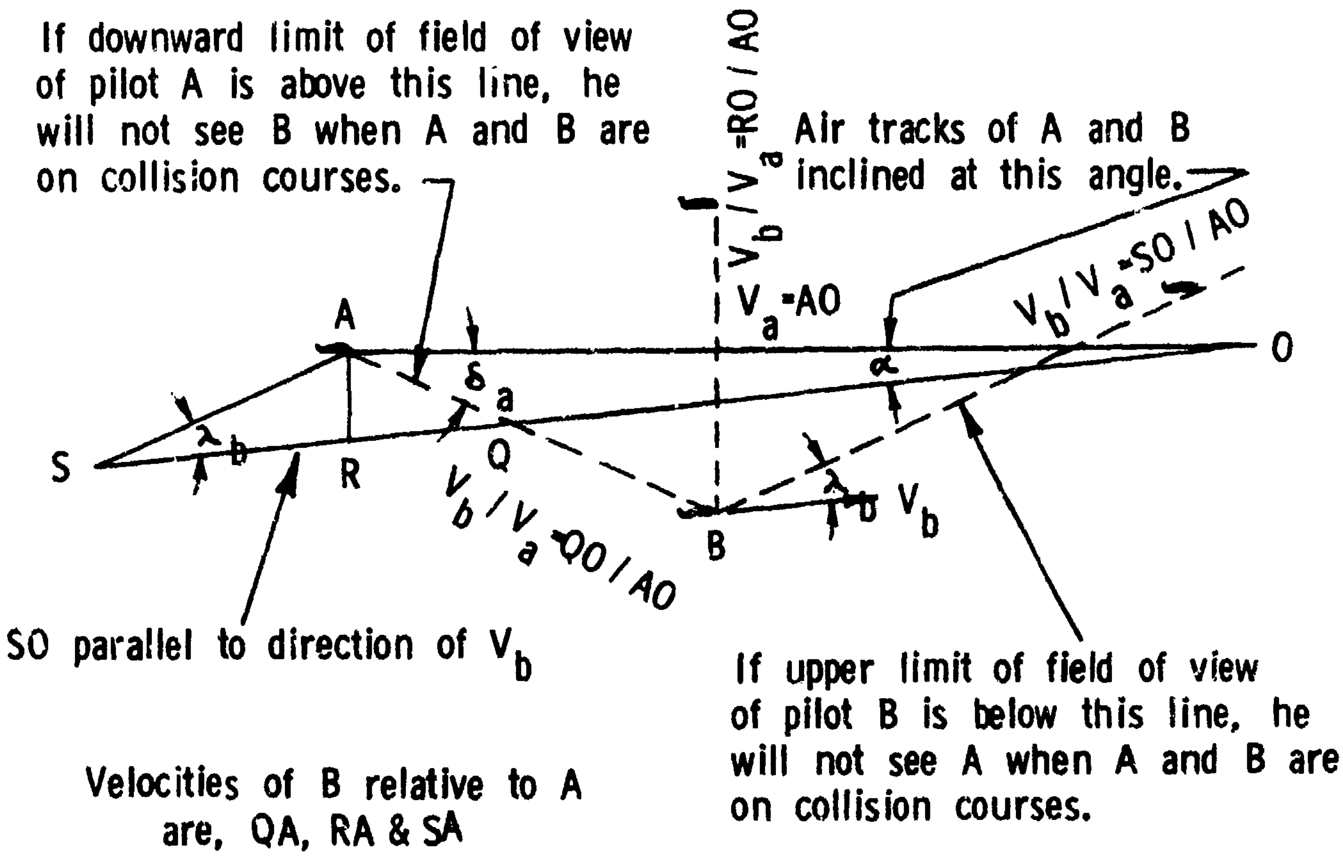


Figure 24 [13:330]

If A and B are on collision courses, pilot of A will not see B if V_b/V_a is greater than QO / AO, and pilot of B will not see A if V_b / V_a is less than SO / AO. In a one way traffic stream collisions will therefore be blind if V_b / V_a is between $\sin \delta_a / \sin(\delta_a + \alpha)$ and $\sin(\lambda_a + \alpha) / \sin \lambda_b$. If collision does not occur one pilot will see an aircraft suddenly rise or descend through his field of view, and will report a "near miss". The pilot of the other aircraft will see nothing.

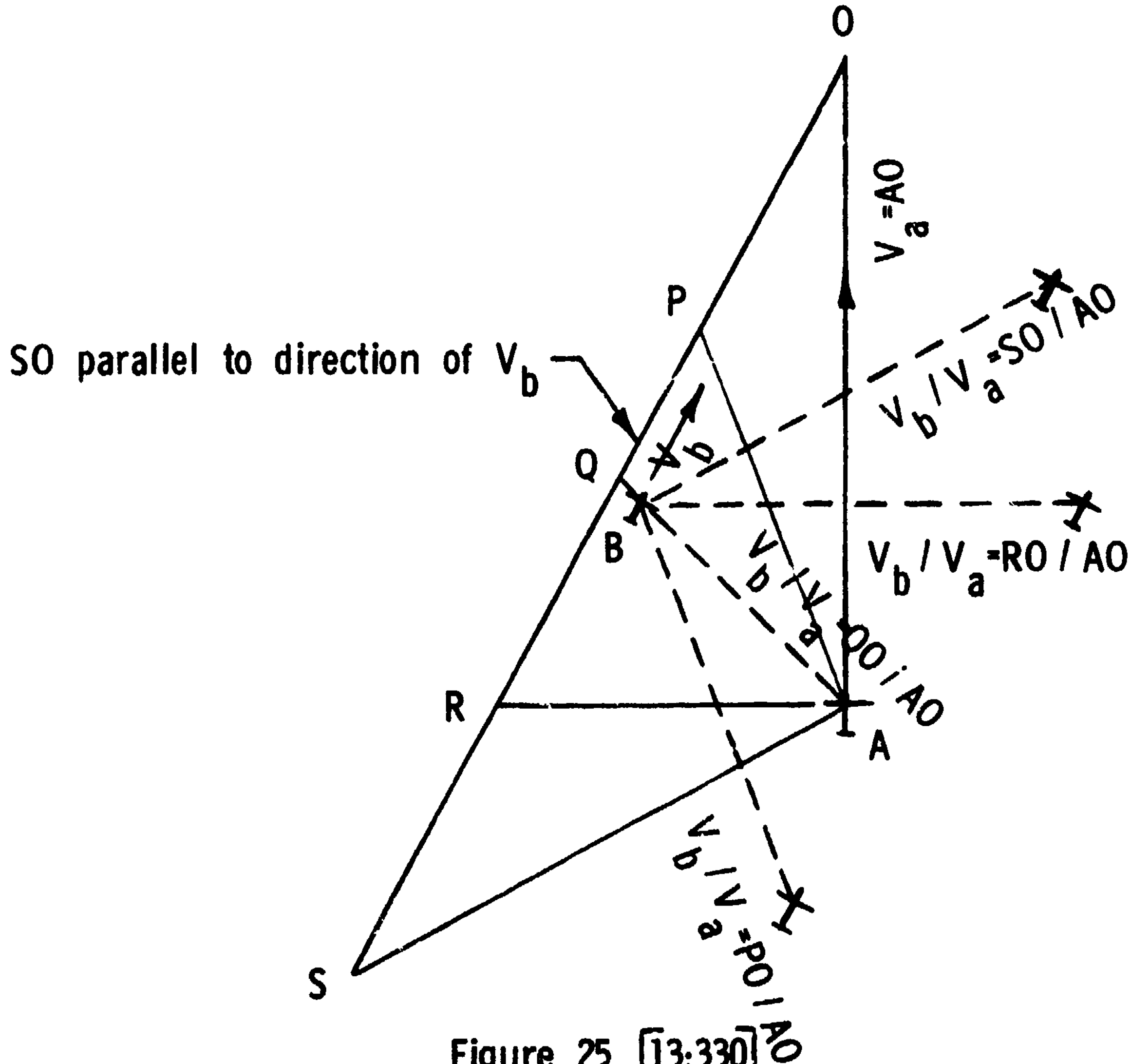


Figure 25 [13:330]

In figs. 24, 25 and 26, collision occurs if V_b / V_a=QO / AO. Threats of collision will be indicated to each pilot by the fact that other aircraft will be seen on a fixed bearing and in a fixed aspect. The range also decreases at a fixed rate, i.e. the apparent size of B, or the brightness of a light on B, increase at a fixed rate.

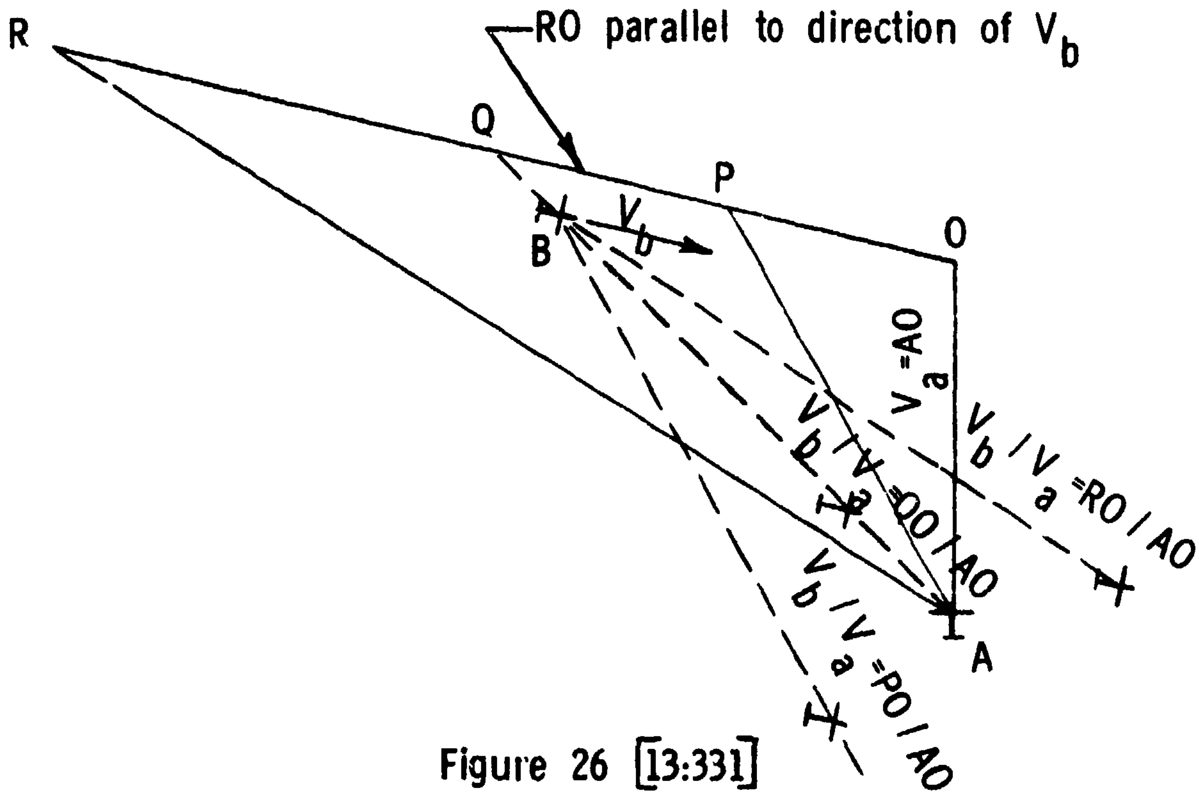
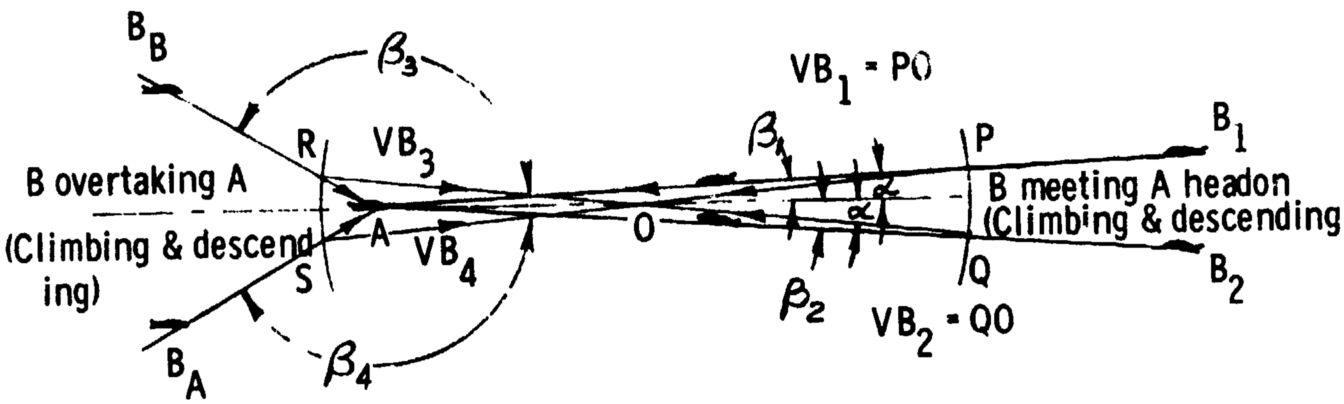


Figure 26 [13:331]

FIGS. 24, 25 and 26. TRACK, ASPECT AND VELOCITY OF B RELATIVE TO A FOR VARIOUS VALUES OF V_b/V_a.

V_a and V_b are velocities of A and B relative to air. In any one diagram, V_b has several magnitudes but the same direction. The diagrams show the picture as it would be seen by an observer carried by a framework with the velocity V_a, i.e. the observer may be regarded as flying in formation with A. A is therefore at rest in the framework.



$V_A = AO$ in magnitude and direction. Magnitude of V_B is radius of circle. Angle between V_A and V_B is $\pm\alpha$. Velocities of B relative to A are PA, QA, RA, and SA.

Figure 27 [13:332]

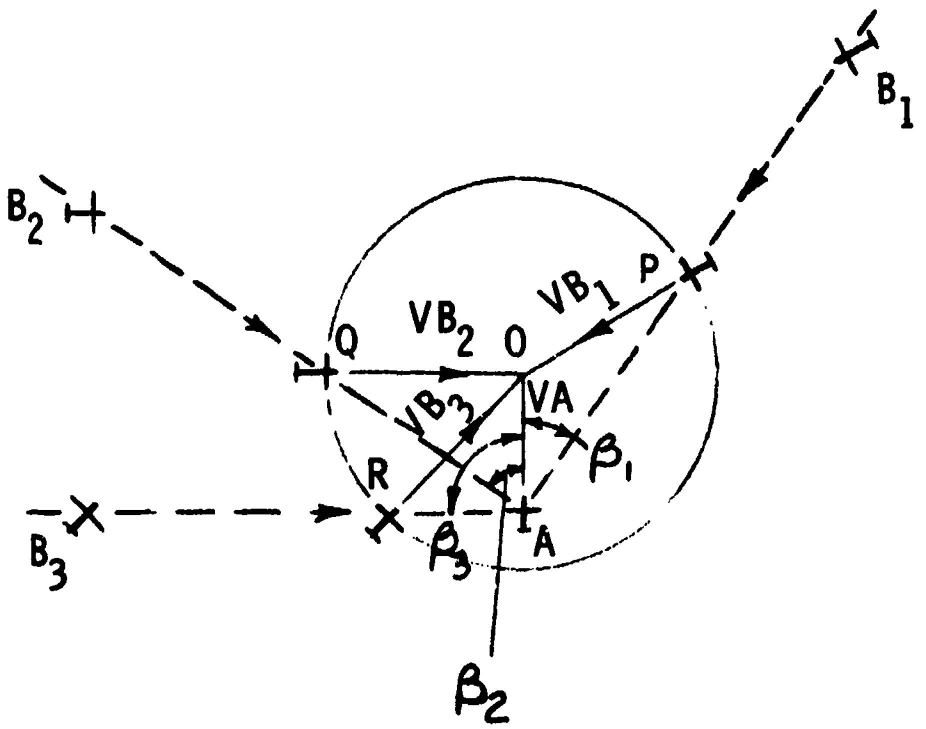


Figure 28 [13:332]

VA=AO in magnitude and direction. Magnitude of VB is radius of cirlce. Velocities of B relative to A are PA, QA and RA.

FIGS. 27 and 28. TRACK, ASPECT AND VELOCITY OF B RELATIVE TO A FOR CONSTANT VALUE OF VB / VA.

Diagrams show B closing A on various collision courses, i.e. on various constant bearings, β , vertical and horizontal.

velocities V_A being represented by AO in each case. As observers we see the situations develop as if we were flying in close formation with A. A is always fixed on the figure as the frame of reference is taken around it and B moves relative to it. In Figures 24 to 26 we suddenly see B on the bearing and aspect shown (remember as observers we are moving next to A but not in A and are not forced to view from the cockpit with its associated visual blockage). The broken lines and the small pictures of B show how the situation would appear to develop if V_B had various values. In Figures 27 and 28 we see B on various collision courses with A.

The most important point to see from these diagrams is that if B is on a collision course with A, the bearing and aspect of B and the rate-of-change of range appear to the pilot of A to be constant. If A observes B as an unmoving target relative to his aircraft, then A knows he is on a collision course with B. It is not, however, a simple task for A to make this determination because his observation platform is unstable. This instability will cause all distant objects to have a small periodic motion relative to A's frame of reference, the amplitude depending on the speed and type of A's aircraft, and if it is being flown by a human pilot or an auto pilot.

Calvert points out, "If the pilot does maneuver, the other aircraft will immediately appear to move with a large angular velocity, and he will become 'blind' in the sense that he will have no further information until he is again flying on a straight course at a constant velocity. He, therefore, does not know how long to hold the maneuver, but he probably realizes that if, while the other aircraft is at a long range, he begins the maneuver after a short period of observation, say less than ten seconds, he will have to hold it for a long time, say 40 seconds, in order to eliminate the risk. If, on the other hand, he had used a longer observation time, he might have detected angular motion, and not had to maneuver at all. These three factors, i.e., confusing indications, bad information, and uncertainty in the time of observation and maneuver, mean that the pilot finds himself in a dilemma which he may not be able to resolve in the short time available. It is, therefore, no wonder that he tends to hold his course, with the intention of maneuvering only if and when the situation appears to be really serious, in which case the maneuver will be violent. This may be called 'the technique of the bull-fighters jump,' and in cases where a high acceleration can be applied with little delay, it is probably the most effective technique." [13:331-332] The "technique of the bull-fighters jump" was apparently being used by the subject pilots in the "small" aircraft visibility flight test (paragraph 2.5.4.2) described earlier.

2.6.2 USE OF GEOMETRIES IN VISIBILITY PREDICTION

Figures 24 and 27 both show examples of a situation in which aircraft are climbing and decending in a traffic stream. One or both of these aircraft may be completely blind to the other. It is a most disturbing situation to pilots to have another aircraft suddenly arise or descend through their field of view, and nearly all have experienced it. Here we find another situation in which proximity warning devices might be useful, especially if they were to give a relative bearing to aid in the visual search.

At night the pilot is faced with another problem. Using the unmoving target criteria in determining if he is on a collision course, the pilot finds he is on a collision course with every star. If he mistakes a star for a light on an aircraft (a more common occurrence than non-flyers would expect) and maneuvers, he will find that this light is still on a collision course when he resumes straight and level flight. Exactly the same thing happens if the light is on another aircraft and the pilot maneuvers too soon for too short a time.

2.6.3 BASIC RELATIONSHIPS

An interesting paper written by Howell, et al [14], presents geometric relationships relative to collision flight paths in the following four categories:

a. Straight and Level Flight

b. Straight Climb and Decent

c. One Aircraft Turning and One Flying Straight and Level

d. Two Aircraft Turning in Same Direction

The authors found it possible to limit the coverage of the charts for straight and level, climbing and descending flight by the assumption of logical limits for the data. However, it was much more difficult to establish practical parameters for the turning conditions of flight. The limits for turning flight were established from recording 250 flight paths of aircraft in the vicinity of airports. The collision cases presented in this report were designed around the assumption that the aircraft were flying at constant speeds, constant rates of climb or decent, and constant angles of bank during level turns, as these conditions were applicable. The authors point out that by necessity, the collision conditions covered by their report constitute only a small part of the total number of possible collision cases.

The report by Calvert [13] and Howell [14] are highly recommended for the reader who wishes to study further the geometric relationships of midair collisions. It is important to note that problems in relative motion are seldom amenable to common sense since human response has been learned relative to the fixed framework of the Earth. If there is no framework, then habits which have been formed through the everyday experience of moving about on land must be put aside in favor of the geometric aspects. This is what many people find extremely difficult because they "know" so many things which are not so. This is also why the geometric aspects of midair collision must be studied so as to make clear to all pilots what is actually occurring and to develop systems which will aid the pilot in making those determinations.

2.7 MIDAIR COLLISION MODELS

Midair collision models have been discussed as a means for predicting the number of collisions to be expected and as a simulation technique for the prediction of the effectiveness of midair prevention systems. The two models which follow were developed by the experimenters studying the Near Midair Collision Report Data of 1968 and from the Civil Aviation Midair Collision Analysis Data (paragraph 2.3 and 2.2 respectively). The intent here is to show how two data sets were modeled. The following discussion will examine the findings of these two models and compare them.

2.7.1 THE NEAR MIDAIR COLLISION TRAFFIC MODEL [3:App E-10]

This model resulted in an algebraic expression which relates the expected number of reported near midair collisions to the air traffic density in the terminal area. The derivation was based on the assumption that the near midair collision risk per aircraft operation is directly proportional to the number of aircraft using a fixed volume of airspace. The expression derived is:

Expected NMAC = $K N_o M_o$ where:

N_o = Number of annual aircraft operations for group 1 aircraft (e.g., General Aviation)

M_o = Number of annual aircraft operations for group 2 aircraft (e.g., Air Carrier)

K = A proportionality factor which is independent of N_o and M_o.

The result is an expression of the "square law" where $c = an^b = an^2$ can be easily shown. If we assume that only the two groups use the terminal air space volume, then:

$$n = N_o + M_o = \text{total aircraft operations}$$

and since $b = 2$

$$c = a\,(N_o + M_o)^2 = a\,N_o^2 + 2\,a\,N_o\,M_o + a\,M_o^2$$

where: $a\,N_o^2$ is the term associated with near midairs between two general aviation aircraft (GA-GA).

$2\,a\,N_o\,M_o$ is the term associated with near midairs between a general aviation aircraft and an air carrier (GA-AC). This is the term of interest in the model.

$a\,M_o^2$ is the term associated with near midairs between two air carriers (AC-AC).

To establish the validity of the model, it was correlated to the actually reported near midair collisions at the 21 large hubs for which the study had data. The correlation coefficient was calculated to be 0.8998. The authors then concluded "...it is possible to predict with some confidence the expected rate of reported 'near midairs' by extrapolating the straight line (relationship to higher predicted densities)...." "For example, if these operations each increase by a like factor, then the expected number of reported near midair collisions will increase by the square of that factor."

2.7.2 <u>THE CIVIL AVIATION MIDAIR COLLISION ANALYSIS MODEL</u> [4:App C]

Inspection of the data from this report also suggested that midair collision risk increases with airport activity level. Three separate analyses were performed. (1) A graphical analysis which developed a quasi-continuous curve for the average collision per airport over the eight years as a function of average aircraft operations per airport in CY 1971 [4:App C, Section 3]. (2) A regression analysis which develops an explicit analytical expression for the average collisions per airport over the eight years as a function of average aircraft operations per airport in CY 1971 [4:App C, Section 4]. (3) A statistical analysis which established confidence limits on the expected number of collisions as a function of aircraft operations, given the observed data, and which tests for statistically significant deviations between the observed estimate of the expected number of collisions and the actual number of collisions for specific sub sets of that data [4:App C, Section 5].

The benefit of having the three analyses was that each served as an independent check on the results of the other two and each point of view yielded useful interpretations of the data and its implications.

This model also assumed the square law relationship between collisions and operations discussed in paragraph 2.7.1 above.

2.7.3 COMPARISON OF THE TWO MODELS

Reference 3 [3:F-7] made these points in comparing the two models:

a. High correlation is not a sufficient test of model validity. The a priori expression assumed for the near midair collision traffic model produced a 90% correlation with the observed data. It should be noted that high correlation between a particular theoretical model and the observed data does not necessarily imply that the "best" model has been found. In fact, with "noisy" data it is possible to get equally good fits with a wide range of models. Picking a model a priori and declaring it the "best" without having examined other fits can lead to an erroneous conclusion.

The results of the model developed in Reference 3 were obtained by deriving the exponent b in the assumed relation $c = an^b$ from the data. The value ranges from "linear" to "square law," depending upon the particular airport category examined.

b. The square law relationship may only reflect the properties of an insufficient data set. Both studies identify a "square law" relationship for extremely rare events, based on a limited number of events. The relationship of Reference 3 may be "square law" only in the sense that it is the best single explanation for zero collisions at the unbusy airports and non-zero collisions at the busier airports. Doubling the sampling period to 16 years might well produce a different (more nearly linear) result.

c. The "square law" relationships identified in both studies apply to significantly different situations. The results of Reference 3 apply to all aircraft within five miles and below 2000 feet AGL of an airport, where that airport is a member of some sub set of all airports. The model of Reference 4 addresses a definite sub set of all aircraft within 30 miles and below 10,000 feet mean sea level (MSL) of the larger metropolitan terminal areas.

The "square law" explanations developed by both studies to relate (near) collisions to aircraft operations levels should be interpreted and used with care and with due regard for the assumptions and the data limitations imposed on both studies.

2.8 THE MIDAIR COLLISION PROBLEM AND THE AIR FORCE

As was stated in the preface to this report, the work effort being reported was conducted in pursuance of improving aircraft anticollision protection through the use of high intensity xenon lighting (commonly referred to as Strobe Lights). This section (Section 2.0) has tried to highlight the literature search and data analysis performed in an attempt to "scope" the midair collision problem and to determine the characteristics required of strobe lights to reduce the midair collision potential.

Examination of USAF Statistics (paragraph 2.1) resulted in the following conclusions:

a. Seventy-six and five-tenths percent of USAF midairs were of a type which would not be affected by strobe lights (formation and associated flying).

b. All of the collisions which may have been prevented, had strobe lights been in use, occurred when one or both of the aircraft involved was flying VFR. This indicates that human operators cannot perform to the level required by VFR.

c. Eighty-six and nine-tenths percent of all collisions which may have been prevented had strobe lights been in use occurred during daylight flight.

d. Midair collisions are concentrated around airfields where flying activity in concentrated. Takeoffs and landing were found to be significant areas of occurrence as one would expect (in the heart of concentrated operations when aircraft are operating at reduced speeds, and therefore have less ability to maneuver).

e. Half of all midair collisions occurred below 3000 feet AGL as would be expected from d above.

Examination of civil aviation statistics (paragraph 2.2) supports the conclusions found above. The greatest non-military midair collision threat to the USAF appears to be from general aviation aircraft as they were involved in 99.5% of all civil aviation collisions.

Large air carriers appear to be the least likely to be involved in an encounter with USAF aircraft as they generally fly IFR, along well published airways, and conform to published schedules.

The near midair collision data (paragraph 2.3) over emphasizes the involvement of military and commercial aircraft involved in near midair collisions. This is primarily due to the incident reporting methods.

Aircraft visibility is primarily dependent on the contrast between the aircraft and its background. Aircraft which are detectable to 14 miles by an observer could not be found by uninformed scanning pilots until they were within three to five miles of each other. This finding provides a strong argument for direction indicating proximity warning indicators. While smaller aircraft could not be detected at similar ranges, the ratio between the informed and uninformed pilot remained approximately the same (i.e., the informed pilot sighting the intruder at approximately three times the range of the uninformed).

The study of midair collision geometries and midair modeling techniques holds promise in areas related to analysis, simulation, and maneuvering solutions. Development of accurate dynamic models will allow testing to determine which parameter modification will effect a reduction in midair collisions before large sums are spent on expensive flight testing.

3.0 STROBE LIGHTS

3.1 THE "SEE AND AVOID" CONCEPT

Federal Aviation regulations set forth the concept of "see and avoid" or "see and be seen"as it is sometimes called. This concept requires all pilots to maintain a vigilant lookout for other aircraft thereby avoiding midair collisions and applies to all aircraft flying visual flight rules as well as those flying instrument flight rules whenever weather conditions permit.

Aircraft lighting has been provided to allow implementation of the "see and avoid" concept during hours of darkness (when the aircraft silhouette is not visible). As pointed out in Section 1.3 lighting systems have historically been designed to address the collision avoidance problem relative to nighttime use. The development of high intensity lighting as exemplified by strobe anticollision lights is an attempt to expand the useful range of the lighting aided "see and avoid" concept into the dawn-dusk and even the daytime problem.

In the sections that follow we will examine the theoretical performance of strobe lights, some actual strobe light testing, and problem areas associated with strobe anticollision lights.

3.2 THEORETICAL PERFORMANCE

3.2.1 SEEING LIGHTS - BASIC PRINCIPALS

Light is radiant energy that can be sensed by the human eye. Radiant energy, like any other form of energy, is measured in ergs in the c.g.s. system and joules in the m.k.s. system. These units have a corresponding series of radiometric concepts listed in Table 7. Unfortunately, the quantities listed in Table 7 are not a measure of light. This is because the sensation of brightness is not a linear function of the amount of radiant energy received by the eye. Figure 29 shows the relative spectral luminous efficiency vs wavelength as seen by an average observer. The fact that visual response is being evaluated has led to the development of photometry. In photometry, the eye itself is used as the sensor with the observer comparing the brightness of the light source being measured to a known standard light source. Photometric concepts are psychophysical in nature and are listed in Table 8.

Photometric units are arbitrarily based on the international candle, originally an actual sperm candle weighing one-sixth pound and burning at the rate of 120 grains of wax an hour. The new candle or candela was adopted in Great Britain and in the United States on

TABLE 7

RADIOMETRIC CONCEPTS

RADIATOR - Source of Radiant Energy

RADIATION - Process

	SYMBOL	c.g.s. UNIT	m.k.s. UNIT
RADIANT ENERGY	U	erg	joule
RADIANT DENSITY	u	erg/cm^3	$joule/m^3$
RADIANT FLUX	P	erg/sec	watt
RADIANT EMITTANCE	W	$erg/(sec \times cm^2)$	$watt/m^2$
RADIANT INTENSITY	J	erg/(sec x w) *	watt/w*
RADIANCE	N	$erg/(sec \times w \times cm^2)$	$watt.(w \times m^2)$
IRRADIANCE	H	$erg/(sec \times cm^2)$	$watt/m^2$

* w = unit solid angle, normally the steradian.

TABLE 8

PHOTOMETRIC CONCEPTS

Luminator - Source of Luminous Energy

Lumination - Process

	SYMBOL	c.g.s. SYSTEM	m.k.s. SYSTEM
LUMINOUS ENERGY	Q	lumerg	talbot
LUMINOUS DENSITY	q	$lumerg/cm^3$	$talbot/m^3$
LUMINOUS FLUX	F	lumerg/sec	lumen
LUMINOUS EMITTANCE	L	$lumerg/(sec \times cm^2)$	$lumen/m^2$
LUMINOUS INTENSITY	I	lumerg/(sec x w)	lumen/w(candle)
LUMINANCE	B	$lumerg/(sec \times w \times cm^2)$	$lumen (w \times m^2)$
ILLUMINANCE	E	$lumerg/(sec \times cm^2)$	$lumen/m^2$(lux)

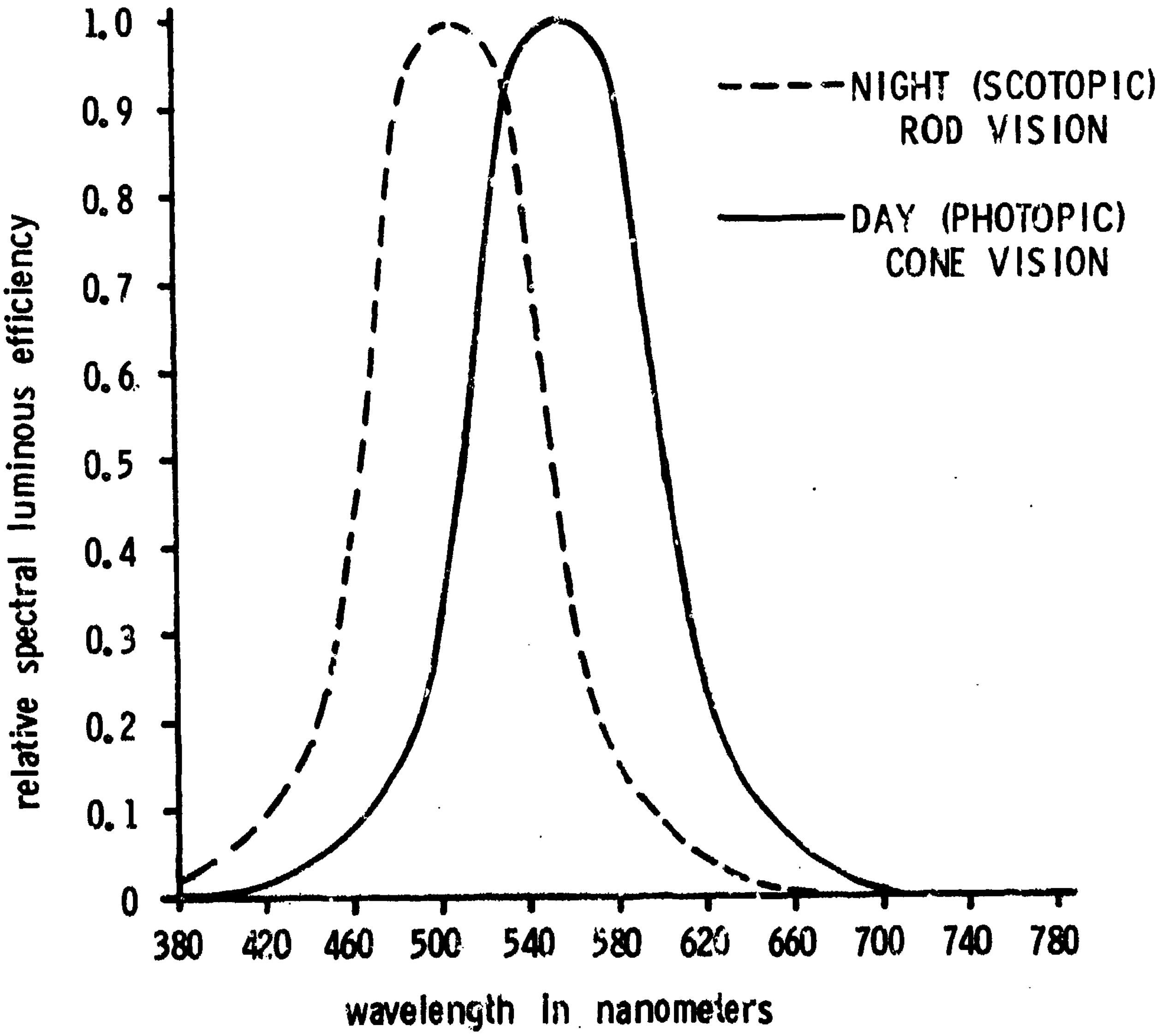

NIGHT (SCOTOPIC) ROD VISION
DAY (PHOTOPIC) CONE VISION
relative spectral luminous efficiency
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
380 420 460 500 540 580 620 660 700 740 780
wavelength in nanometers

FIGURE 29

1 January 1948. "One candela is defined as the luminous intensity of 1/600,000 square meter of projected area of a blackbody radiator operating at the temperature of solidification of platinum under a pressure of 101,325 newtons per square meter." [15:1-4] What this really means can be expressed by looking at the difference between the candela and the old international candle. The difference is so small that only measurements of high precision are affected (the candela is actually less than two percent lower than the old international candle) but the reproducibility of the standard has greatly increased.

The basic unit of light flux is the lumen. The lumen is defined as $1/(4\pi)$ times the total flux emitted by a point source equal to one candela. Since we are usually concerned with light flux in a given direction rather than total flux, the above definition helps in mathematical manipulation (there is a total of 4π steradians of solid angle, ω, about a point, giving one lumen per steradian).

Flux emitted by a point source per unit of solid angle is called intensity (I). Intensity is measured in lumens per steradian (that is a point source of one candela has an average intensity of one lumen per steradian).

Light striking a surface at some distance from the source is called illuminance (E). Illuminance is measured in lumens per unit area. Since a point source emits light in a spherical distribution, the illuminance on the surface of the sphere is related to the intensity of the source by the law of inverse squares. This law simply states that the surface area of a sphere subtending a given solid angle increases with the square of the distance from the source. The concentration of flux on the surface of the sphere must, therefore, decrease in proportion to the square of the radius of the sphere (the source being at the center).

It is the illumination at an observer's eye, produced by a light, that determines if the light will be seen. If the surface being illuminated is the retina of the eye and the source of illumination is a point source of intensity I at a distance x, then the illuminance on the retina is

$$E = \frac{I}{x^2} \quad (1)$$

Light source visibility can be conveniently defined in terms of the threshold illumination produced at the observer's eye under a given set of conditions. Threshold is defined as "the value of a physical stimulus that permits an object to be seen a specific percentage of the time or at a specific accuracy level. In many psychophysical experiments the thresholds are presented in terms of 50% accuracy of accurately 50% of the time. However, the threshold also is expressed as the value of the physical variable that permits the object to be just barely seen." [15:1-20] Threshold for light sources is determined by many physical and psychological factors such as:

a. The source intensity, size and shape, color, movement, and distance from the observer.

b. Luminance of the background.

c. The atmosphere.

d. Backscatter.

e. Other sources in the field of view.

f. Optical quality and location of intermittent mediums (glass, plastics, etc).

g. The portion of the observer's retina on which the source image impinges.

h. The observer's adaptive state, physiological environment, individual visual capability, alertness, and search habits.

i. Distractions diverting the observer's attention.

Threshold illumination, E_0, has been the subject of many investigations with results that vary over an extraordinarily wide range. This variance is due in part to the considerable variability among individual observers in any experiment as well as in any observer from one experimental session to the next. Another source of variation is the uncertainty of the criteria used to determine threshold. Threshold judgements by observers are largely subjective and are affected significantly by the instructions they receive as well as by the design of the experiment.

Threshold illumination for point-source lights observed against dark backgrounds with a high probability of being seen under favorable conditions was found to be 0.01 mile-candela. [16:480] (The illumination produced by a source of intensity 0.01 candela at a distance of one mile in perfectly clear air.) Field sightings with random location and random timing presentation result in considerably higher threshold illuminations and are much more variable than those obtained above. A field value for threshold illumination has been agreed upon by experts in the area which is considered reasonably representative of search situations such as exist in aircraft collision avoidance. This agreed upon threshold value equals 0.5 mile-candela and is used for estimation purposes. [9:99, 9; 18:30; 19; 20] The value of 0.5 mile-candela is for a background luminance in the range from total darkness to starlit sky. However, as background luminance increases above the starlit sky, threshold illumination can increase to as much as 100 times greater than the 0.5 mile-candela level. [16; 9:97f; 21]

Equation 1 assumes that the atmosphere is perfectly clear. This situation never actually exists of course, as the atmosphere is never perfectly clear (even theoretically pure air would attenuate light somewhat). Equation 1 can, however, be modified to account for the effect of atmospheric attenuation by adding a term called transmissivity (t) to the equation. Equation 1 then becomes:

$$E = \frac{I}{x^2} t^x \qquad (2)$$

where t is the transmissivity of the atmosphere, or the transmission per unit distance (same units that x is measured in). Equation 2 is Allard's Law [9:137].

Transmissivity describes only the effects of the atmosphere on the light transmitted as it is the ratio of the transmitted light to the incident light received. Transmissivity does not, however, describe what causes the source attenuation. The attenuation of light signals results from absorption and scattering (due to reflection, refraction and defraction). In atmospheres consisting essentially of air and water vapor (aerosols) absorption of light is very small compared to scattering and can generally be neglected [9]. Absorption only becomes significant in atmospheres containing large amounts of industrial smokes or dust (a situation becoming more and more prevelant around large metropolitan areas).

Aerosols scatter light in all directions. "Backscatter," light scattered at or near 180 degress (back toward the light source), is of special concern, especially in the airborne application of light. If backscatter becomes so high that it begins to have detrimental effects on the pilot, he will be forced to turn off his anticollision light leaving his aircraft without anticollision protection in a poor visibility situation, when it is most needed. The detrimental effects of backscatter include:

a. Reduction of light signal visibility on other aircraft due to an increase in the background luminance against which they are viewed.

b. Loss of dark adaptation at night resulting in reduced ability to detect other sources in the field of view.

c. Disorienting effects caused by flashing lights. It should be noted that this problem creates differing effects depending on how the flashing is created. Rotating beacons can have different effects than electronically flashed (on-off) lights.

Backscatter intensity is proportional to the intensity of the source that causes it. Obviously, as the intensity of an anticollision light is increased a proportional increase in backscatter can be expected. As higher intensity lights are proposed for design into an airframe backscatter minimization becomes a more important design factor. Backscatter can be minimized in a number of ways:

a. Maximum lateral separation of the pilot from the light source. Wing tips then are the most favorable location for forward projecting lights.

b. Maximum longitudinal separation of the pilot from the light source. This will not result in a great reduction in backscatter as will lateral separation, but distance from the source does result in a reduction in the luminous flux density (inverse square law). Fuselage lights should therefore be mounted as far back from the cockpit as possible.

c. Sharp cut off of the intensity distribution inboard coupled with lateral separation. This will result in low backscatter brightness in the area directly forward of the cockpit, while allowing high intensity forward for intruder aircraft.

Using Equation 2 then, it should be possible to generate curves which will predict the distance (D) that a light of intensity (I) may be observed vs the transmissivity (t). The threshold illumination required at the eye for varying background brightness has been determined in the laboratory and has been published [15:3-35]. Threshold illumination E_o can then be used to rewrite Equation 2:

$$E_o = \frac{I \quad t^D}{D^2} \qquad (3)$$

The following four sets of curves were generated with the laboratory determined threshold illumination value multiplied by a factor of five. This assumes that the observer is always alert and carefully searching for the target [22:177]. If the light is viewed against a non-uniform background or the observer is not alert, the threshold values should be multiplied by factors of 100 to 1000 [23:785]. The background against which an aircraft anticollision light may be viewed can vary from 10^{-5} to 10^4 footlamberts [15:3-36 Fig. 3-50].

As an example, with a background luminance of one footlambert threshold illumination is one mile candela. As above, this factor is multiplied by a factor of five. E_o then equals five mile candela. Figure 30 is a plot of these conditions. Using Figure 30 to continue the example we find that a light source of 3500 candela with an atmospheric transmissivity of 0.7 should be detected up to seven miles. With an atmospheric transmissivity of 0.07 the same source would be visible up to 1.59 miles

Figures 31 through 33 are plots for lights of the same intensity as Figure 30 with the background luminance equal to 10, 100, and 1000 footlamberts respectively. Obviously as E_o increases a constant intensity curve shifts left (toward decreasing D) as D is the only variable to adjust the right side of the equation. Since t is always less than one, both terms containing D (D^2 and t^D) drive the right side of the equation down with increasing distance.

3.2.2 FLASHING LIGHTS

Flashing lights are used extensively as signals and warnings because this characteristic is supposed to make them superior in attracting attention. Because of this characteristic, flashing beacons were established as the required lighting for anticollision lights. Beacons can be made to flash several ways. These include rotation (reflectors or source), flashing incandescent, and gas discharge (strobe for example).

When a light signal consists of separate flashes, the maximum intensity during the flash must be greater than the intensity of a study light to have the same apparent intensity. Flashing lights

E_o = 5 Mile Candela

DAWN-DUSK CONDITIONS

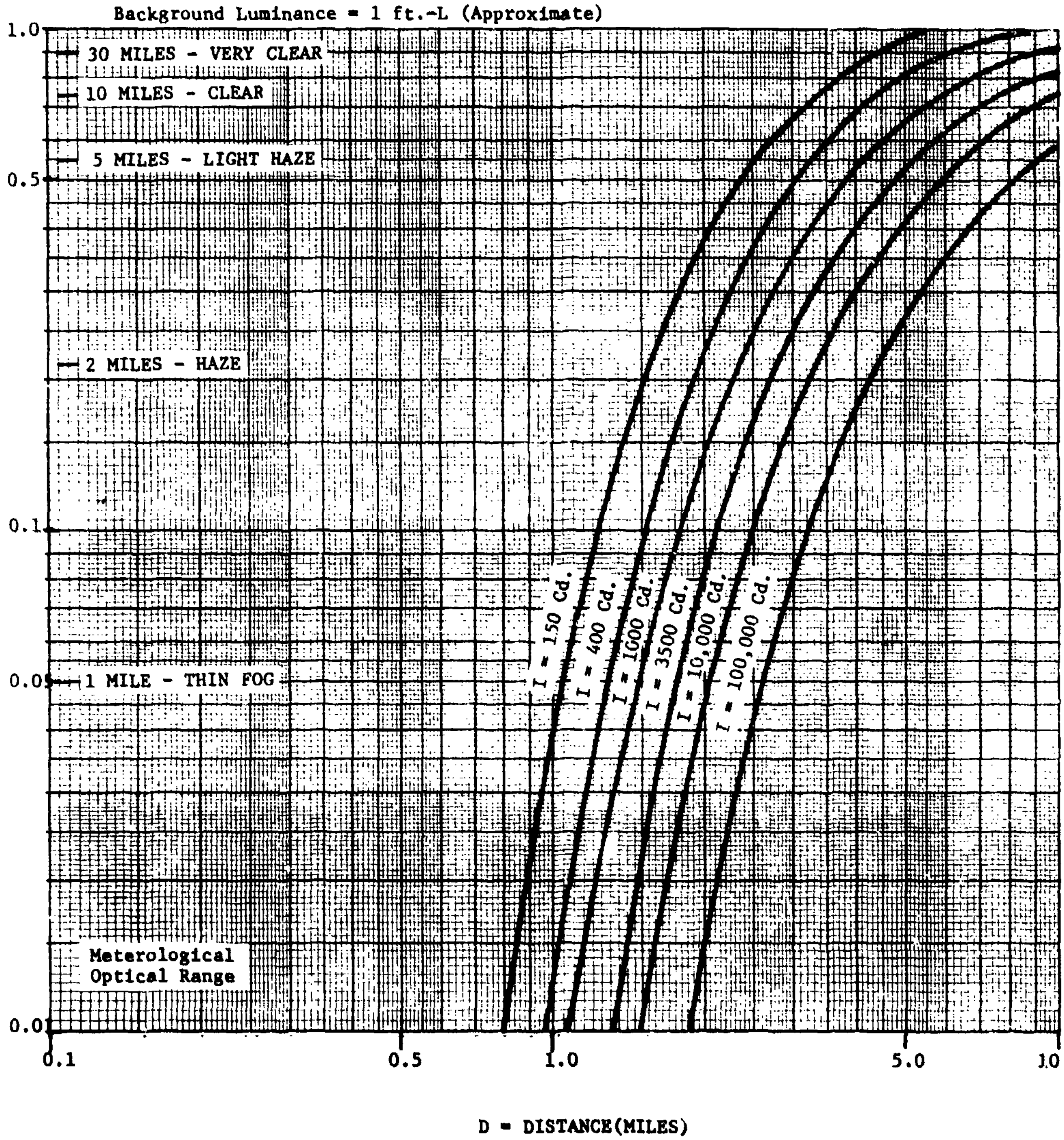


FIGURE 30.

E_o = 25 Mile Candelas

<u>DAYLIGHT CONDITIONS</u>
Very Dark Day
Background Luminance = 10 ft.-L (Approximate)

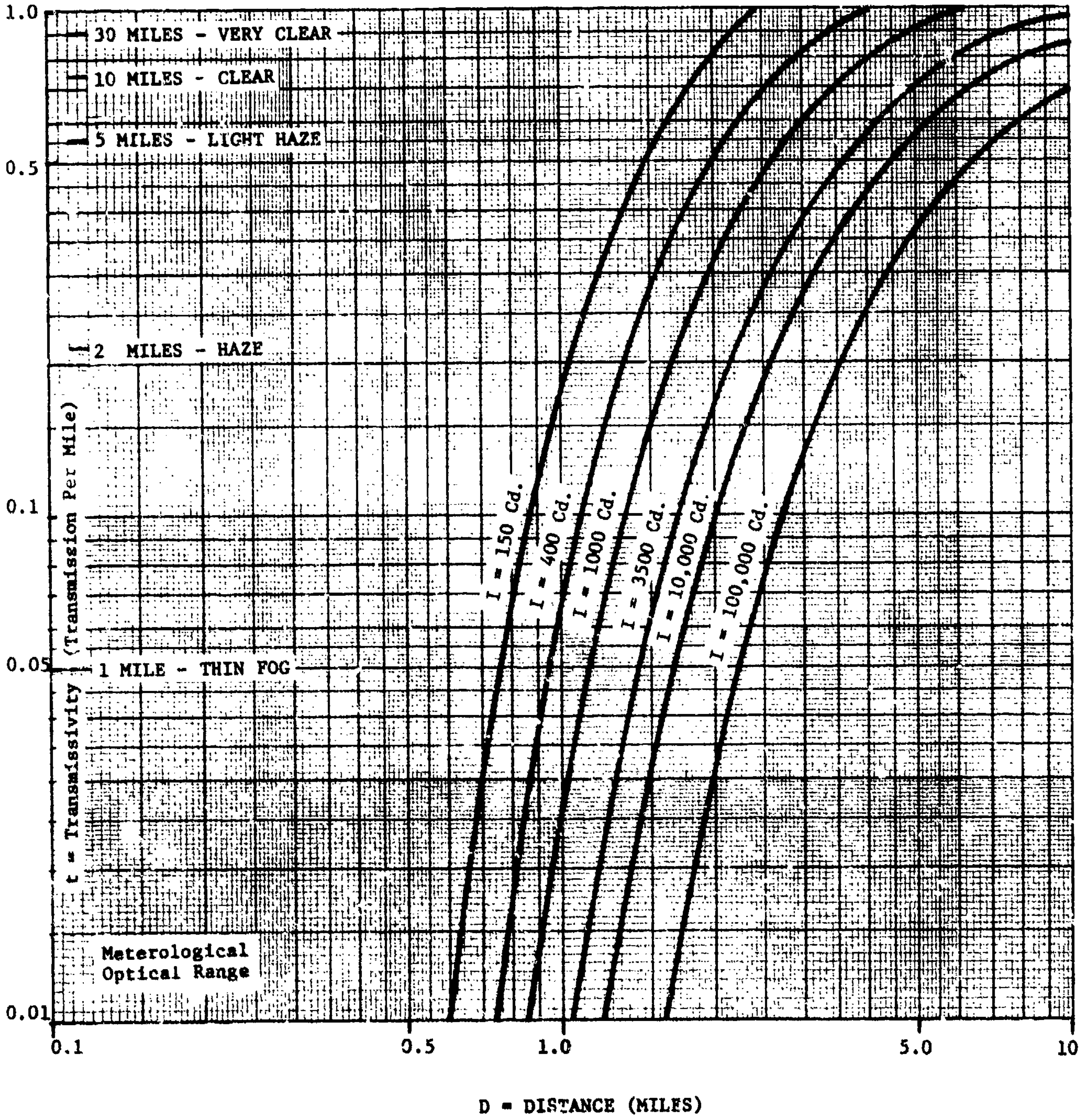


FIGURE 31.

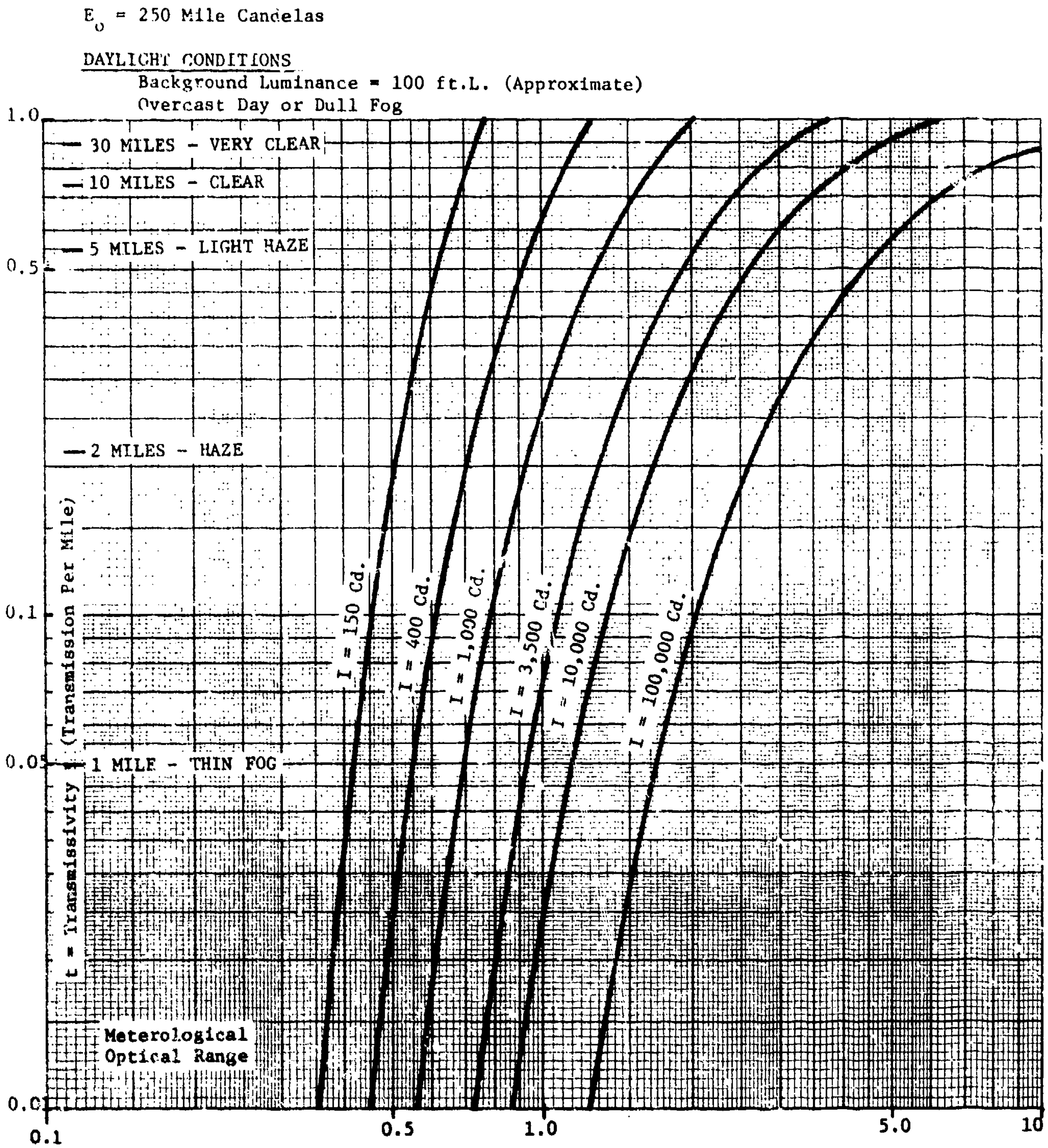

E_o = 250 Mile Candelas
DAYLIGHT CONDITIONS
Background Luminance = 100 ft.L. (Approximate)
Overcast Day or Dull Fog
1.0
0.5
0.1
0.05
0.01
30 MILES - VERY CLEAR
10 MILES - CLEAR
5 MILES - LIGHT HAZE
2 MILES - HAZE
1 MILE - THIN FOG
Meterological Optical Range
t = Transmissivity (Transmission Per Mile)
I = 150 Cd.
I = 400 Cd.
I = 1,000 Cd.
I = 3,500 Cd.
I = 10,000 Cd.
I = 100,000 Cd.
0.1
0.5
1.0
5.0
10
D = DISTANCE (MILES)

FIGURE 32.

E_o = 2500 Mile Candelas

DAYLIGHT CONDITIONS:
Background Luminance = 1000 ft.-L (Approximate)
Clear Sky or Light Fog

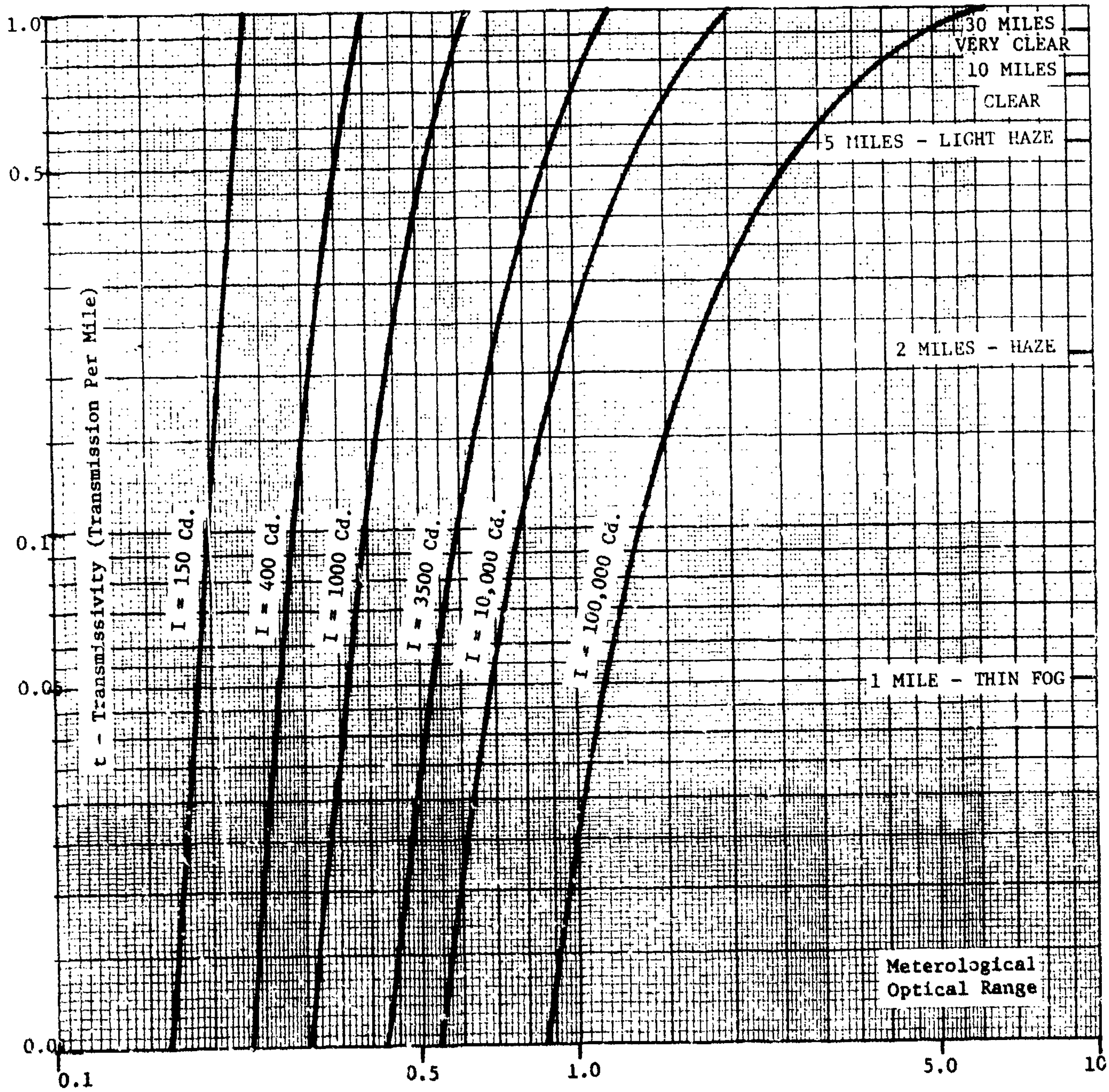


FIGURE 33.

are usually evaluated in terms of Effective Intensity, I_E, the intensity of a steady light which appears equally bright when viewed at threshold and is expressed in Effective Candelas.

The current Air Force specification for anticollision lights (as well as FAA Airworthiness requirements) uses the following equation, known as the Blondel-Rey equation [24] for the computation of the effective intensity of flashing lights:

$$I_E = \frac{\int_{t_1}^{t_2} I(t)\ dt}{0.2 + (t_2 - t_1)} \qquad (4)$$

where I_E = effective intensity

$I(t)$ = instantaneous intensity as a function of time

$t_2 - t_1$ = flash duration (seconds)

The maximum computed value of I_E results when t_2 and t_1 are chosen such that $I(t) = I_E$ at t_1 and t_2 [25]. For flashes with a significantly short duration compared to 0.2 seconds, $t_2 - t_1$ becomes insignificant (strobe light for one) and the total flash is integrated. Equation (4) then becomes

$$I_E = 5 \int_{t_1}^{t_2} I(t)\ dt \qquad (5)$$

It should be noted that while Blondel and Rey use a constant of 0.2 in their equation for I_E (equation (4) above), other experimenters have supported their findings but with varying values of the constant. One experimenter [26] in a review found values ranging from 0.055 to 0.35 second. The specific value of this constant varies with such things as background luminance, pulse length, pulse shape, time between flashes, just to name a few. While the debate over the most appropriate value for the constant rages on, the need for continuing engineering development of flashing light systems also exists. The engineer's approach may seem heresy to scientists but it seems more important for us all to adapt a consistent, almost empirical, relation that is "near enough" than to find the most accurate relation for each type of signal. A value of 0.2 has been adopted as the conventional value for the constant in the Blondel and Rey relationship (equation (4)).

This value has the merits of simplicity, wide acceptability, and for nearly every application, the prime advantage of "near-enough-ness."

3.2.3 THEORETICAL PERFORMANCE OF STROBE LIGHTS

Strobe light performance can be predicted using Equation (3) with $I = I_E$ as found in equation (5). The flash duration of strobe lights is sufficiently short so that the $t_2 - t_1$ term in equation (4) may be ignored and equation (5) may be used for calculation of I_E. Performance of strobe lights is then found by:

$$E_o = \frac{I_E}{D^2} t^D \qquad (6)$$

Figures 30 through 33 then, provide actual values for the expected performance since the only change to Equation (3) is the method of finding one of the terms and not that of terms numerical value in equation (6).

3.3 EARLY TESTS

3.3.1 B-52 TESTS

The first documented Air Force tests were conducted on a B-52 aircraft in 1957. Three anticollision light systems were tested. The three test lighting systems were:

a. Grimes Rotating Beacon. Three Grimes Rotating Beacons were installed on the aircraft body, two beacons 16 inches on either side of the aircraft centerline on the upper surface at body station 1324 and one beacon installed on the aircraft centerline on the lower surface at body station 1230. The upper lights were installed off the centerline so that one or both would be visible from directly behind the aircraft. Each beacon contained two 40 watt bulbs which rotated at approximately 60 RPM inside a red colored glass dome. Thus the Grimes beacon had a flash rate of 120 per minute.

b. Atkins Strobes. The Atkins strobe lights were installed on the aircraft centerline, the upper unit at body station 500 and the lower unit at body station 1300. Each unit contained four discharge tubes illuminating four sectors parallel to the longitudinal and lateral axes of the aircraft. Each tube produced a sufficiently wide cone of light to overlap adjacent sectors and to be seen above and below the aircraft horizontal plane. The flash rate was 160 per minute for the forward light, 80 for the side light, and 40 for the aft light.

c. WADC Exhibit WCLEE 5-70 Anticollision Lights. This light system consisted of a total of 19 individual 40 watt incandescent lamps installed in groups on the aircraft. These groups were located as follows:

(1) Two groups consisting of four bulbs each were located in the leading edges of the wings near the wing tips. These lights flashed at 150 flashes per minute. The lamps were covered with a transparent fairing flush to the leading edge of the wings.

(2) A group of three lamps was installed in the trailing edge of the left wing tip. The lamps were covered by a streamline plexiglas fairing which protruded above the wing surface at the trailing edge. These lights were directed behind the aircraft.

(3) A group of eight lamps was installed in the fin forward of the spar. Four lamps were directed to the left and four to the right of the fin. These lamps covered the side areas and were flashed at 50 flashes per minute.

A RC-97E was used as an observation aircraft on a flight from Boeing Field south to Portland, Oregon and back to Boeing Field. Various courses were taken to avoid cloud formations and to set up different positions relative to the B-52. Test passes were conducted at altitudes varying from 3,000 feet to 12,000 feet. Head-on approach, overtaking from the rear, and various side approaches were examined with each type of anticollision light.

Grimes rotating beacons were selected by the evaluation team as the best system presented. The Atkins strobe lights were rejected because their reflections caused visual interference in the cockpit and like the WADC system, the flash characteristics were not considered of value in providing direction of flight information.

3.3.2 AIR TRAINING COMMAND TESTS OF 1958

The Air Training Command (ATC) conducted flight tests to compare strobe anticollision lights with incandescent anticollision lights in 1958. The tests were conducted on T-33A aircraft. Four variations of two basic anticollision lighting systems were made available for this test. They were as follows:

a. Beacon Types.

(1) Grimes white light consisting of two counter rotating beacons, one located on the top and one located on the bottom of the fuselage.

(2) Grimes red light consisting of two counter rotating beacons, one located on the top and one located on the bottom of the fuselage.

b. Strobe Types.

(1) Madsen lights consisting of three strobe type lights on each side of the aircraft firing in rapid sequence from aft to forward thus giving the appearance of a moving streak of light in the direction of the aircraft motion.

(2) Atkins lights consisting of four strobe lamps flashing at different rates in different zones around the aircraft.

The ATC tests resulted in the following conclusions:

a. None of the anticollision light systems were effective as a daylight anticollision system.

b. All of the systems tested were superior to the standard night navigation lighting (see paragraph 1.1).

c. For fighter type aircraft a tip tank installation of anticollision lights appears to be superior to a fuselage installation due to backscatter.

d. Strobe type lamps are superior to rotating beacons or standard flashing lamps.

e. The order of effectiveness of the anticollision light systems available for this service test was as follows:

(1) Atkins Relative Danger Light

(2) Madsen Aeronautical Direction Light System

(3) Grimes Rotating White Beacon

(4) Grimes Rotating Red Beacon

(5) Standard Navigation Lighting

f. All of the anticollision light systems were found to be mechanically reliable, although the number of hours each of the systems operated was insufficient for the degree of mechanical reliability to be determined.

As a result of the tests ATC proposed that condenser discharge anticollision lights be installed on all trainer aircraft as a Class V modification. This program was turned down by HQ USAF since it did not meet the requirements for a Class V modification as outlined in AFR 57-4. However, HQ USAF stated the lights could be installed if a Class IVA modification requirement could be established. In view of this information HQ AMC (now AFLC) verbally stated that approval would not be given for installation of the condenser discharge lights on all training aircraft. This decision was primarily due to the limited testing that could be accomplished on the one aircraft equipped with the requested light. Therefore, an activity at Wright Air Development Center (WADC) proposed that a number of aircraft at one training base be equipped with the referenced lights for tests. The proposal was accepted. As a result a project was established to procure 16 lights. Fifteen of these lights were to be installed in aircraft for flight test. The sixteenth was to be used for laboratory tests. Funds were allocated, specifications prepared and arrangements made for starting the project. HQ USAF then directed that AFSC obtain permission from the FAA for conducting the tests. That organization refused to grant permission.

3.3.3 WPAFB TESTS OF 1958

Flight tests were conducted at Wright-Patterson AFB in the summer of 1958 on a T-33 aircraft equipped with a condenser discharge light. This was one of the aircraft used by Training Command in the tests referenced in paragraph 3.3.2 above. Results of the test showed that the light tested, though visible for a slightly greater distance in daylight than an incandescent anticollision light, had no significant value as a daylight anticollision light. Furthermore, the capacitor discharge light was found to be undesirable in haze and during landings.

The report recommended that the development of strobe lights as an anticollision measure in daylight and at night with a frequency indication of direction be discontinued.

3.3.4 SAC TESTING - 1971 and 1972

SAC began testing of two prototype 800 candela strobe units from Grimes Manufacturing Co. installed in the upper and lower positions of an FB-111 in April of 1971. These tests concentrated on using strobes for collision avoidance and improved visibility for visual air refueling rendezvous. The test showed general enthusiasm by flight crews and a preference for the strobes when compared to present rotating beacons. Tests on B-52 and KC-135 aircraft resulted in similar general comments.

3.3.5 US ARMY HELICOPTER TEST - 1970 [27]

The US Army Medical Research and Development Command published a report in January 1971 entitled "The Use of High Intensity Xenon Lighting to Enhance US Army Aircraft Day/Night Conspicuity." This report presents the in-flight studies performed at Fort Walters TX to compare the effectiveness of aircraft-mounted, high-intensity xenon flash tube lights for increasing the conspicuity of small trainer helicopters (TH-55) during both daytime and nighttime flights.

3.3.5.1 GROUND-TO-AIR OBSERVATION SEQUENCE

In the ground-to-air observation sequence test subjects were located on a pinnacle approximately 250 feet high and overlooking a valley (see Figure 34). A three-fourths inch white square on a black background was used as a fixation target in the center of a partial circle, the subjects seated approximately ten feet from the target and 15 degrees apart. Two subjects (one in front of the other) were seated at each position. The positions of the subjects were designated at 15° left, 30° left, 45° left, 60° left, 15° right, 30° right, 45° right, and 60° right. Right or left referring to the direction the aircraft appeared to approach the subject. A xenon light equipped TH-55 and a standard TH-55 aircraft (with the standard rotating red anticollision light operating) approached the pinnacle from the east, approximately four miles away, at 50 knots airspeed and 30 feet below the pinnacle. The subjects were instructed to look only at the fixation target.

The intensity level on the strobe-equipped TH-55 was changed to one of three different values (1800, 2300 or 3300 E.Cd.) on each pass. The standard lighted TH-55 followed on the same flight path about three minutes behind the strobe equipped aircraft. This procedure was used on the morning of 22 September 1970 and afternoon of 23 September 1970.

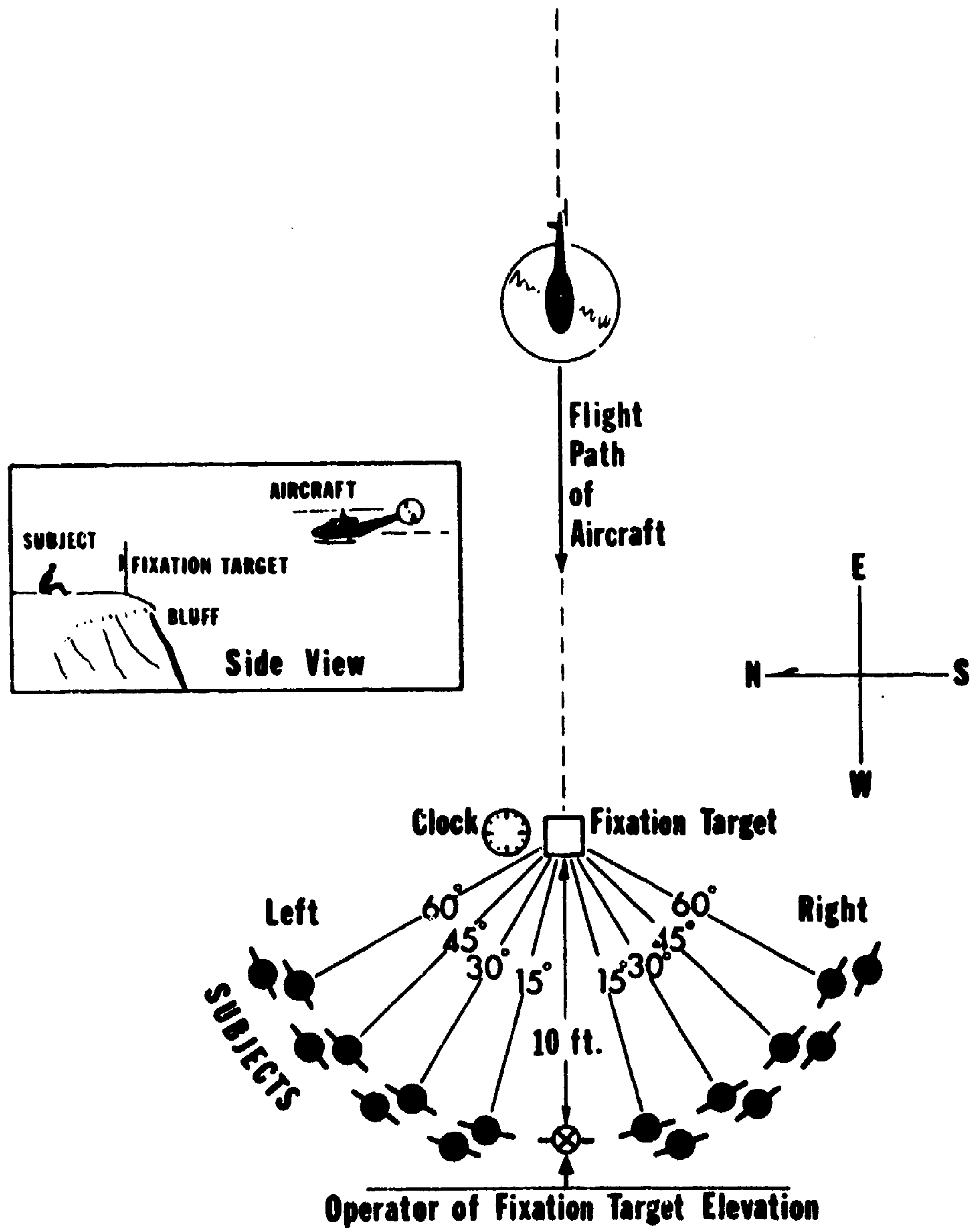


Figure 34

Ground-to-Air Observation Sequence

On the last four passes in the afternoon session, both aircraft flew 50 feet above the pinnacle in order to obtain data on aircraft viewed against a sky background.

When each subject could first detect the approaching aircraft, he noted the time on a 12 inch electric clock positioned below the fixation target (to the nearest second) and recorded this on a form. When the aircraft passed directly overhead, one designated individual announced the time for each subject to record.

Twenty-eight volunteer subjects were utilized as observers during the conduct of the experiment. Fifteen of the subjects were rated aviators and the remaining thirteen subjects were Warrant Officer Candidates who had been selected but had not yet begun the Army flight program.

On 22 September 1970 the weather conditions at the test site consisted of winds 15-18 mph and gusting with scattered clouds. On 23 September 1970, because of the effects of a cold front, half of the sky was light gray and the other half was clear and cloudless, winds calm.

3.3.5.2 GROUND-TO-AIR RESULTS

Tables 9 and 10 give the results of the experiment where all angles and all subjects were considered together. The tables present the following:

a. n = the number of observations.

b. $\bar{X}$ = the mean value of the time it took from the moment of recognition of the aircraft until it passed directly overhead.

c. s = the standard deviation.

d. D = the average increase in distance the aircraft could be detected by equipping it with a high intensity light.

The result shown in Table 10 was considered more valid than those of Table 9 by the Army experimenters. The weather conditions during the collection of the data in Table 9 consisted of a fairly strong crosswind that kept the pilots from flying the precise assigned course with the result that some erratic responses were obtained.

Table 9 (22 Sep 70)

All Angles and Subjects

Level (Eff. Cd.)	w/Strobe	w/o Strobe
3300	$n = 14$	$n = 14$
	$\bar{X}_S = 30.0$ sec	$\bar{X}_N = 13.6$ sec
	$s = 14.5$ sec	$s = 4.7$ sec
	$D = (\bar{X}_S \quad \bar{X}_N)(64.33) = 1,380$ ft	
2300	$n = 15$	$n = 15$
	$\bar{X}_S = 31.3$	$\bar{X}_N = 20.1$
	$s = 15.3$	$s = 8.2$
	$D = 944$ ft	
1800	$n = 15$	$n = 15$
	$\bar{X}_S = 32.3$	$\bar{X}_N = 15.1$
	$s = 17.0$	$s = 7.9$
	$D = 1450$ ft	

Table 10 (23 Sep 70)

All Angles and Subjects

Level (Eff. Cd.)	w/Strobe	w/o Strobe
3300	$n = 48$	$n = 48$
	$\overline{X}_S = 38.69$	$\overline{X}_N = 12.50$
	$s = 16.90$	$s = 6.02$
	D = 2210 ft.	
2300	$n = 48$	$n = 48$
	$\overline{X}_S = 29.23$	$\overline{X}_N = 14.19$
	$s = 14.26$	$s = 4.98$
	D = 1270 ft.	
1800	$n = 48$	$n = 48$
	$\overline{X}_S = 28.10$	$\overline{X}_N = 14.42$
	$s = 15.62$	$s = 6.04$
	D = 1150 ft.	

The results shown in Tables 9 and 10 are independent of the various angles. When the data is considered according to angle, Figures 35 and 36 result. As the experimenter points out, Figure 35 presents results that were not expected. He further notes that each point on the graph is represented by only two or three responses. The large standard deviation now becomes much more important. It would be very difficult to draw any conclusions from this data as the sample is much too small.

Figure 36 presents the data of Table 10 graphically by angle. The Army experimenter felt that this data is much more valid as the weather conditions were better and the observers more experienced. Although the experimenter claims to have two to three times as many data points (four to nine) per point on the graph, the amount is still far from sufficient as is indicated by the large standard deviation (about half of $\overline{X}$). The experimenter points out that the only unexpected occurrence takes place at the 60^{o} position of Figure 36. According to theory, the graph of time ($\overline{X}$) as a function of angle should show a uniform decrease as the angle increases. The experimenter assumes that someone at the 60^{o} position is not keeping his eyes on the fixation target and hense performing as an observer would at 0^{o}. This same assumption can be made about one of the observers at the 15^{o} right location. Right and left data should match, but the data indicates that the right 15^{o} performs twice as well as the left 15^{o} location.

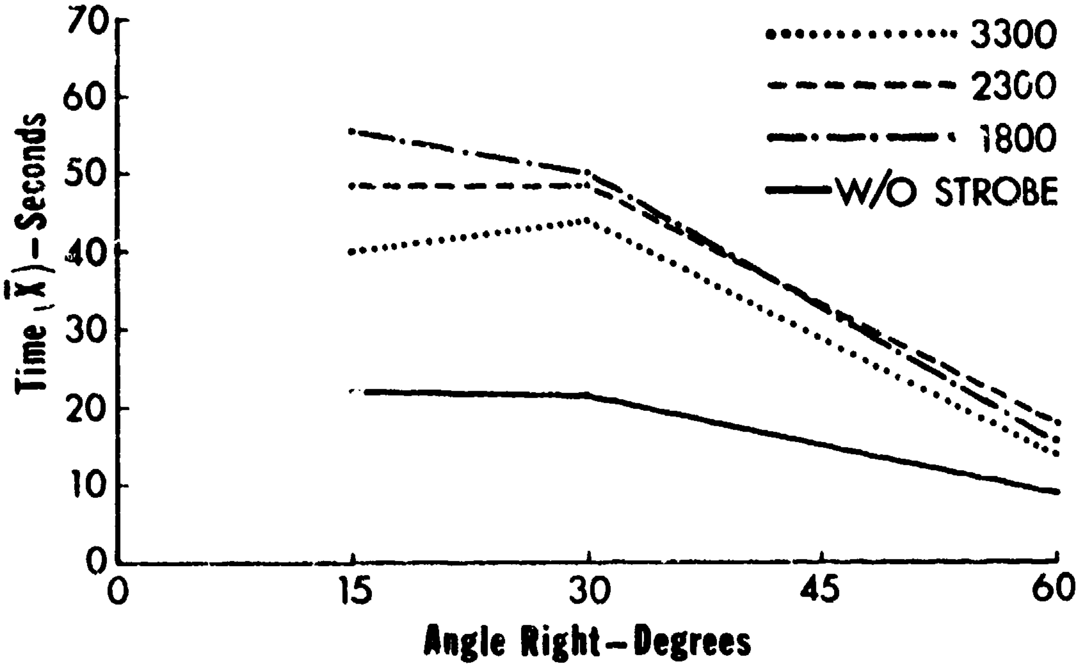
Questions of whether or not the observers were looking at the fixation target and the lack of a large enough sample bring this data under serious question.

The above results (Figures 35 and 36) represent data where the helicopter and light are viewed against relatively dark background, the ground. It must be remembered that for almost every aircraft viewed against the ground, there is an aircraft above to be seen against the sky. The results of using the strobe at the 3300 E.Cd. level against daytime sky can be seen in Table 11. Very little difference is apparent in the strobe equipped and non-strobe equipped cases. However, there is a large improvement in the visibility of the aircraft compared to when viewed against the ground. This is to be expected since the contrast between the day sky and the strobe is much less than that between the strobe and the ground.

TABLE 11
ALL ANGLES AND SUBJECTS
(23 SEP 70)
3300 E.Cd. LEVEL W/SKY BACKGROUND

W/STROBE	W/O STROBE
n = 32	n = 31
$\overline{X}_s$ = 33.5 sec	$\overline{X}_n$ = 29.0 sec
s = 15.4 sec	s = 13.4 sec

ALL SUBJECTS – 22 SEPT., 1970



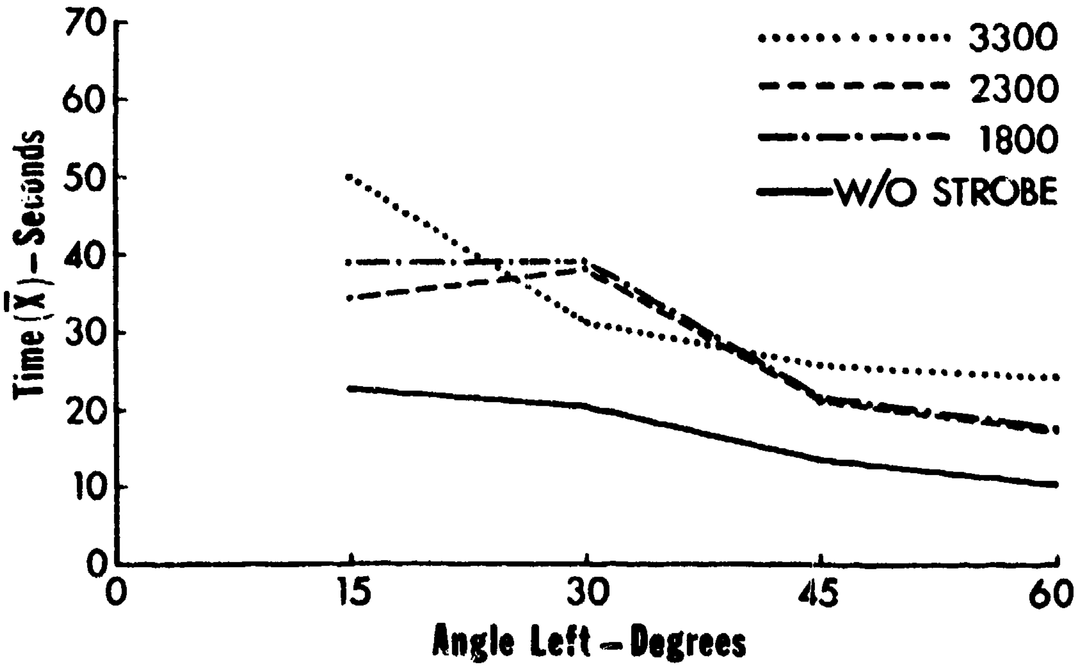


Figure 35

ALL SUBJECTS – 23 SEPT., 1970

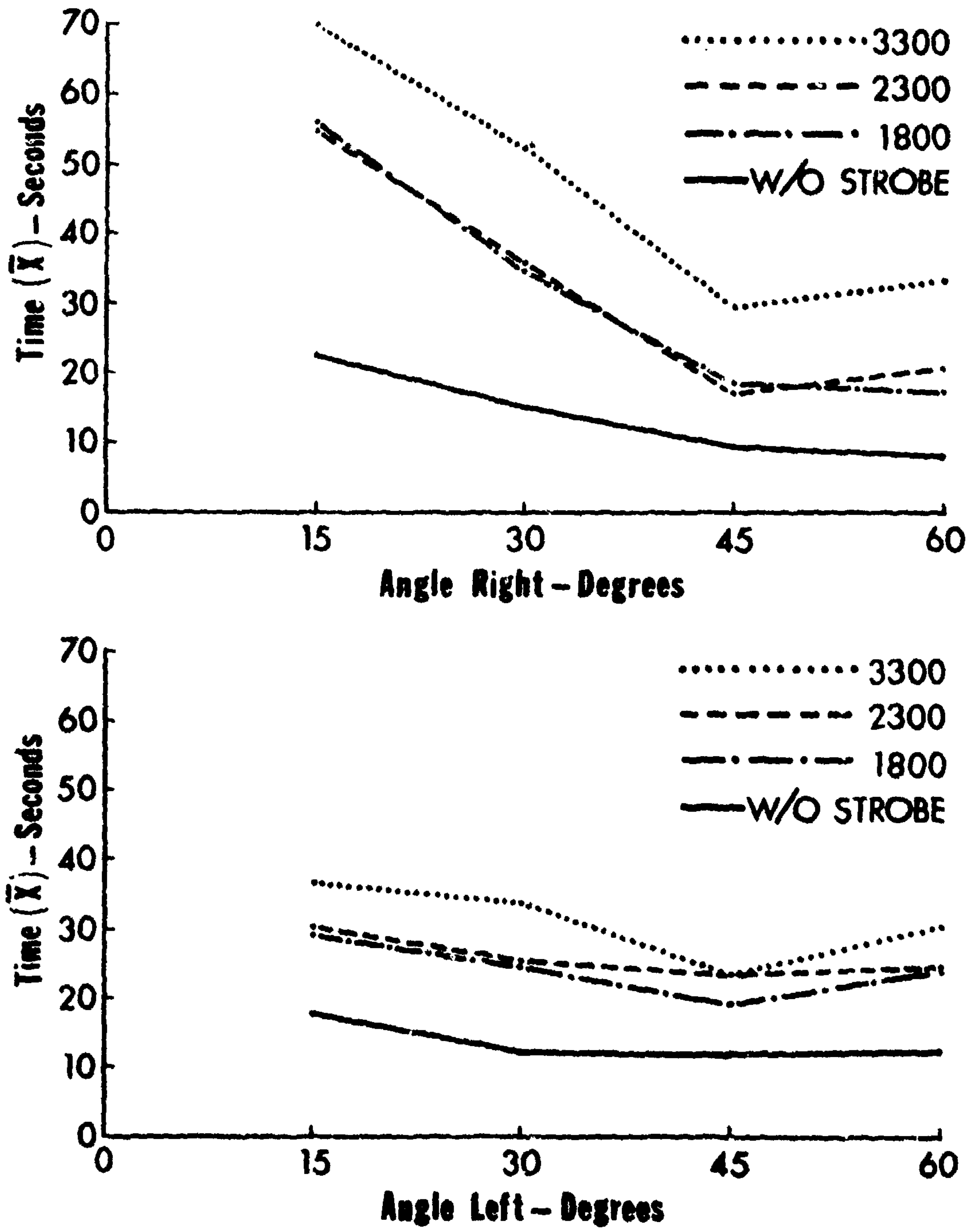


Figure 36

3.3.5.2 AIR-TO-AIR OBSERVATION SEQUENCE

Two TH-55 aircraft were used as target aircraft and observations were made from two OH-23 aircraft each carrying two subjects at a time. One of the TH-55 aircraft was equipped with the multi-level flash tube lighting system and the other was unaltered.

Three different observation phases were conducted and a subjective ranking was obtained from the observers. The observation phases were as follows:

a. Phase I. The distance between the two TH-55 target aircraft was approximately 50 to 75 feet. The distance from the observation aircraft to the two target aircraft varied considerably but was approximately 125 to 200 feet most of the time. The subjects used a rating scale to compare the relative conspicuity of the two aircraft:

0 = no difference in the conspicuity of the two target aircraft
1 = lighted aircraft slightly superior
2 = lighted aircraft moderately superior
3 = lighted aircraft strongly superior

The pilots of the test aircraft and observer aircraft flew a similar flight pattern for all subjects. The three light settings were viewed for approximately one minute each for the different backgrounds. Comparison of the conspicuity of the two test aircraft was made using three different backgrounds:

a. Viewing the test aircraft against a ground background.

b. Viewing the test aircraft at the same altitude.

c. Viewing the test aircraft positioned above the observation aircraft with a bright sky or cloud background.

b. Phase II. In this sequence, the observer aircraft approached first the standard lighted aircraft and then the strobe lighted, on a converging midair collision course. The subjects were instructed to observe the instrument panel and determine the relative value of the light in attracting their attention and providing visual warning.

c. Phase III. The final procedure was designed to recreate one of the most common accident producing attitudes for small trainer helicopters, i.e., two aircraft at different altitudes and either the upper descending upon the lower, or the lower ascending into the upper. This was accomplished by having the TH-55 target aircraft fly side by side with a sufficient rotor separation to allow the observer aircraft to fly from behind and below up between them. The object was for the subjects to maintain fixation on the instrument panel and judge the relative conspicuity of the lighted and non-lighted target helicopters as they moved up between them.

3.3.5.4 AIR-TO-AIR RESULTS

The results of the air-to-air observations are outlined in Table 12. Phase I results for the rated (R) and nonrated (N) personnel are shown with the target aircraft viewed against a ground background, same level, and the target aircraft above (sky background). These observations were made at all three intensity levels.

Tests for Phase II and Phase III were conducted using the 3300 E.Cd. intensity level. The value of this subjective data is questionable but is presented here as collected.

3.3.5.5 NIGHT LIGHTING AND ARMY HELICOPTERS

Two off-the-shelf white Xenon strobes, each having an output of 300 to 400 E.Cd. were tested on a TH-55 helicopter at Fort Walters, Texas by four pilots during all phases of normal night operations. All four pilots agreed that the problem of backscatter was too severe. Light reflecting into the cockpit, particularly during the hover mode, was very annoying.

Two lamps were later obtained each having a red light output of 100 to 200 E.Cd. Three pilots at Fort Walters tested this system on a TH-55 and found that the backscatter problem had been solved. The experimenters state (without any apparent data) that the visibility characteristics of the red strobe were considerably better than the standard rotating beacon (of the same intensity) for three reasons.

a. The light distribution above and below the horizontal plane was 60^{o} instead of 30^{o}, and the loss in light output at these extremities was 25% versus 90% for the rotating beacons.

b. The rapid flash characteristics of the strobe were more conspicuous.

c. The strobe lamp radiates a full 360^{o} with each flash, rather than the sweeping motion of the beacon. It must be noted that these comments are the subjective opinion of the experimenter as no test was

Table 12

In-Flight Preference Study

		Phase I						Phase II Converging		Phase III From Below	
		Ground		Level		Above					
		R	N	R	N	R	N	R	N	R	N
3300 Level	P	2.68	2.28	1.97	2.05	1.36	1.65	2.33	2.10	1.61	1.90
	n	54	40	54	40	54	40	27	20	27	20
2300 Level	P	2.00	2.10	2.00	2.00	1.62	1.30				
	n	13	10	13	10	13	10				
1800 Level	P	1.77	1.90	1.69	1.70	1.38	1.30				
	n	13	10	13	10	13	10				

Rating Scale

0 - no difference in conspicuity of lighted and non-lighted aircraft.

1 - lighted aircraft slightly superior.

2 - " " moderately "

3 - " " strongly "

P - mean value of preference

n - number of observations

run to demonstrate that the strobe had a higher probability of detection than the rotating beacon.

3.3.6 <u>F-111 STROBE TEST OF 1971</u> [28]

Two test article strobe lights were furnished at no cost to the Government by Grimes Manufacturing Co., Urbana, Ohio. These lights were installed on an FB-111 aircraft on 15 March 1971. The test article strobe lights were direct replacements for the existing rotating beacons. The strobe light power supply was designed to replace the retracting mechanism of the rotating beacon. The strobe light was not retractable. The strobe lights were rated at 800 E.Cd. and had a flash rate of 60 per minute. The cylindrical Pyrex housing of the strobe extended 2.5 inches above the fuselage and had a diameter of 2.75 inches.

Flight crews were briefed and post flight evaluation form[illegible]re used to aid in analysis of the effectiveness and limitations o[illegible] lights. Data from 16 flights were collected, six were at night, seven were under IFR conditions and eight involved air refueling. Comments were collected from the test aircraft crew, tanker operators, and ground observers.

The test report indicates that pilot reaction was very enthusiastic, and tower personnel reported that visual acquisition of the test aircraft in the traffic pattern was greatly facilitated. Tanker sightings occurred at thirty miles in some instances, with an average visual acquisition range of 20 miles at night and ten miles in the daytime.

Some crews experienced cockpit distractions during the [illegible] flights and resulted in pilots turning the lights off. There were also distractions reported in cell formation.

After the sixteen flights at Carswell, the test lights were shipped to Edwards AFB CA for supersonic flight testing. There were three flights at up to mach 2.2 and 50,000 feet altitude. Testing terminated when the chase plane reported the lower light out after a supersonic run on the third flight.

Three failures were experienced during the testing:

a. The strobe lights were reported to be intermittent during the first flights. It was discovered that as the xenon in the flash tube heated during operation, the trigger voltage (15KV) applied was not sufficient to ionize the gas. Installation of grids, surr[illegible]ing the tube, to increase the field strength corrected this problem. Although not indicated in the test report, installation of this grid will most likely reduce the light output as will heating of the xenon gas. The report does not indicate that this was tested.

b. The secon failure occurred at the end of the Carswell testing when the upper light failed. Contractor analysis found a chafed wire caused by a construction peculiar to the test units. The contractor gave assurance that design of production units would eliminate the possibility of this failure.

c. On the third supersonic flight at Edwards AFB the lower light failed. Vendor analysis found a cold solder point on the printed circuit board of the power supply. Better quality control and proper wire support should prevent a recurrence.

It is important to note that a daytime visibility of ten miles is extremely optimistic when considering an 800 E.Cd. source. Most of the test data from other tests have indicated that the theoretical data (paragraph 3.2.1 and Figures 30-33) is a good and accurate indication of expected performance. The theoretical data indicates that an 800 E.Cd. light should be visible (at threshold) approximately 0.5 miles on a standard day with ten mile (metrological visibility (1000 ft.L. background and transmissivity approximately .7). For a ten mile visibility background luminance would have to be at or near 1 ft.L. (early dawn or late dusk conditions) and a transmissivity greater than 0.9 (greater than 30 miles metrological visibility).

3.3.7 T-38 AIRCRAFT BEACON/STROBE LIGHT VISIBILITY TEST OF 1972 [29]

Standard T-38A aircraft anticollision lights consist of two red rotating beacons. One beacon is located near the top of the vertical stabilizer and is visible from either side, with the other beacon being located underneath the fuselage (approximately under the front cockpit). An Air Training Command T-38A was modified by replacing the rotating beacons with two strobe lights rated at 2000 E.Cd. in the horizontal plane. This specially modified T-38A and a T-38A with the standard rotating beacons were used as target aircraft. An F-106B was used as a chase aircraft.

The test flights were performed at two different altitudes. High altitude passes were made at 37,000 feet, 0.90 mach for the interceptor and 39,000 feet, 0.75-0.80 mach for the target aircraft. Low altitude tests were performed at 5,000 feet, 0.55-0.60 mach for the interceptor and 7,000 feet, 0.55-0.60 mach for the targets.

Radar lock-on was achieved with visual sightings occurring at the respective ranges noted in Table 13. The head-on and stern passes were performed with the target aircraft in line abreast formation (approximately two ships separation) and the other passes were flown with target aircraft

TABLE 13

T-38A/F-106 BEACON/STROBE TEST DATA

@ 37,000 feet

ANGLE	0°		45°	90°	135°	180°
AIRCRAFT	4nm	6nm	6nm	9nm	SAW AIRCRAFT BUT	
STROBE LIGHT	0.8nm	0.8nm	1nm	0.5nm	COULD NOT SEE	
BEACON	0.3nm	0.5nm	0.75nm	NOT SIGHTED	BEACON OR STROBE	

@ 5,000 feet

ANGLE	0°	45°	90°	135°	180°
AIRCRAFT	2.5nm	2nm	2nm	SAW AIRCRAFT BUT	
STROBE LIGHT	1.5nm	1.3nm	1nm	COULD NOT SEE	
BEACON	0.2nm	0.5nm	NOT SIGHTED	BEACON OR STROBE	

flying loose trail formation (approximately three or four ship lengths separation). Sightings were made at aspect angles of 0° and 45° stern, 90° Beam, 135° and 180° Front. On all passes the target aircraft was initially 2,000 feet higher than the chase aircraft, with separation of between 1,000-2,000 feet maintained after radar lock-on. In the stern passes the chase aircraft started with 2,000 feet separation and then climbed to co-altitude in an attempt to find an optimum sighting position.

3.3.7.1 DATA EVALUATION AND ANALYSIS

At the lower altitudes tested (5KFT) pilots reported definite haze conditions. The ranges at which aircraft sightings were made are significantly lower than those reported for high altitudes (37KFT). In the majority of the cases the strobe lights were sighted at slightly greater ranges in the haze conditions; however, the interceptor was at much lower speeds (.9 mach @ 37KFT, .55-.6 mach @ 5KFT). In all cases the aircraft was sighted first followed by the strobe light and slightly later the beacon. The beacon could not be seen in the 90° beam pass and none of the lights could be definitely seen in the 135° and 180° fronts because of the high closing rates (900FT/SEC. at 90° BEAM to 1600 FT/SEC. at 180° Front). Pilots' comments were that one system was not significantly better than the other as anticollision lighting in the test environment for this flight.

3.3.8 USAF-IG STROBE EVALUATION OF 1973 [1]

The USAF-IG strobe evaluation of 1973 was developed as a result of the Air Force Systems Command conference of April 1973 which was held to determine the status of high intensity strobe light research and development and to determine the applicability of such lights to USAF use. From this conference the following conclusions were presented by the USAF members who participated in the conference.

a. The USAF does not have a formal program to evaluate strobes for midair collision avoidance.

b. Several major commands have tested strobes and strongly supported immediate installation. However, operational evaluation is required to determine the optimum configuration and intensity for installation on USAF aircraft.

c. The test parameters of the 1973 bird/aircraft strike hazard (BASH) evaluation at Mountain Home AFB are not adequate to completely judge midair collision avoidance characteristics of strobes.

d. Engineering developments have reached a point where high intensity strobe lights could be utilized as a suitable replacement for the existing anticollision lights.

e. The US Army has done extensive research and development in the area of anticollision devices on rotary wing aircraft. It is proposed that the USAF adopt the basic recommendations of the Army, adding any requirements special to the Air Force mission and implement them for the Air Force helicopter force.

From this meeting the IG agreed to conduct an evaluation in an attempt to provide definitive information as to the effectiveness and reliability of strobe light equipped aircraft in reducing the midair collision potential. The specific objectives of the IG strobe light evaluation were to:

a. Determine effectiveness of strobe lights as midair collision avoidance devices on USAF aircraft in an operational environment.

b. Determine operational suitability, maintainability, and reliability of strobe lights on USAF aircraft.

c. Determine human factor aspects of strobe lights on aircrews.

Prototype strobe lights were procured and installed in the existing anticollision light receptacle on the B-52D, KC-135A, C-141, T-39, FB-111, and T-38 aircraft. Specifically, MAC installed 3,000 E.Cd. white lights on both the C-141 and the T-39, for daytime operations, while during nighttime operations red lenses reduced this intensity to 400-600 E.Cd. SAC configured the B-52D with a 3,000 E.Cd. white strobe light, the FB-111 with a 1400 E.Cd. white strobe light which was subsequently partially shielded to reduce backscatter effects. The KC-135 was configured with a dual red/white light with 300 E.Cd. in the red mode and 2,700 E.Cd. in the white mode. ATC configured the T-38 with a dual red/white light also with 300 E.Cd. in the red mode and 2,700 E.Cd. in the white mode. All lights were designed to provide omnidirectional coverage with the optimum intensity established in the horizontal plane. The strobe equipment available for Air Force testing was limited by the requirement (Air Force imposed) that the lights be "screw driver retrofits" so test aircraft could be easily be returned to their original configuration.

The test data was collected in conjunction with normal training missions. 573 sorties were flown from which pilot/ground controller questionnaires were received and evaluated. The following test results were presented in the report and comments relative to these results are also presented.

a. "Commonality: A common strobe light for all aircraft is neither feasible nor desirable. Proper consideration of the requirements for individual aircraft type and operation will dictate a wide variance in strobe light design and performance factors. Aircraft differences will impact such factors as strobe light intensity, location and number of units. The geometry of the aircraft must be considered so that strobe lights can provide maximum coverage without unacceptable backscatter or excessive blockage from the aircraft itself."

Comments. The experimenter seems to be implying that strobe light requirements are determined by the type aircraft and/or aircraft operational requirements. It must be remembered that the performance requirements of an anticollision light system must be determined from the standpoint of the observer. Light intensity, distribution around the aircraft, and flash rate requirements are determined by the eyes ability to see and not the size or configuration of the aircraft. As indicated by the midair collision and near midair collision data, incidents occur under very similar circumstances (with respect to closing speed and location) restricting the variation in required anticollision light performance. The type aircraft, will affect strobe light performance on an individual light basis only as a tailoring aspect toward achieving the total system requirements. While one common strobe for all aircraft would not be feasible, three to four standardized types may be feasible based on grouping aircraft by performance characteristics.

b. "Location: Anticollision lights are most commonly located on the top and bottom of the fuselage or on the top of the vertical fin. Other acceptable locations are in the wing tips and tail or in the wing root and tailcone. This latter location may be desirable with variable geometry wing aircraft or with aircraft having very thin wing tips. However, everything considered, the wing tips and tail location can be considered ideal. Locating high intensity strobe lights in the extremities of the aircraft will create fewer backscatter, EMI and reflection problems. Care must be taken in locating strobe lights to insure that they do not interfere with other aircraft systems or that the other systems do not prevent the strobes from functioning properly. In the event of a strobe light retrofit program the location of existing anticollision light receptacles may be considered ideal to keep engineering and installation costs to a minimum; however, consideration must be given to backscatter/reflection problems."

Comments. There is general agreement with the material presented. However, the material is purely speculative on the part of the experimenter as none of the comments can be drawn from the data collected. The only lights tested during this evaluation were fuselage mounted.

c. "Intensity: Strobe light effectiveness during day VMC improves as the intensity increases. The optimum intensity for a particular type aircraft depends on aircraft size, power available, space, operational requirements, reflecting surfaces, lighting receptacles and locations of crew stations. It is neither feasible nor desirable to set a minimum intensity standard for USAF aircraft due to differences in present and future aircraft. However, every effort must be made to optimize the intensity for individual aircraft based on current state-of-the-art equipment available."

Comments. While the effectiveness of strobe lights probably increases during day VMC with increasing intensity (as can be seen in the theoretical data of Figures 30-33) data collected during this evaluation could not be used to verify this fact. As noted earlier, the aircraft with the higher intensity lights were the larger (B-52, KC-135, etc.) and aircraft with lower intensity lights were smaller (FB-111, T-37, etc.). The data is not the type that would allow separation of the effects of aircraft size from light intensity. Under most daylight VMC conditions all of these aircraft will be visible at ranges two to three times that of a 3000 E.Cd. strobe at threshold. It must be again emphasized that aircraft size, power available, space etc., do not define the optimum intensity required of a strobe light. These factors may indeed result in design compromises but do not change the requirement.

d. "Conspicuity: High intensity strobe lights, regardless of color, increased aircraft conspicuity during hours of darkness, twilight or reduced visibility. SAC was unable to support the conclusion that during bright daylight hours strobe lights substantially increased aircraft conspicuity, although both MAC and TAC could strongly support this conclusion. It appears the differences of opinion could be attributed to some basic cause factors:

(1) Aircraft Size

(2) Location of Lights

(3) Light Intensities

(4) Flash Rates

(SAC was the only command which established a flash rate of 60/minute)."

Comments. Any comparisons involving two lights will always find the brighter light visible at a greater distance (see Figures 30-33). But conspicuity is not based solely on visual rnage. A in the case of the T-38 evaluation (paragraph 3.3.7), the beacon was visible in one case at 0.5 nm, the strobe at 1.3 nm and the aircraft at 2.0 nm which indicates an almost 3X improvement in anticollision light detectability from beacon to strobe. But it must also be noted that aircraft conspicuity was not improved as it was visible 0.3 nm before the strobe. The idea is to detect the aircraft not the light.

e. "Reliability: An increase in anticollision light reliability could be realized if high intensity strobe lights were procured to replace the present rotating beacon. Presently Mean Time Between Failure (MTBF) on the rotating beacon averages 200 hours while minimum MTBF for the US Army Strobe Light Specification was established at 800 hours. It is well within the state-of-the-art to provide strobe lights with MTBF in excess of 2,000 hours."

Comments. The data presented here is again speculative as this type information is not obtainable from the IG analysis. At the writing of this report the MTBF for the Army light is only a specification value. No strobe light equipment has demonstrated an 800 hour MTBF and that meets the other requirements of the Army specification, let alone 2,000 hour estimate provided.

f. "Suitability: Light reflections and backscatter from the white strobe light caused an operational annoyance to some aircrews during night IMC operations, day IMC operations and some night VMC operations. Under these conditions the white strobe lights were turned off. Under those conditions where the crew had the capability to either select a lower intensity red strobe light or to have a red lens installed prior to flight, the operational annoyance was reduced to a minimum level."

Comments. Reduction of the operational annoyance by selecting a lower intensity red light reduces light intensity by at least 80% with an associated reduction in anticollision light effectiveness. How the lower intensity light was determined to provide "minimum annoyance" is unknown since lights of slightly lower or higher intensity were not tested.

g. "Maintainability: The strobe lights were operated and maintained by military personnel in the field throughout this evaluation without difficulty. All lights evaluated were prototype lights that were designed to operate in the existing anticollision light receptacle. If a failure occurred during the course of this evaluation the unit was returned to the contractor for repair/evaluation. However, qualified maintenance personnel estimated that in-shop repair of strobe lights would require 0.5 hours compared with 5.0 hours for the present rotating beacon."

Comments. The estimate of 0.5 hours in-shop repair of strobe lights is the subjective opinion of maintenance personnel without sufficient data. The repair time for a strobe system will depend on the maintenance concept chosen and cannot be based solely on the remove-and-replace repair used during the IG evaluation.

h. "Electromagnetic Interference (EMI): The strobe lights used in these tests did not meet certain specifications in MIL-I-6181D for transmitted radio frequency interference (RFI). However, no significant EMI during the test period was attributable to the strobe lights. Minor interference in the interphone system of the T-37 was resolved by the incorporation of filters. A reduction in transmitted RFI can be achieved, if necessary by using a special RFI coated lens. The reduction in transmitted RFI will result in a cost to effective candela of approximately ten percent."

Comments. It should be noted that EMI levels in military specifications have not been chosen arbitrarily. This test did not collect data relative to EMI and specific aircraft systems other than to ask the flight crews if they had noticed any. Unfortunately the squelch circuit on most aircraft radio equipment is such that strobe noise would be blanked. While the aircrew may not be aware of the EMI, it could nevertheless result in desensitization of the receiver front end and a reduction in performance unknown to the flight crew.

i. "Backscatter/Reflection: These phenomena are factors under conditions of haze, rain or clouds. Although crew members who experienced headaches or nausea were rare the psychological/physiological effects are less pronounced under conditions of red strobe lighting. Properly designed strobe lights, i.e., those lights which provide the option of selecting a reduced candela when using red strobe lights, will produce a psychological/physiological effect no more hazardous than the existing red rotating beacon."

Comments. This major problem area needs more study. It must be remembered that conditions of reduced visibility are precisely those where anticollision systems are needed. Reducing the intensity, installing colored filters, or masking of the fixture all reduce the adverse flight crew effects but reduce much more the effectiveness of the anticollision system.

j. "Flash Rates: Adverse psychological effects vary with flash rate and intensity, but are expected to be tolerable at rates which are effective in gaining the attention of aircrew members of another aircraft. Flash rates of 60 and 120 flashes per minute were evaluated. The faster rate was more effective in increasing aircraft conspicuity. Flicker vertigo can occur as rates exceed 180 flashes per minute; such rates must be avoided."

Comments. As pointed out by the writer, the only flash rates tested were 60 and 120 flashes per minute. The faster rate was identified as increasing aircraft conspicuity. This is again subjective opinion as no data was collected that could show an objective increase. An interesting question here would be "what are the units of conspicuity and how large of an increase was there?"

k. "Formation: High intensity white strobe lights are normally too distracting for day or night formation flying. Under day VMC it would be feasible for the wing man to continue to emit white strobe lighting; however, under conditions of reduced visibility (day or night) or night VMC the option of selecting the red strobe light would be mandatory."

Comments. The requirement for red lights at night only indicates a preference for reduced intensity. No white lights were tested at an intensity equal to the red lights.

l. "Refueling: The high intensity strobe light (red or white) markedly increased visual sighting of both strobe equipped receivers and strobe equipped tankers during the rendezvous phase. This condition was especially true at night or under reduced visibility conditions."

Comments. This finding is expected, since the red strobe is four to five times the intensity of the present KC-135 rotating beacon and the white light is at least 30 times as bright. Data from other testing would indicate that neither of these lights would provide a daytime increase in conspicuity.

3.4 ASD'S "QUICK LOOK FLIGHT TEST"

The T-43 Undergraduate Navigation Trainer is a modified Boeing

737 and as such was delivered to the Air Force with the wing tip-tail strobe system found in most commercial 737s. A "quick look" flight test was arranged with Air Training Command (ATC) and the Air Defense Command (ADC) to investigate if the strobe significantly increases the range at which the T-43 can be seen. ADC F-106s, under radar control, made training intercepts on the ATC T-43. During the intercepts, the F-106 pilots recorded the ranges at which strobe and T-43 were sighted using their forward looking radar. The overall objective of this quick look flight test was to determine whether a 4000 effective candela strobe is sufficient (as has been suggested by manufacturers and several of the Air Force commands) for daylight anticollision purposes. The "quick look" test also provided experience with strobe flight testing which would be invaluable should more testing become necessary.

3.4.1 TEST CONCLUSIONS

In all cases, the test aircraft was sighted before the strobe light. Aircraft sightings averaged 11.2 nautical miles for the 30 passes where data was recorded while sightings of the strobe light averaged 1.5 nautical miles. It should be noted that half of the aircraft sightings were made between 12 and 18 nautical miles. The F-106 pilots were required to have positive radar contact before proceeding with the intercept. The pilots stated that many times upon finishing the intercept set up, they would look outside the cockpit and immediately see the T-43. They estimated that, under the conditions present at the test site, the T-43 aircraft was visible at approximately 15 miles, but that they many times did not get to look for the target until they were well inside this range. No significant difference in detection range was noted between the two altitudes (3,000 ft and 15,000 ft).

3.4.2 DISCUSSION OF TESTING

a. Test Objectives:

"The "quick look" flight test was an attempt to gather subjective data concerning the effectiveness of aircraft high intensity strobe lights as a means of reducing the daytime midair collision potential. The test used an existing system (T-43) in the evaluation. The test program objectives were defined as follows:

(1) To determine the effectiveness of a 4,000 effective candela (E.Cd.) strobe light in the daylight air-to-air environment.

(2) To determine the visual acquisition range of the T-43 aircraft.

(3) To determine the visual acquisition range of the 4000 E.Cd. strobe light on the T-43 aircraft.

(4) To provide experience with strobe flight testing should more testing become necessary.

b. Program Authority:

The program was assigned to ASD/AEA by AFSC/SDA letter, dated 1 March 1976, subject, Aircraft Visibility. AFSC requested that ATC and ADC support the test program in AFSC/SDA letter, dated 3 March 1976, subject, Aircraft Visibility Testing.

c. Background Information:

The Avionics and Aircraft Accessories System Program Office (ASD/AEA) was tasked in November 1975 to develop a specification for aircraft strobe light systems to be installed on all Air Force aircraft. In attempting to determine the parameters of the specification, the true effectiveness of strobe lights to reduce the daytime midair potential became suspect. Most of the data that supported the installation of strobe lights was subjective. The little objective data that was available indicated that strobes would not be very effective during daylight hours.

The T-43 is the only Air Force production aircraft that has a 4000 candela strobe light (this intensity is near the present limit for off-the-shelf aircraft strobe systems). The flight evaluation of this system provided objective data concerning the visual acquisition ranges of the light and the aircraft. An evaluation of this data, coupled with other data, will enable an evaluation of the effectiveness of strobe lights under daylight conditions. Ultimately, the intensity parameters for the specification will be determined. This was not an elaborate test, but the information obtained is useful because it will give specific data on the 4000 candela/T-43 installation, and verification in the flight environment of the data obtained in the ground testing.

d. Test Conditions and Procedures:

(1) Test Conditions:

The test flights were conducted on 3 June 1976 between 0650 and 0910 PDT off the California coast in W-260. Weather conditions provided 20+ miles air-to-air visibility in the test area with partly cloudy skies below the low level test altitude.

(2) Procedures:

(a) The T-43 departed Mather AFB CA so as to arrive at 276/60 OAK at 0645 PDT, 3 June 1976. UHF contact was made with the Ground Control Intercept (GCI) site at Luke AFB AZ (Arizona Pete) on 260.8 MHz. Arizona Pete then assumed control of the T-43 and vectored the aircraft to the working airspace. The T-43 airspeed was set at a constant 210 KIAS throughout the testing portion of the mission. The T-43 was directed to 3,000 ft for the low level intercepts and to 15,000 ft for the high intercepts.

(b) Two flights of two F-106s departed Castle AFB CA, the first flight arriving at 276/60 OAK at 0700 hours PDT, 3 June 1976. The second flight of two F-106s was launched so as to arrive in the testing area shortly after the departure of the first flight. The first flight was able to complete eight good intercepts during the time on station and the second flight completed seven intercepts for a total of 30 passes. Arizona Pete attempted to vector the F-106s in to the T-43 along the lines indicated by the arrows in Figure 37. These lines at co-altitude provide the maximum output from the T-43 strobes.

e. Instrumentation and Data Acquisition:

The pilots of the F-106s recorded the intercepts on data cards and on radar scope film allowing a more accurate review of the data. The instrumentation then consisted of the pilot's handwritten notes and 16 mm radar scope film. Solar azimuth and elevation were provided by a navigator in the T-43. Briefly, the procedure followed by the F-106 pilots was to obtain a radar lock-on and visually scan the area for sight of either the T-43 or the strobe light. The nose/tail switch was activated when the T-43 was sighted visually, and the trigger switch was activated when the strobe light was sighted, placing markers on the radar scope film. The pilot also recorded this data on his data card, which was later verified upon review of the scope film. Intercepts were terminated when the strobe and aircraft had both been sighted.

f. Data Evaluation and Analysis:

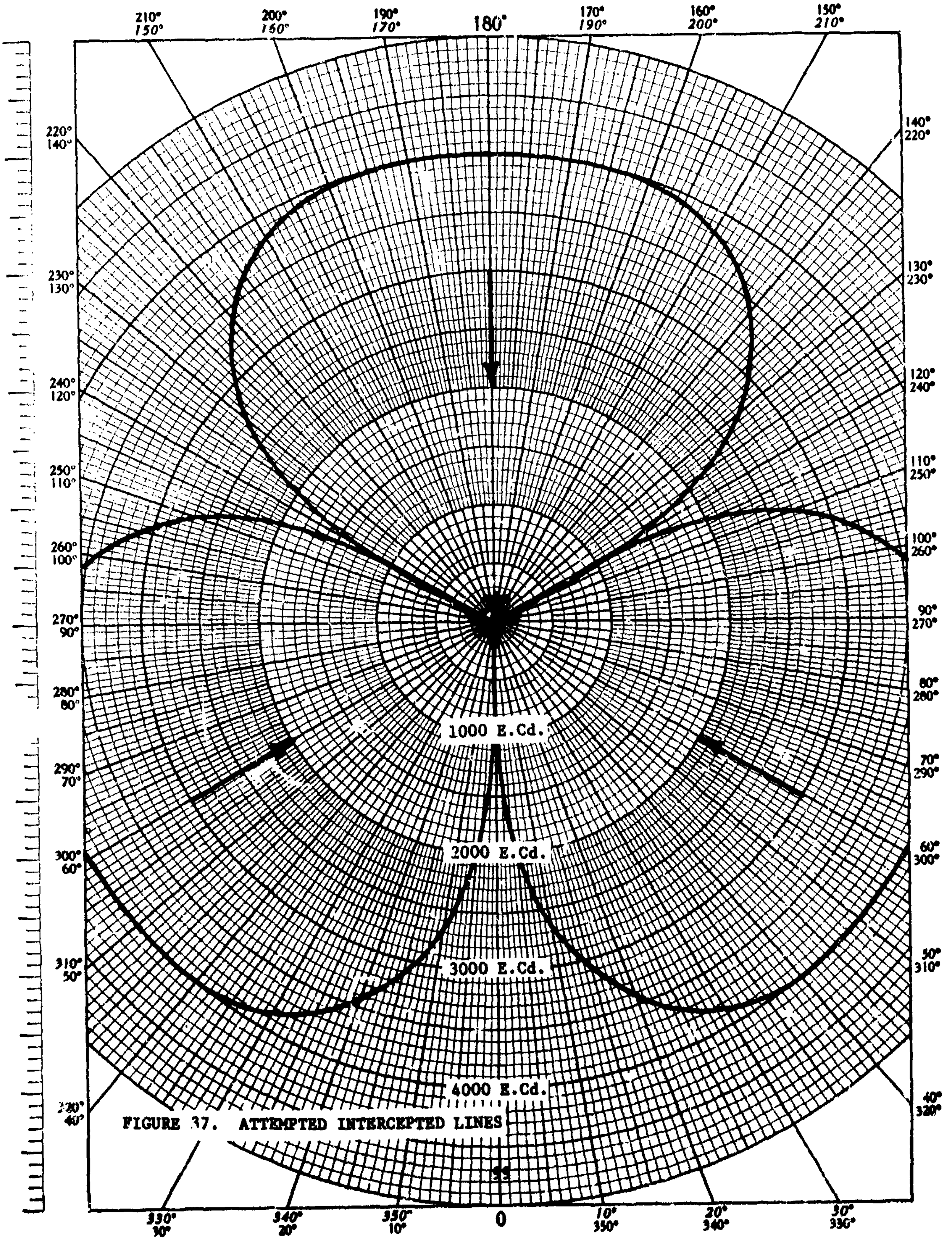


FIGURE 37. ATTEMPTED INTERCEPTED LINES

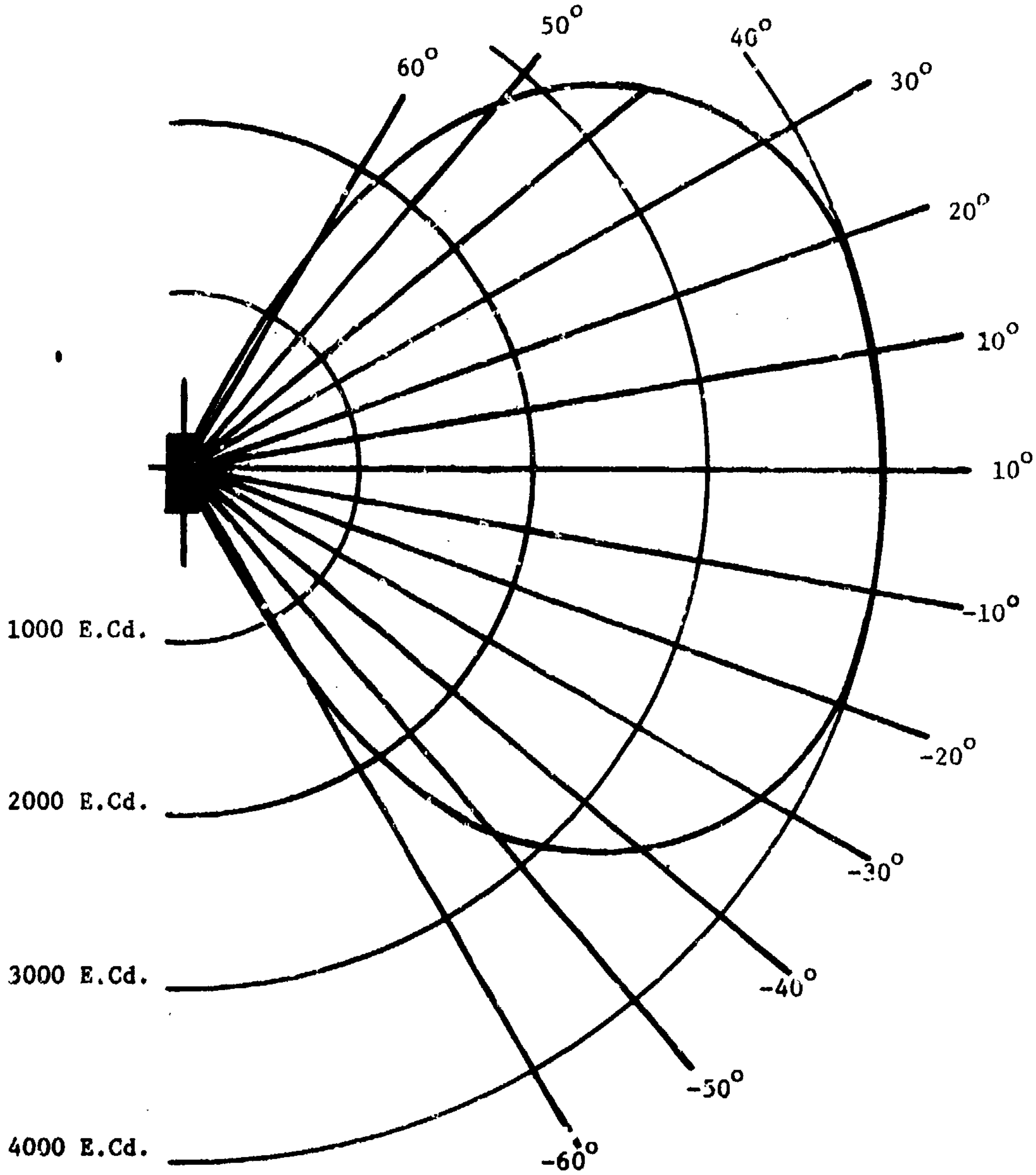
The data cards and solar data provided by the T-43 navigator were expanded into individual passes. Of 30 passes attempted along the radial lines marked with arrows in Figure 37, 12 were along the 60° radial (60° right of the nose), two along the 180° radial (tail approach), 12 were along the 300° radial (60° left of the nose), and four along the 0° radial (head-on). Tail approaches were minimized to conserve fuel.

The T-43 strobe lights were measured along the 0° axis of Figures 38 and 39 prior to the test flight using an EG&G Photometer/ Radiometer model 450 and the model 550-3 Pulse Integration Module (for the EG&G model 450). The strobe lights were measured as follows:

Right Wing Tip	-	862.2 E.Cd.
Left Wing Tip	-	1384.6 E.Cd.
Tail Light	-	1457.9 E.Cd.

While these values at first seem low when compared to the specification values (Figures 38 and 39), they appear more reasonable upon consideration of two important factors. First, the lights as measured on the aircraft were measured through their plexiglass covers while the distribution curves of Figures 38 and 39 are of the light assembly mounted in a laboratory test fixture. Secondly, the strobe lights on this aircraft are original equipment and have been in service 22 months. Measuring the strobes through the plexiglass will result in losses due to reflection, refraction and light scattering. Light scattering is amplified by surface abrasion and dirt on the outer surface of the plexiglass. These losses can easily approach 30%. Grimes Manufacturing Company has indicated that the lamps in the T-43 system (produced by Grimes) are, after 22 months, probably down to half the rated output. Looking at these loss estimations, it is expected that the lights should have a measured output of approximately 1400 E.Cd. As can be seen above, the left wing tip and tail light are very close to this value. The right wing tip is apparently failing because of other unknown additional factors (it is approximately 60% compared to the other two lights) and was observed to operate somewhat sporadically, missing one flash in every five or six.

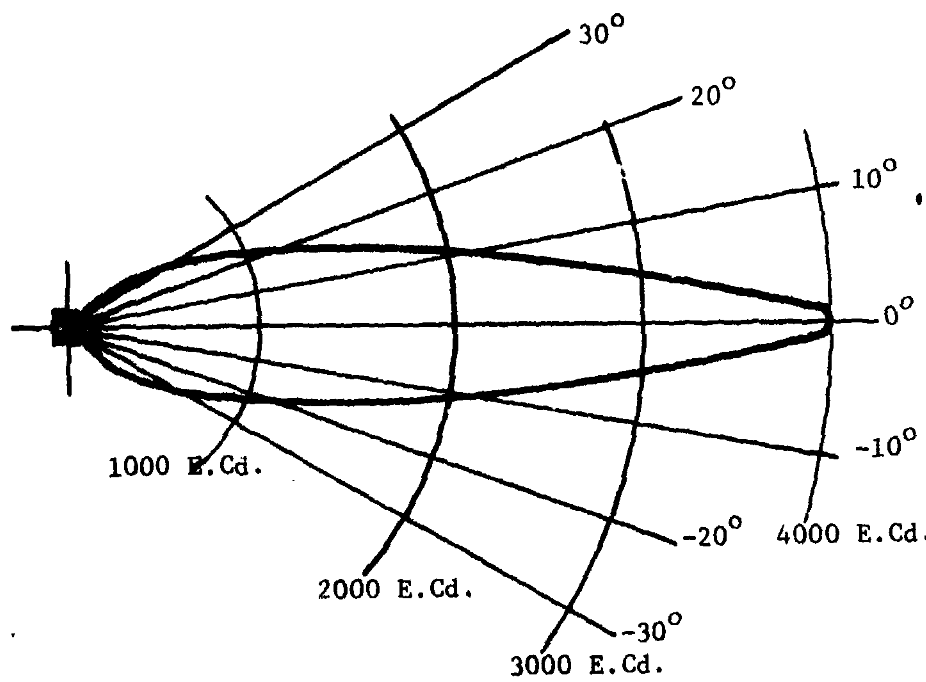
The data indicates an average sighting range of 11.2 miles for the aircraft and 1.5 miles for the strobe light. In all cases, the aircraft was sighted before the strobe. To see the strobe light at all, the interceptor pilot had to stare at the light source location. This indicates that the ranges for strobe light sighting are more indicative of threshold data than good collision avoidance ranges. It is doubtful that an observer unaware of the existance of the light would see it at even half the ranges sighted by the interceptor pilots in this test. What appears to be happening is the aircraft is



HORIZONTAL DISTRIBUTION OF T-43 STROBE LIGHT ASSEMBLY

Light Output: Horiz. Angle from Lamp Center	Average Effective Candle Power
± 0°	4000
± 10°	4000
± 20°	3900
± 30°	3800
± 40°	3300
± 50°	2400
± 60	1200

FIGURE 38.



VERTICAL DISTRIBUTION OF T-43 STROBE LIGHT ASSEMBLY

Light Output: Vert. Angle from Lamp Center	Average Effective Candle Power
± 0°	4000
± 10°	2000
± 20°	1000
± 30°	675

FIGURE 39

becoming the background against which the light is being observed. This means the contrast ratio between the light and the background is increasing significantly compared to a sky background making the light more visible. If this increase in contrast is required to make the light visible, then the light is not an effective collision avoidance device under these conditions as the aircraft must be seen first.

3.4.3 FOLLOW-UP TESTING

Due to the extremely poor performance of the T-43 strobe lights and the observation by test personnel that many of the strobes on other T-43s were operating sporadically, ASD personnel returned to Mather AFB on 1 September 1976 and measured eighteen (18) of the nineteen (19) strobe equipped T-43s. Figure 40 is a compilation of the measurements taken.

The first four aircraft of Figure 40 were the only aircraft measured with the plexiglass cover removed as well as covers in place. The covers are extremely hard to remove because of the large number of fasteners used. The tail light has no removeable cover.

Figure 41 is test data generated at Boeing showing life data for 1500 hours. The test sheet indicates that the tests were performed in June 1975. Note that the test sheet shows a degradation to .88 of the original output. This means that after 1500 hours of operation of the 4000 E.Cd. light should be 3520 E.Cd. Aircraft 73-1155 and 73-1156 are near the 1500 hour operating time if it is assumed that indicated hours and operational hours of the light are equal. The average intensity of the six lights on these two aircraft is 1455 E.Cd. This is 36% of the rated 4000 E.Cd. and 41% of the value of the test light after 1500 hours of operation, a long way from the 88% figure found by Boeing. It is interesting to note, however, that we have no way of determining if in fact the light tested by Boeing was initially 4000 E.Cd. Thus, the 1455 E.Cd. level may indeed be 88% of the initial intensity level of the lights on the two aircraft being discussed.

The data points out that maintenance of strobe systems is much more difficult than is many times supposed and also results in serious questions regarding MTBF estimates being published by contractors.

3.4.4 CONTRACTOR RESPONSE

The test data was provided to Grimes Manufacturing Co. who had originally provided the strobe light system to Boeing for the T-43

Aircraft No.	Service Date	Indicated Hrs	Right Wing Tip W/Cover (E.Cd.)	Right Wing Tip W/O Cover (E.Cd)	Right Wing Tip Percent Decrease	Left Wing Tip W/Cover (E.Cd.)	Left Wing Tip W/O Cover (E.Cd.)	Left Wing Tip Percent Decrease	Tail (E.Cd.)	Notes
71-1403	Aug 73	2427.6	1848.17	2305.75	20%	1338.29	1556.02	14%	—	a.
71-1404	Sep 73	2196.1	1339.02	2718.30	51%	1472.86	1911.90	23%	1311.19	b.
73-1150	Apr 74	1918.6	1517.60	1902.33	20%	2254.51	2558.19	12%	2841.80	
73-1151	May 74	1804.0	1634.31	2266.99	28%	1015.90	1470.39	31%	802.37	
71-1405	Oct 73	2078.6	1374.13	—	—	1573.39	—	—	2052.08	c.
71-1406	Nov 73	2260.4	2691.47	—	—	1951.49	—	—	2089.81	
72-0282	Dec 73	1893.8	1366.68	—	—	1285.99	—	—	290.59	
72-0283	Jan 74	1926.0	1575.17	—	—	2151.97	—	—	1817.99	d.
72-0284	Jan 74	2126.2	2988.78	—	—	1563.24	—	—	1078.80	
72-0285	Feb 74	1962.5	2950.92	—	—	3470.15	—	—	1280.05	e.
72-0286	Feb 74	1792.7	2369.14	—	—	1657.38	—	—	1409.86	f.
72-0287	Mar 74	1850.2	2376.36	—	—	3150.22	—	—	1841.73	g.
72-0288	Mar 74	1715.3	1583.57	—	—	1930.88	—	—	2093.73	h.
73-1149	Apr 74	1697.7	1000.27	—	—	1752.86	—	—	1590.12	i.
73-1152	May 74	1716.6	3528.73	—	—	1271.82	—	—	2902.06	
73-1153	Jun 74	1890.9	Hangared							
73-1154	Jun 74	1739.1	1695.12	—	—	1673.39	—	—	3490.2	j.
73-1155	Jul 74	1563.9	1199.24	—	—	1104.83	—	—	2327.53	
73-1156	Jul 74	1458.8	1563.35	—	—	1460.37	—	—	1078.00	

FIGURE 40a

NOTES:

a. The tail light on this aircraft has failed and is flashing so sporadically that it cannot be measured with any confidence.

b. The plexiglass covering on the right wingtip is extremely dirty on the inside. This was observed on several of the other lights that were not measured both with the plexiglass cover in place and removed. This problem is not easily solved as the removal of the plexiglass cover is so difficult (due to the large number of screws) that the maintenance people will not remove the cover just to clean the inside. Several were noted to have moisture condensation also.

c. The tail light on this aircraft was flashing at a visibly different intensity with each flash. The intensity measurement here should be suspect as it is the average of five consecutive flashes.

d. Same as c above.

e. The right wingtip light was flashing sporadically. The left wingtip light is flashing slower than the required 1 Hertz rate (approximately 1 every 2 seconds or 0.5 Hertz). This allows the capacitors to take on more change and produce more light. At 1 Hertz, the light would not be as bright.

f. The right wingtip light has failed, but is still flashing at a reduced rate. The rate is regular but slow (0.5 to 0.33 Hertz). The left wingtip is flashing sporadically.

g. The right wingtip light is varying in intensity with each flash. Measurement of this light should be suspect as the measurement is the average of five consecutive flashes. The tail light is flashing at a reduced rate (0.5 to 0.33 Hertz).

h. Right wingtip light sporadic.

i. Tail light flashing at reduced rate (0.5 to 0.33 Hertz).

j. Same as i above.

FIGURE 40b COMMENTS

FIGURE 41. BOEING DATA

PART NUMBER	30-0866-1	30-0910-1	30-0941-1	30-0934-1
SERIAL NUMBER	006	002	SAMPLE B	SAMPLE B
VENDOR	GRIMES	GRIMES	GRIMES	GRIMES
				(60-2461-1
COMPONENT TEMPERATURES				POWER SUPP.
FLASHTUBE HOUSING AMBIENT	192°F	115°F ▷1	303°F	
TRIGGER TRANSFORMER AMBIENT	188°F	196°F	204°F	
FLASH CAPACITOR CASE	151°F	155°F	180°F	151°F
ELECTRONIC CIRCUIT BOARD AMB	145°F	158°F	180°F	135°F
FLASH HEAD CASE (OUTSIDE)	185°F			
HOUSING CASE (OUTSIDE)	140°F	157°F		157°F
TEST AMBIENT (INSIDE BOX)	114°F	115°F	117°F	105°F
ROOM AMBIENT	75°F	75°F	75°F	75°F
FLASH RATE	60 FPM	59 FPM	59 FPM	64 FPM
LIGHT OUTPUT (RELATIVE)				
0 HOURS	1.00	1.00	1.00	1.00
250	.96	.93	.96	
500	.97	.97		
750	.94	.92	1.05 ▷2	.94
1000	.92	.93	1.01	.78
1250	.90	.92		
1500	.88	.95		
ELECTRICAL PARAMETERS				
INPUT VOLTAGE	115V, 417HZ	115V, 417HZ	115V, 417HZ	115V, 417HZ
INPUT CURRENT	1.42 AMPS	.96 AMPS	1.67 AMPS	.52 AMPS
FLASHTUBE VOLTAGE	375 VOLTS	580 VOLTS	530 VOLTS	470 VOLTS

▷1 A/P LENS NOT INSTALLED.

▷2 LENS COATED WITH WHITE POWDER

[illegible]
6-11-75

aircraft. They too indicated concern for the poor performance of the tested equipment.

Grimes requested that one of the aircraft systems be returned to them for test and analysis. Their evaluation found that the flash tube provided to them through a subcontractor was not meeting designed life characteristics. As a result of their analysis, Grimes has offered, at no cost to the Government, to replace all of the flash tubes in the T-43 fleet to correct the problem.

3.5 ASD'S TOWER TEST [30]

3.5.1 INTRODUCTION

The primary purpose of the experiment described in this section was to determine the intensity of a strobe anticollision light which would provide improved conspicuity of Air Force aircraft under daylight flight conditions. Although most pilot opinion favors the use of strobe lighting to enhance the "see and avoid" doctrine, analytical studies have shown that practical strobe lights would be of little or no value under most daylight flight conditions. Previous experiments with strobe lights are not generalizable to the flight regime of most Air Force aircraft. This study represents the most comprehensive field evaluation of strobe anticollision lights ever reported.

Secondary objectives included a determination of the intensity and color of strobes for reliable detection under dawn and dusk conditions, and an evaluation of the effect of visibility, range and location of the light signal source on the viewer's eye.

Although carried out in the field, rather than in a laboratory all aspects of the experiment were carefully controlled and the scientific method and contemporary data analysis techniques were used. The results of this study are sufficient to resolve differences of opinion regarding the capability of strobe anticollision lights to increase the daylight conspicuity of Air Force aircraft.

As many as twenty-six Air Force subject pilots were seated in a semicircle of 20 foot diameter, fixating on a light fixture at the center of the semicircle. Seven strobe lights of varying luminous output and color were mounted on a tower 210 feet above ground level and viewed at ranges of 2.88 and 4.68 statute miles from the observers. Subjects were asked to indicate when they observed the appearance of a strobe light source. The delay in each observer's response was measured. Visibility and background luminance were also measured. During twenty-two data collection periods, 20,555 threshold data points were obtained.

Reaction time, probability of detection and probability of false alarms were used as criteria to evaluate the effects of strobe color and intensity, location of strobe in visual field, visibility background luminance and range. A general linear multivariate model was employed for the statistical analysis of the data.

The following conclusions were drawn as a result of this experiment:

a. When viewed against background luminances which most frequently occur during daylight flight, a strobe of even 36,000 effective candela (E.Cd.) results in an unacceptably low probability of detection (0.15). It is beyond the state-of-the-art to design a strobe source of this luminance output for practical installation on aircraft. Strobes of 10,000 and 3500 E.Cd. resulted in probabilities of detection of 0.09 and 0.04 respectively under the same conditions.

b. As predicted by Allard's Law, background luminance is more significant than light signal source luminous output in determining detectability of sources. Therefore, under daylight conditions, large increases in luminous output result in relatively small increases in detectability.

c. Under dawn/dusk conditions, when a significant number of detections occurred, the probability of detection is higher within $\pm$ 30° of the center of the retina. The very short duration of the strobe source did not result in increased peripheral detection.

d. Due to the good weather which prevailed during data collection, most of the data was collected at meteorological visibilities of greater than five miles. No significant difference was observed with visibilities between five to ten miles and visibilities greater than ten miles.

e. Due to the rapid changes in background luminance which occur at dawn and dusk, insufficient data were collected to determine precisely the intensity of strobe anticollision lights for dawn/dusk operations.

f. Contrary to some published literature, red strobes were not superior to white of the same luminous intensity. In fact, white was slightly, but significantly, superior to red under the darker conditions, when a reasonable number of detections occurred.

3.5.2 FACTORS INVESTIGATED

There are many factors which influence the detectability of light signal sources. The following factors were studied in this evaluation.

a. Strobe luminous flux (intensity).

b. Strobe color (red vs white).

c. Atmospheric transmissivity (visibility).

d. Background luminance.

e. Retinal location of strobe signal.

3.5.3 LIMITATIONS OF TEST

While the tower test described herein was far less expensive than a flight test, it imposes certain limitations. The implications of these are discussed in the following paragraphs.

3.5.3.1 KNOWLEDGE OF LOCATION OF STROBE

Since the strobe was mounted on a fixed tower, all subjects knew the location of the source. In the real world, another aircraft could appear anywhere within the pilot's area of visual scan. The effect of this limitation would be to lower the threshold data, i.e., to indicate better performance of the light sources than could be expected in flight conditions.

3.5.3.2 NO MULTIPLE LIGHT SOURCES

Multiple light sources installed in a single aircraft could increase the probability of detection while single sources on several aircraft in proximity (in a pattern, for example) might increase the probability of confusion. This is an area which might require investigation, but it is beyond the scope of obtaining threshold data.

3.5.3.3 ATMOSPHERIC SCINTILLATION

Atmospheric scintillation at ground level is greater than at altitude. Due to the short duration of the strobe source, and the relatively narrow angular beam of the strobes used in the tower test, there was an increased probability of the light being refracted away from the subjects' eyes. However, the strobes were turned on for ten seconds per trial, with the subjects knowing where the source was located. It is most unlikely, therefore, that the increased scintillation at ground level had a significant impact on the results.

3.5.3.4 FLASH RATE

Only the currently mandated (by Federal Air Regulation) 60 flahses per minute, or 1 Hz, rate was used. There is evidence that higher flash rates (2 Hz or 4 Hz) yield significant improvements in probability of detection (reference 31, e.g.). Note, however, that there are tradeoffs involved in going to higher flash frequencies. Total luminous flux in a flash must be traded off for power, weight, life, etc., as frequencies are increased. Thus, in the real world, there may or may not be a practical advantage to utilizing higher frequencies than 1 Hz.

3.5.3.5 SUMMARY OF LIMITATIONS

Within these limits, however, the results are generalizable, and, it is believed that they represent the first comprehensive and objective evaluation of the effectiveness of strobe lighting for aircraft conspicuity enhancement during daylight conditions.

3.5.4 EXPERIMENTAL DESIGN

The most economical and efficient experimental design which can be applied to determine the relative attention getting capabilities of various strobe light configurations under a variety of conditions is a factorial design. In this design, the important influential variables are referred to as factors. Each factor, in turn, is divided into levels. For example, since visibility was a factor, it was divided into three levels, three to five miles, five to ten miles and greater than ten miles. If every level of every factor is tested, the design is called a complete factorial. In the case of the tower test, a complete factorial was not possible, but it is important to recognize that the data analysis technique allows for missing data, with little loss in sensitivity. The following paragraphs define the factors which were varied, and the levels at which each were tested in the tower test.

3.5.4.1 FACTORS

a. Light Sources.

Seven light sources were used as follows:

Approximate Effective Candela (E.Cd)	Color
1000	Red and White
2000	Red and White
3500	White
10,000	White
36,000	White

Only one repetition rate, namely 1 Hz, was used throughout. The total "on" time per cycle was approximately 0.0003 sec.

A wide range of luminous intensities was used in an effort to determine the minimum luminous intensity which would be effective for collision avoidance purposes.

b. Range.

The light sources were viewed from two sites. The range between the sources and the viewers were 2.88 and 4.68 miles. These viewing ranges were chosen because they are of interest for collision avoidance purposes to the Air Force problem.

c. Visibility.

Visibility from the viewing sites to the strobe tower was determined by measuring the atmospheric transmissivity, t. The transmissivity is defined by the ratio:

$$t = \frac{\text{Luminance of Tower at Site}}{\text{Luminance of Tower at Tower}}$$

where t is the transmissivity of the atmosphere. Readings from two calibrated photometers were used, to simultaneously measure the luminance of the side of the tower building from the viewing site and from a point adjacent to the tower.

Transmissivity was then coverted into the more commonly used visibility range in accordance with the following table.

Visibility (Miles)	t
3 to 5	.25 to .55
5 to 10	.55 to .74
> 10	> .74

Although it was hoped to collect approximately one-third of the data at each of the three levels of visibility, the weather during the week of data collection was unusually good and very little data was obtained under the three to five mile condition.

d. Background Luminance

Background luminance was measured by means of the site photometer during data collection. The following four levels were used:

Luminance (Ft.L.)	Descriptor
< 10	Twilight to Night Sky
10-100	Dark Day, Horizon Sky
100-1000	Dark Earth or Medium Horizon Sky
> 1000	Bright Sky or Snow on Sunny Day

e. Retinal Location

In flight, a pilot is required to search throughout his complete visual field for other aircraft. One of the potential advantages of the brief strobe flash is that it will increase the probability of detection of an intruder because it will be detected peripherally, i.e., "out of the corner of your eye." To determine the probability of detection over a full 180° horizontal field of view, subjects were seated in a semicircle, fixating on a nearby display. (See Section 3.5.6 below) Thirteen levels of retinal location, varying from 0° (foveal) to +90° in the periphery were tested.

Figure 42 is a schematic of the arrangement of the subjects.

3.5.5 TEST SITES

As stated above, observer sites with a .468 mile and 2.88 mile viewing range were used. The source tower had a south westerly bearing with respect to the observer site at 4.68 miles and a southerly bearing with respect to the site at 2.88 miles. The sites were selected so as to have an unobstructed view of a large portion of the tower on which the light signal sources were mounted (see Figure 44). Secondary considerations included the availability of power, telephone lines, subject conveniences, etc. Figure 43 is a map showing the location of the tower and the viewing sites.

The top of the tower building is 190 feet above ground level. The strobe lights were mounted on top of a 20 foot antenna tower, to put the strobes at 210 feet above ground level (see Figure 45). When viewing from both sites, the strobes were definitely viewed against the horizon sky background.

3.5.6 PHYSICAL ARRANGEMENT

Initially, twenty-six subjects were seated in a complete semicircle. After completion of at least one day at both the three and

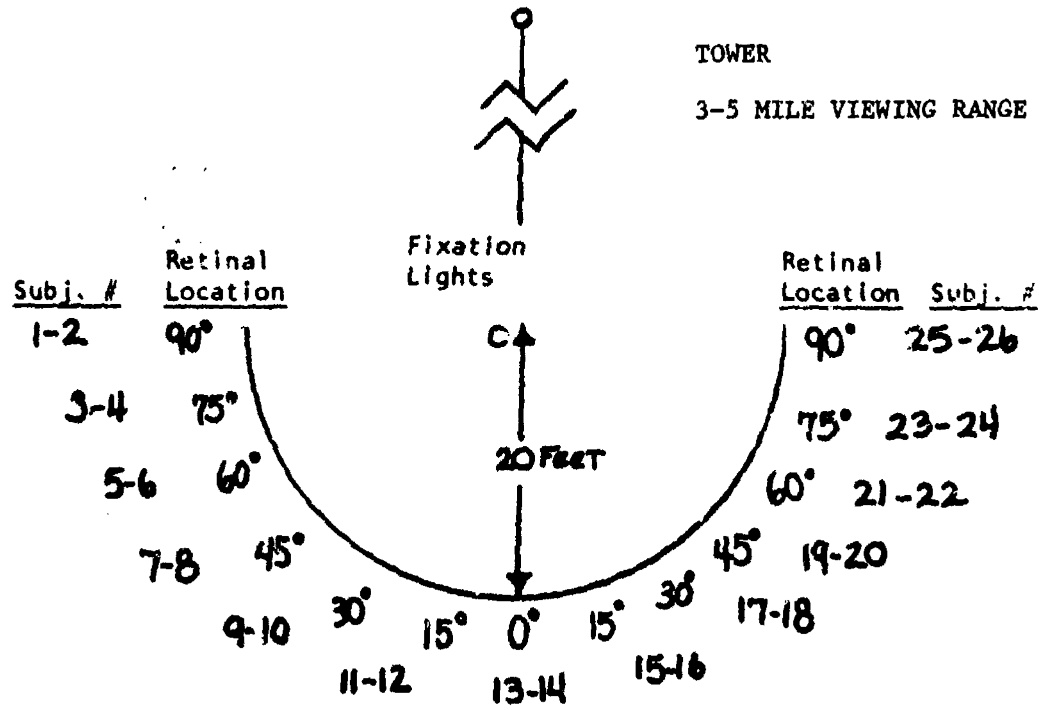


FIGURE 42. ARRANGEMENT OF SUBJECTS

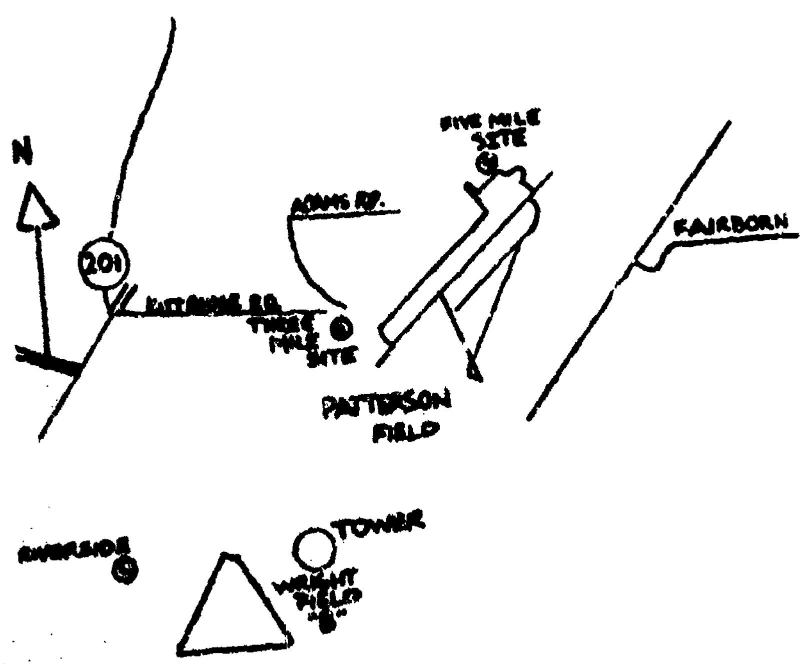


FIGURE 43. LOCATION OF TOWER AND SITES.

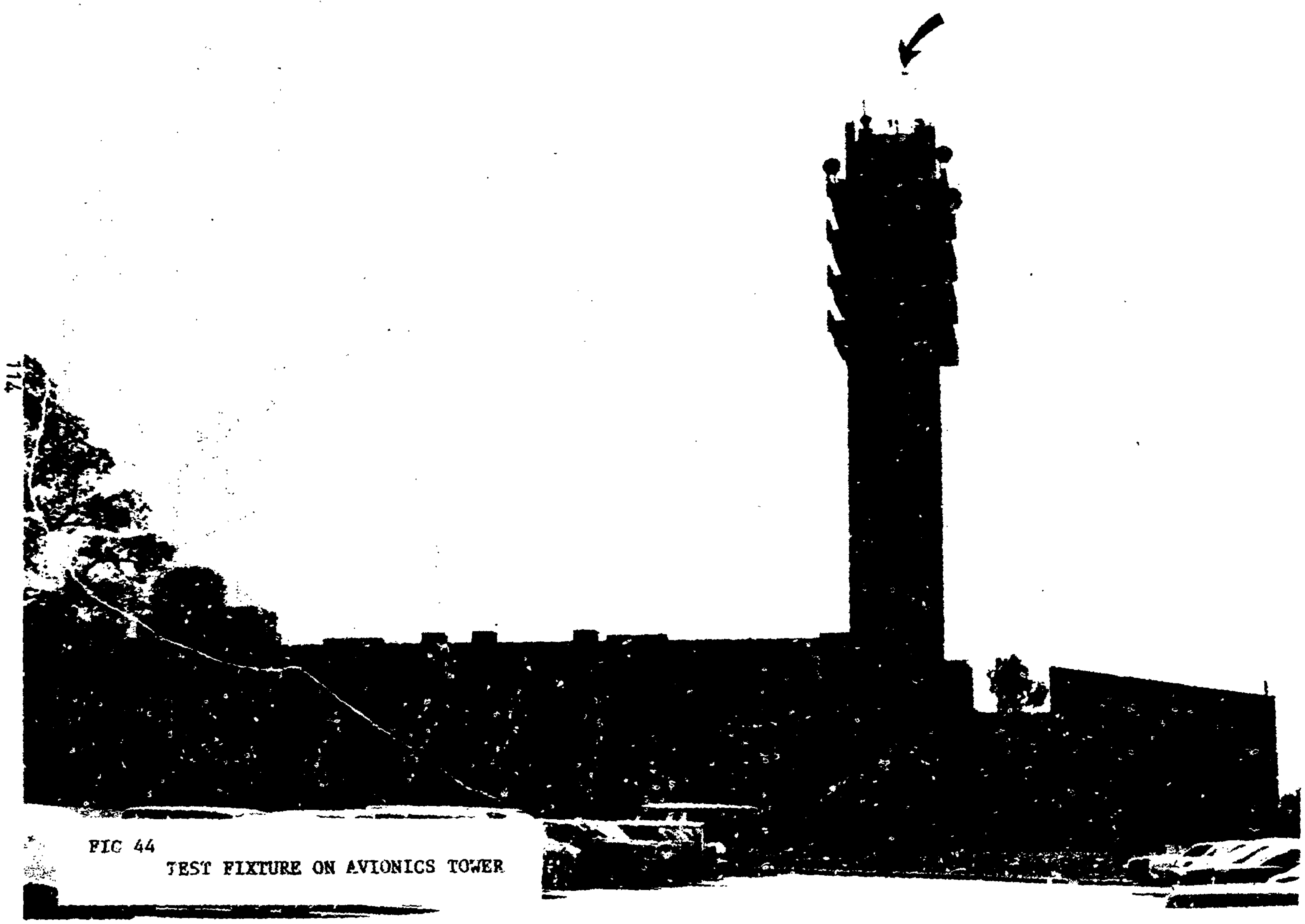


FIG 44
TEST FIXTURE ON AVIONICS TOWER

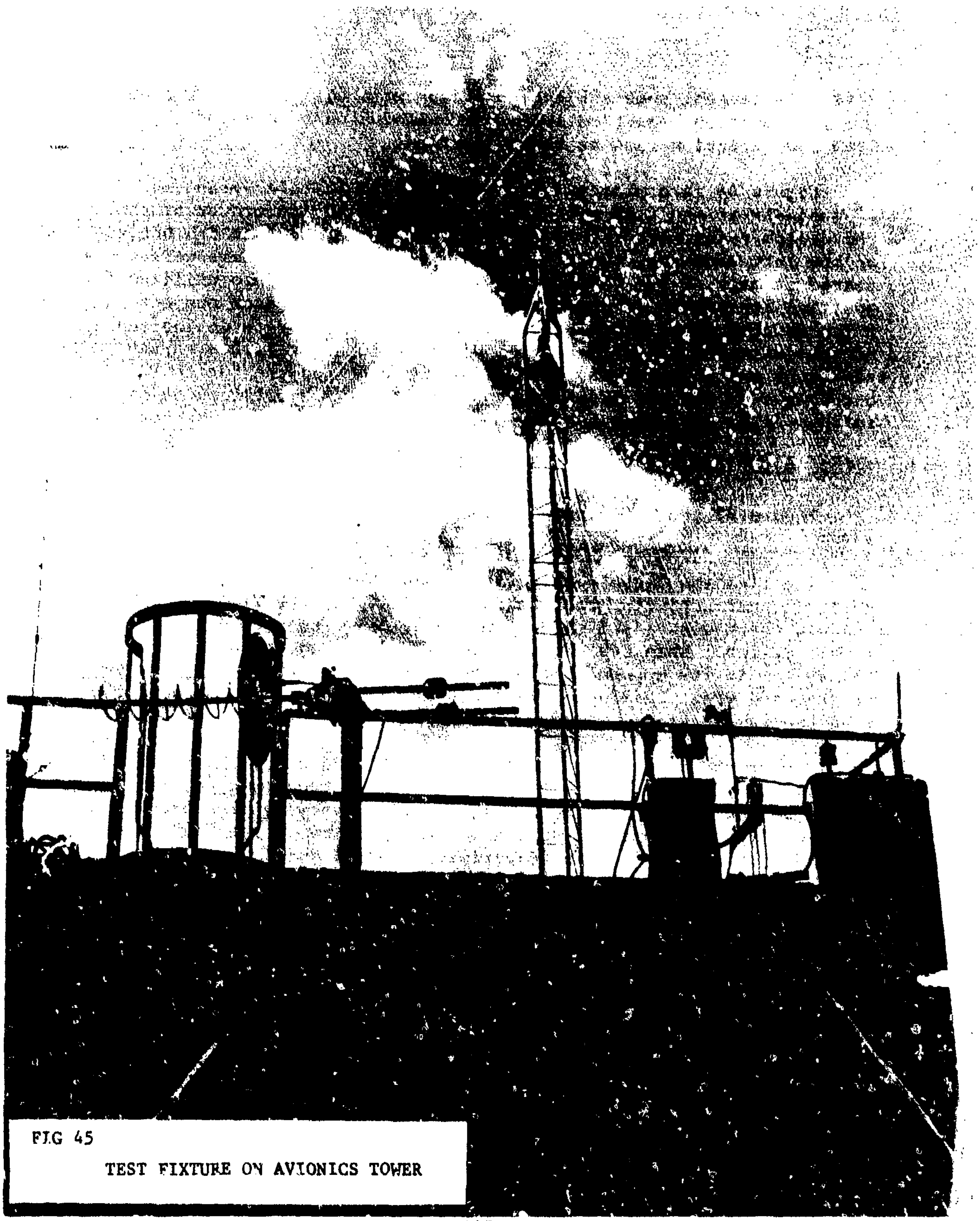


FIG 45

TEST FIXTURE ON AVIONICS TOWER

five mile ranges, some subject positions were eliminated. The 90° and 75° positions, particularly, were eliminated because of the very low detection rate at these locations.

Figure 46 is a photograph showing the semicircle arrangement of subjects at the 4.68 mile site. The arrow at the center of the photograph points out the fixation lights. The arrow at the horizon on the left shows the tower in the distance. Two subjects were seated at each of the thirteen positions. The procedure utilized for position assignment is described in Section 3.5.8. Each subject had a lap mounted panel containing two switches, one for detection and one to indicate the state of each of three fixation lights. Each subject's switch panel was covered with cloth, and the "detect" button was silent in operation, to prevent any subject from being influenced by any other subject's performance.

3.5.7 FIXATION LIGHTS

Figure 46 shows the three light fixation light configuration used.

The fixation light configuration was used to insure, insofar as possible that subjects were, in fact, looking at the fixation lights and not the tower. Each subject was provided with a three position toggle switch. When the top fixation light was on, he was to keep the switch in its uppermost position. Similarly, the switch was to be centered when the middle light was on, and in its bottom position when the lowest light was on.

One of the three fixation lights was turned on at the start of a trial. The state of each fixation light was then changed, in a pseudo random manner, during a trial at rates varying from once per second to once per two seconds. The position of the "on" light was under the control of the experiment control and data collection (ECDC) system. No data was recorded from the fixation light toggle switch, however, subject observers were not informed of this fact.

3.5.8 EXPERIMENTAL PROCEDURE

Data collection was divided into a series of 22 sessions completed in a five day period. Each session was divided into six "blocks." Each "block" consisted of eight thirty second trials during which one or none of the strobes was presented. Each of the seven strobes and a "blank" was presented once, in a pseudo random order, during each block.

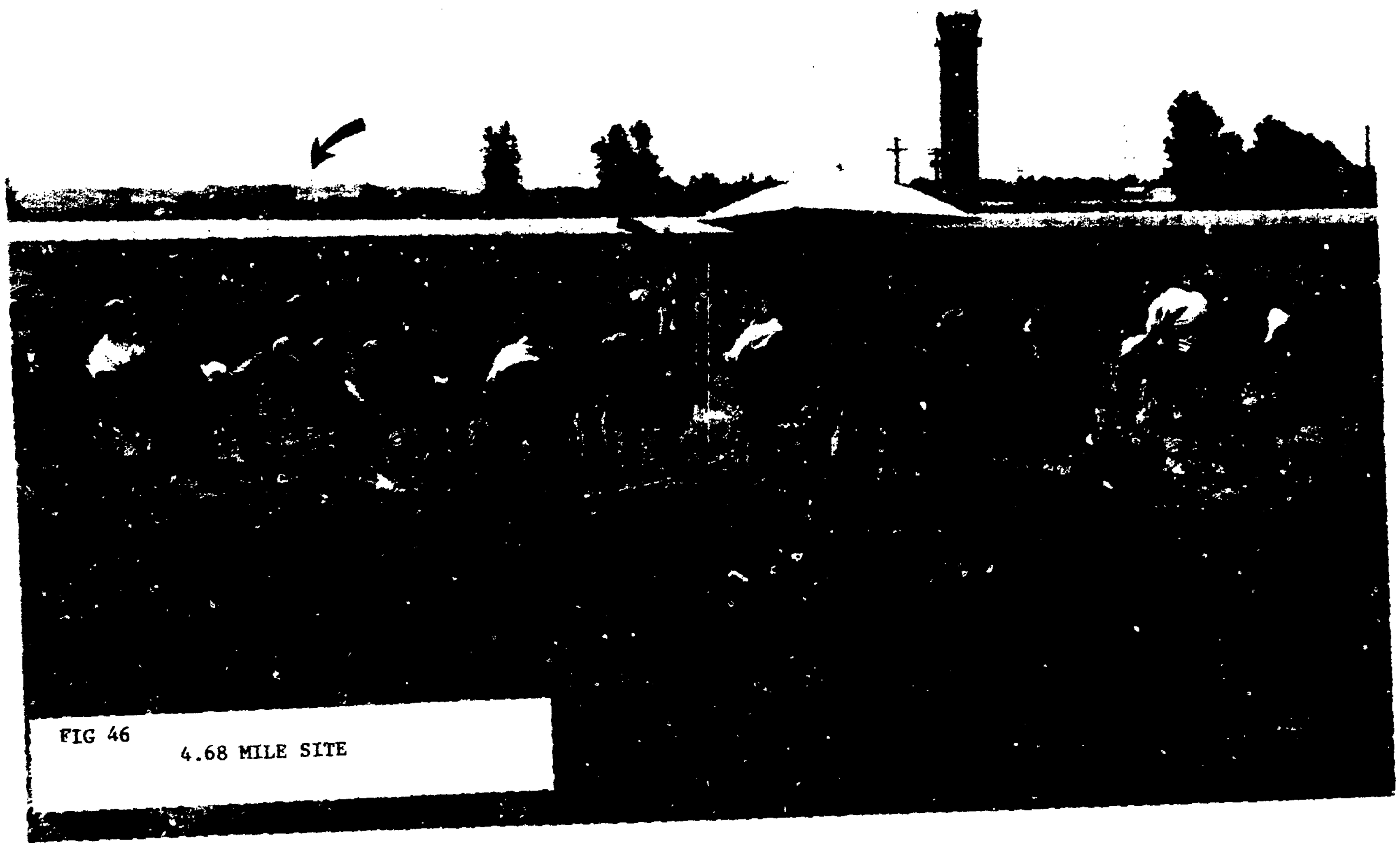


FIG 46 4.68 MILE SITE

Each session, therefore, contained a total of 48 trials, with each strobe and the blank being presented a total of six times each. The "blank" trials were included as an experimental control to permit the calculation of the frequency of "False Positives" for the data analysis.

Each experimental session lasted a total of 54 minutes. Each trial began with the activation of one of the fixation lights. The appropriate strobe was then turned on by the ECDC after random delays varying between two and nineteen seconds. The strobe remained on for ten seconds, or ten cycles at the 1 Hz rate used.

The time between trials was planned to be 15 seconds, but, after several sessions, it was the consensus of the subjects that a ten second inter trial interval was preferable, and it was used for all following sessions.

A two minute rest period was allowed after each eight trials (six minutes) of data collection. A ten minute break followed the third block of data collection as shown in Figure 47.

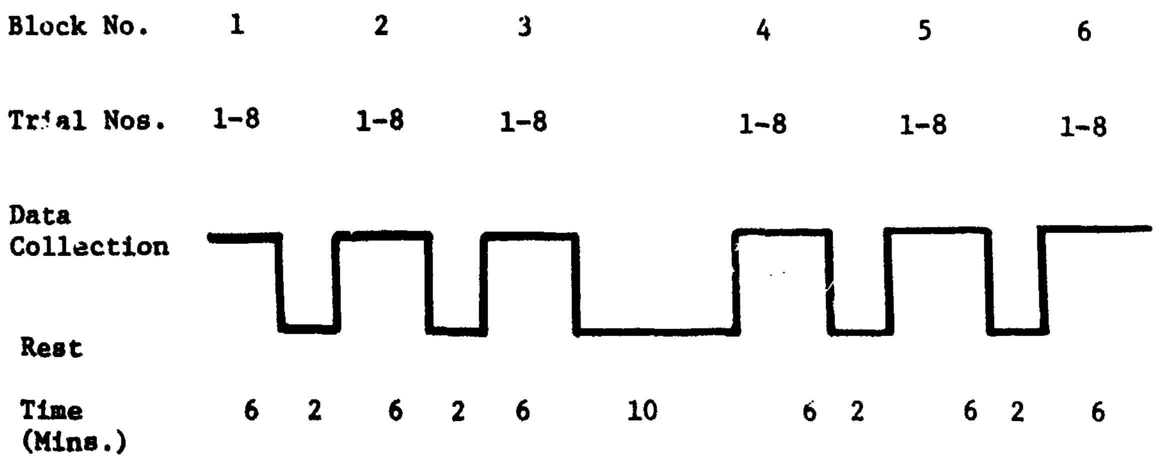


FIGURE 47. SCHEDULE FOR SINGLE SESSION.

Eleven of the sessions were "day" sessions, when the background luminance was above 1000 foot lamberts (ft.L.). Eleven of the sessions were "Dawn/Dusk" sessions when the background luminance was below 1000 ft.L. Actually, these sessions either began or ended under what would normally be called "Night" conditions.

3.5.9 RANDOM ASSIGNMENT OF SUBJECTS

To assure the random assignment of subjects to retinal locations, each of the subjects was issued a tablet having a letter, from A to Z. A was assigned seat 1, B seat 2, through Z seat 26. The subjects retained the letter until after switching seats at mid-session, when the letters were collected. This procedure was repeated for each session. At the end of the third block, the subjects changed locations.

3.5.10 SUBJECTS

All subjects used in the study were Air Force pilots ranging from 23 to 54 years of age, with a mean of 31.6 years. It was expected that the older pilots, who tend to have more administrative positions, would have fewer recent flight hours than the younger ones. This was, in fact, the case. The mean age of pilots with no flight hours in the six months prior to the test was 38.0 years.

Performance by all pilots over all retinal locations was so consistent, however, that it can be assumed that the relation between age and flight hours had no significant effect on the sample used.

Twenty-three of the subject pilots were on a temporary duty status at WPAFB for the purpose of taking part in this experiment. The following is a list of the commands and the number of pilots representing each.

Tactical Air Command	4
Strategic Air Command	3
Air Defense Command	2
Military Airlift Command	3
AF Logistics Command	2
Air Training Command	3
AF Systems Command	2
Air National Guard	2
Air Force Reserve	2

Due to the fact that data were collected over as much as eighteen hours per day, additional subjects were required. Approximately 80 pilots from Aeronautical Systems Division at Wright-Patterson AFB also served as subjects.

3.5.11 DATA CONDITIONING

As indicated in Figure 48, the data output is in the form of a six column digital printed tape. The first two digits at the bottom left of each group of data is the trail number. At the right of the trial number is the delay time (TIM) and the strobe (STB) displayed on that trial.

For trial 4, for example, the subject's data should be interpreted as follows:

> Subject Positions 1 and 2 were unoccupied.
> Subjects 3 through 9 did not respond.
> Subject 10 responded 2 seconds after the strobe came on.
> Subjects 12 and 13 responded prematurely.
> The visibility was 2 (5-10 miles) and the background luminance was 3 (100-1000 ft.L.)

The data were analyzed as indicated in paragraph 3.5.12 using the BMD 11V Multivariate General Linear Regression Model on the Aeronautical Systems Division CDC 6600. The BMD 11V Program was chosen because it performs a Multiple Analysis of Variance with unequal cell sizes. Since it was planned to reduce the number of subjects during the experiment, and since an equal distribution of visibility and background luminance could not be obtained, unequal cell sizes were inevitable. However, in order to condition the data for acceptance by the BMD 11V, a computer program was prepared. The procedure for data conditioning was as follows:

The printed tape was transcribed manually to coding forms. Since the data for 13 subjects were punched per card, two cards were required per trial, and a total of 96 cards per session.

A FORTRAN program was prepared to perform the following functions:

(1) Calculate Reaction Time for Correct Detections. This is

$$T_{Subj} - T_{Strobe}$$

1a. For all $T_{Subj} \geq 30$, enter 10.0 as T_{Subj}

(Where the reaction time is greater than 11.0 seconds, i.e., the subject responded after the strobe was turned off, the response is treated as a false alarm.)

28	3	8	3	28	3	28	3
27	2	7	2	27	2	27	2
26	80.0	26	80.0	26	80.0	26	80.0
25	00.0	25	00.0	25	00.0	25	00.0
24	00.0	24	00.0	24	00.0	24	00.0
23	00.0	23	00.0	23	00.0	23	00.0
22	00.0	22	00.0	22	00.0	22	00.0
21	00.0	21	00.0	21	00.0	21	00.0
20	00.0	20	00.0	20	00.0	20	00.0
19	04.1	19	00.0	19	00.0	19	00.0
18	04.2	18	00.0	18	00.0	18	00.0
17	04.1	17	17.6	17	00.0	17	00.0
16	05.5	16	00.0	16	00.0	16	00.0
15	05.4	15	00.0	15	00.0	15	00.0
14	05.5	14	20.6	14	20.3	14	00.0
13	05.5	13	07.9	13	20.0	13	16.1
12	05.4	12	07.7	12	19.1	12	17.0
11	00.0	11	20.0	11	13.2	11	23.4
10	13.3	10	16.4	10	19.0	10	21.9
09	00.0	09	00.0	09	00.0	09	00.0
08	07.6	08	00.0	08	00.0	08	00.0
07	07.4	07	00.0	07	00.0	07	00.0
06	00.0	06	00.0	06	00.0	06	00.0
05	00.0	05	00.0	05	00.0	05	00.0
04	00.0	04	00.0	04	00.0	04	00.0
03	00.0	03	00.0	03	00.0	03	00.0
02	80.0	02	80.0	02	80.0	02	80.0
01	60.0	01	80.0	01	80.0	01	80.0
02	043	06	166	06	198	08	16[illegible]

SUBJECT NO.   TRIAL NO.   DELAY   STROBE #

28	3	28	3	28	3	28	3
27	2	27	2	27	2	27	2
26	80.0	26	80.0	26	90.0	26	80.0
25	00.0	25	00.0	25	00.0	25	00.0
24	00.0	24	00.0	24	00.0	24	00.0
23	00.0	23	00.0	23	00.0	23	00.0
22	00.0	22	00.0	22	00.0	22	00.0
21	00.0	21	00.0	21	00.0	21	00.0
20	00.0	20	00.0	20	00.0	20	00.0
19	00.0	19	00.0	19	00.0	19	00.0
18	00.0	18	00.0	18	23.3	18	00.0
17	00.0	17	00.0	17	00.0	17	00.0
16	00.0	16	00.0	16	19.5	16	00.0
15	00.0	15	00.0	15	15.8	15	00.0
14	00.0	14	00.0	14	15.2	14	22.5
13	00.0	13	29.6	13	14.7	13	22.4
12	00.0	12	00.0	12	14.7	12	22.4
11	00.0	11	00.0	11	14.7	11	21.6
10	00.0	10	00.0	10	15.6	10	21.3
09	00.0	09	00.0	09	00.0	09	00.0
08	00.0	08	00.0	08	17.0	08	00.0
07	04.4	07	00.0	07	17.0	07	00.0
06	00.0	06	00.0	06	00.0	06	00.0
05	04.7	05	00.0	05	00.0	05	00.0
04	04.3	04	00.0	04	00.0	04	00.0
03	00.0	03	04.0	03	00.0	03	00.0
02	80.0	02	80.0	02	80.0	02	80.0
01	80.0	01	80.0	01	80.0	01	80.0
01	020	03	192	05	137	07	205

Figure 48

1b. Eliminate all T_{Subj} > 30 from further analysis

(2) Count the number of $T_{Subj} \geq 30$ Strobes 1-7 by Strobe Number (missed detections).

(3) Count the number of $T_{Subj} < 30$ for Strobe 8 - no strobe (false alarms).

(4) Count the number of $T_{Strobe} - T_{Subj} \geq 1.0$ second for Strobes 1-7 by strobe (early alarms).

(5) The sum of 3 and 4, by strobe (total false alarms).

3.5.11.1 DATA ANALYSIS PROCEDURE

All of the above data were segregated by all of the main effects (factors), and formatted for input to the BMD 11V Multivariate General Linear Hypothesis Model Program.

The BMD 11V Multivariate General Linear Hypothesis Model Program was used to analyze the data. Several analyses were performed, all resulting in regression coefficients and the analyses of variance and covariance. F statistics were separately tested by means of the Scheffe test. The following paragraphs describe these analyses.

a. Reaction Time

Two separate analyses were conducted for reaction time. The reason for this is that, because there were non-detections, reaction time and detection measures were not independent.

The first analysis assigned a value of ten seconds to all non-detections, thus truncating the reaction time distribution, but including all trials. The General Linear Model makes no assumptions regarding the distribution of the data.

The second reaction time analysis was performed, eliminating all non-detections. This analysis, although it utilized only a portion of the data was sensitive to differences between signal sources which were detected.

The first analysis will therefore include reaction times on all data points, whether detects or non-detects. The second analysis will not have reaction times entered for non-detects, and will, therefore, not include all data points for the dependent variable, reaction time.

b. Detections

The number of detections for the trials during which a strobe was present were analyzed. This provided the measure of "hits" or correct detections.

c. False Positives

The number of reported detections for the trials during which no strobe was turned on was subjected to a separate analysis. Similarly, the number of times a detection was recorded prior to the start of the strobe presentation, by more than one second, was analyzed. Finally, the sum of these two types of false positives was analyzed. This is the total false alarms.

d. False Positives

The false positives were used to correct for variations in the criteria employed by the subjects. This correction was applied in the classical psychophysical manner:

$$P_C = \frac{P_o - P_f}{1 - P_f}$$

where P_C is the Corrected Probability of Detection.

P_o is the Empirically Obtained Probability of Detection (subject to the limitations that $P_o = 1$ is set equal to 0.9999 and $P_o = 0.00$ is set equal to 0.0001) P_f is the (obtained) probability of a false alarm.

3.5.12 THE ANALYSIS OF DATA

3.5.12.1 THE MODEL

The model used to statistically test the results of the test is a Multivariate General Linear Hypothesis. Denoting the Main Effects (or factors) as:

L = Lights

V = Visibility

B = Background Luminance

R = Range

E = (Eye) Retinal Location

The model is then:

$$y = u + L_i + V_j + B_k + R_m + E_n + LV_{ij} + LB_{ik} + LR_{im} + LE_{in} + E_{ijkmn}$$

where E_{ijkmn} is the residual error after fitting all the main and interaction effects, and u is the estimate of the population mean.

The L_i through LE_{in} are partial regression coefficients which are used to develop parameters for a Multiple Analysis of Variance. Three Dependent Variables, namely:

RT = Reaction Time

P_c = Corrected Probability of Detection

P_f = Probability of a False Alarm

were used.

The raw data from the printer were key punched to be conditioned for further analysis. The BMD 11V Multivariate General Linear Hypothesis was used to test the fit of the data to the model, by generating approximate F statistics for the Analysis of Variance.

Since this model is susceptible to differing results, depending on the order in which the variance due to Main Effects is partitioned from the model, five separate analyses were performed in the following orders:

LVBRE

RLVBE

VLRBE

BLRVE

ELBRV

3.5.12.2 RESULTS - PRIMARY ANALYSES

The data conditioning program sorted the data in two passes. On pass one, all non detections were assigned a Reaction Time (R.T.) of ten seconds. On pass two, the non detects were eliminated from the Reaction Time Analysis. Separate Analysis of Variance were performed for each pass. Although all three dependent variables (R.T., P_F and P_C) are entered into both analyses, R.T. contributes more to fitting the model on pass one, while P_F and P_C contribute more on pass two. This is due to the fact that, while all data points are present for the dependent variable, R.T. on pass one, only the detect R.T.s are present on pass two.

As stated above, half of the data collection sessions were under daylight conditions and half under dawn/dusk conditions. The data were, therefore, analyzed in the following ways:

a. All Data - Pass one and two

b. Daylight Data - Pass one and two

c. Dawn/Dusk Data - Pass one and two

Also as stated above, the F statistics which result from the analyses differ as a function of the order in which the variances due to main effects are partitioned. For this reason the above analyses were repeated five times each. It was found that, although there were some relatively small differences (the magnitude of the shift of V was, occasionally, fairly large, due to the small number of trials at three to five miles visibility) due to order, the significance of the F statistics was not affected, hence the LVBRE order will be used throughout this report. Because all Daylight Sessions were at backgrounds above 1000 ft.L., B is not a main effect for daylight sessions, and the order for daylight is LVRE. To be conservative, the a priori level chosen was 0.01. No significant interaction effects were observed, hence, all of the following results are based on pooling all interactions with the error term.

<u>ALL SESSIONS</u>

Table 14 shows the obtained F statistics and degrees of freedom for the main effects for all sessions combined.

TABLE 14. MAIN EFFECTS F STATISTICS - ALL SESSIONS

	Pass 1	Pass 2	df	Required F Statistics for Significance
L	121.06	462.58	3,7	8.45
V	40.62	15.37	3,2	30.81
B	975.58	488.92	3,3	29.46
R	33.26	58.59	3,1	34.12
E	60.32	26.29	3,12	5.95

Obviously, all main effects are significant except for V on pass two. Recall that pass one weights R.T. more heavily, while pass two weights probability of detection (P_C) more heavily. Although the absolute value of the F statistics cannot be numerically compared to determine the magnitude of the contribution of the various effects, a "feeling" for the importance of the effects can be obtained. In Table 14, above, it is obvious that background luminance and strobe lights were more significant than all other effects.

For the purpose of determining which level(s) of an effect differed from the others, the Scheffe post hoc analysis for multiple contrasts was used with an α level of 0.10 as recommended by Scheffe. Table 15 shows the result for the strobes in this study.

TABLE 15. RESULTS OF SCHEFFE TEST FOR LIGHTS ALL SESSIONS

Pass 1 - R.T.		Pass 2 - P_C	
1000 Red	8.9346	1000 Red	.1678
2000 Red	8.7535	1000 White	.1917
1000 White	8.6088	2000 Red	.1759
2000 White	8.2759	2000 White	.2256
3500 White	8.0298	3500 White	.2789
10,000 White	7.6705	10,000 White	.3345
36,000 White	7.1487	36,000 White	.4016

In Table 15 and following tables, a continuous line connecting levels of the effect indicates that they do not significantly differ from each other. For probability of detection, the order of strobes is in increasing luminous intensity from 1000 Red through 36,000 White. The 36,000, 10,000 and 3,500 E.Cd. strobes result in significantly different probability of detection from each other in the expected order. The 2000 Red and White and the 1000 White do not differ and the 2000 Red and 1000 Red and White do not differ. However, the 2000 White does yield significantly higher probability of detection than the 1000 Red.

The results for all sessions are based on all data points, and are therefore of great interest. It should be repeated, however, that these data are biased in the direction of most of the data being taken at above 1000 ft.L. background luminance and below 10 ft.L. These results, therefore, represent an average of extremes of background luminance.

Again, in Table 15, the reaction time data are similar to the P_C results. The 36,000 and 10,000 differ from each other and all sources. In the case of R.T. 3,500 and 2000 E.Cd. do not differ, nor do 2000 and 1000 White. Note, however, a difference in the order of R.T.s. The 2000 White is significantly better than 2000 Red and 1000 White and Red. These differences are probably of little practical significance, but when coupled with recent laboratory results (9) should probably discredit the belief that Red is superior to White as an anticollision light color for conspicuity enhancement. Backscatter and city background lighting remain as possible arguments for red anticollision lights, but it is clear that red is not superior for conspicuity enhancement.

With respect to performance at the levels of background luminance used in the experiment, Table 16 shows the Corrected Probability of Detection for each strobe signal source under the levels of background luminance.

TABLE 16. PROBABILITY OF DETECTION AGAINST VARIOUS BACKGROUNDS

P_C

Strobe			BACKGROUND LUMINANCE (FT.L.) >1000	100-1000	10-100	<10
1000	-	Red	.004	.13	.26	.46
1000	-	White	.01	.06	.21	.60
2000	-	Red	.02	.17	.23	.56
2000	-	White	.01	.19	.21	.72
3500	-	White	.04	.15	.33	.79
10,000	-	White	.09	.25	.50	.78
36,000	-	Red	.15	.40	.52	.86

Figure 49 is a plot of the data of Table 16.

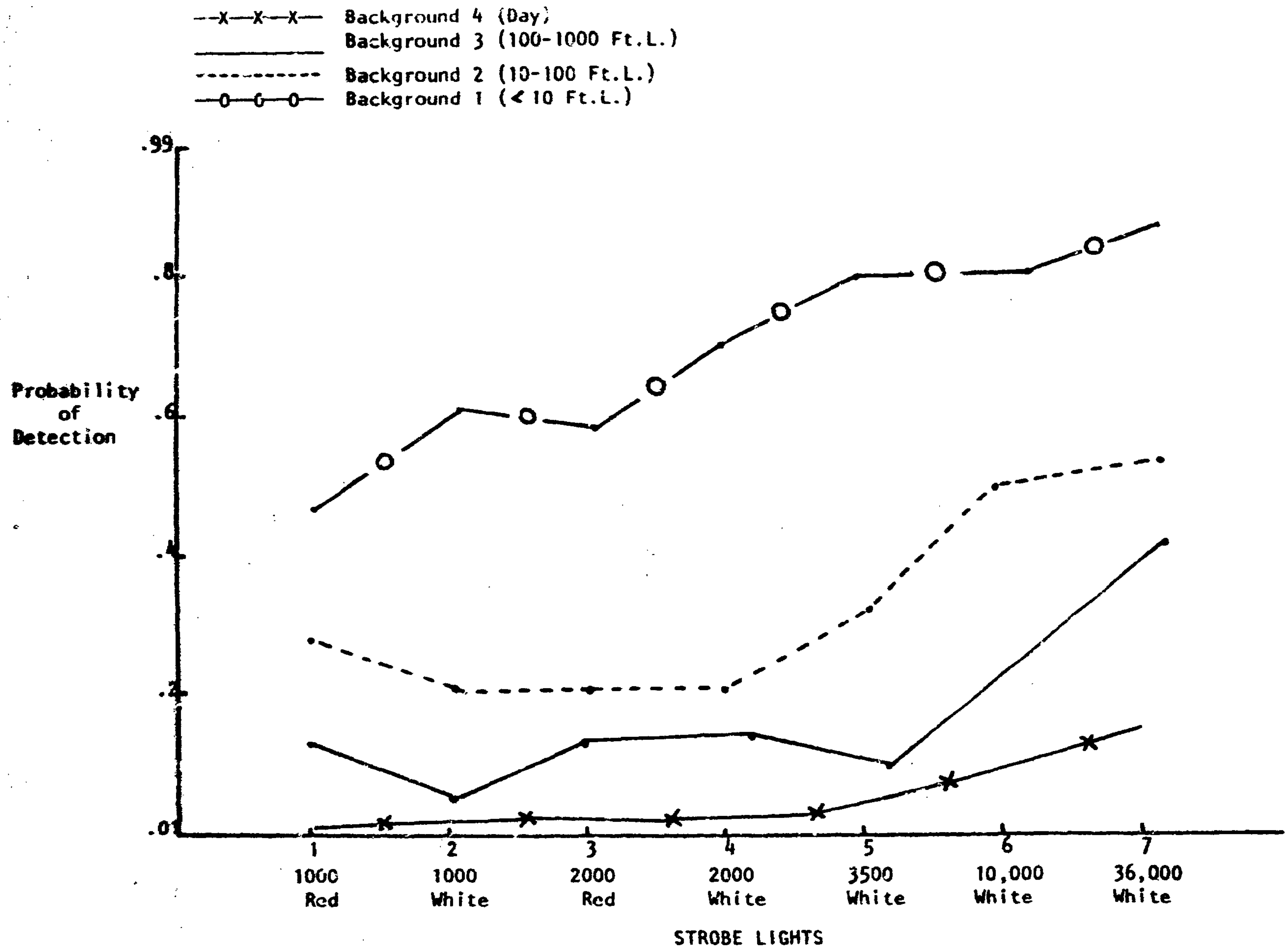
As mentioned above, more data was obtained under the >1000 and <10 Ft.L. conditions, due to the short elapsed time at the middle levels. In addition, the levels chosen proved to be too coarse to specify the optimum intensity for dawn/dusk operation.

It is clear, however, that given a background luminance, large increases in strobe luminous output are required for rather modest gains in probability of detection. This result is to be expected, since, according to Allard's Law, the light reaching the observer's eye from a light source is reduced by the square of the distance and atmospheric transmissivity to the power of the distance, while the background luminance is fixed.

Table 17 shows the result of the Scheffe analysis for background luminances.

TABLE 17. RESULTS OF SCHEFFE TEST FOR BACKGROUND - ALL SESSIONS

(Ft.L.)	Pass 1 R.T. (Secs.)	Pass 2 P_C
>1000	9.76	.05
100-1000	8.94	.19
10-100	7.57	.32
<10	4.68	.68



Background 4 (Day)
Background 3 (100-1000 Ft.L.)
Background 2 (10-100 Ft.L.)
Background 1 (< 10 Ft.L.)
Probability of Detection
.99
.8
.6
.4
.2
.01
1 1000 Red
2 1000 White
3 2000 Red
4 2000 White
5 3500 White
6 10,000 White
7 36,000 White
STROBE LIGHTS

Figure 49

As stated above, if more highly refined levels had been used for the lower levels, it might have been possible to distinguish what strobe luminance is required for dawn/dusk operation. On the basis of the above results, it is possible to conclude only that performance with the strobes used was superior at background luminances below 10 Ft.L.

It has been speculated by many that, because the duration of the strobe flash is short relative to, say, a rotating beacon, that the probability of detection of the brief flash might be higher in the periphery than a comparable rotating beacon.

Table 18 shows the Scheffe test for R.T. and P_C for the thirteen retinal locations tested for all strobes, backgrounds, visibilities and ranges.

TABLE 18. RESULTS OF SCHEFFE TEST FOR RETINAL LOCATION

	Pass 1 R.T. (secs)	Pass 2 P_C
90°	9.75	.02
75°	9.52	.04
60°	8.91	.15
45°	8.50	.22
30°	8.11	.28
15°	7.43	.38
0° (Foveal)	6.45	.50
15°	7.47	.38
30°	7.83	.28
45°	8.67	.24
60°	8.84	.20
75°	8.73	.16
90°	9.30	.06

Since this was not a free search situation, as the subjects were viewing the fixation lights, the result of significantly better foveal performance was to be expected. However, the distribution across the retina appears to be about the same as for lights of longer duration [31]. Figure 50 is a plot of average probability of detection around the semicircle of subjects' seats.

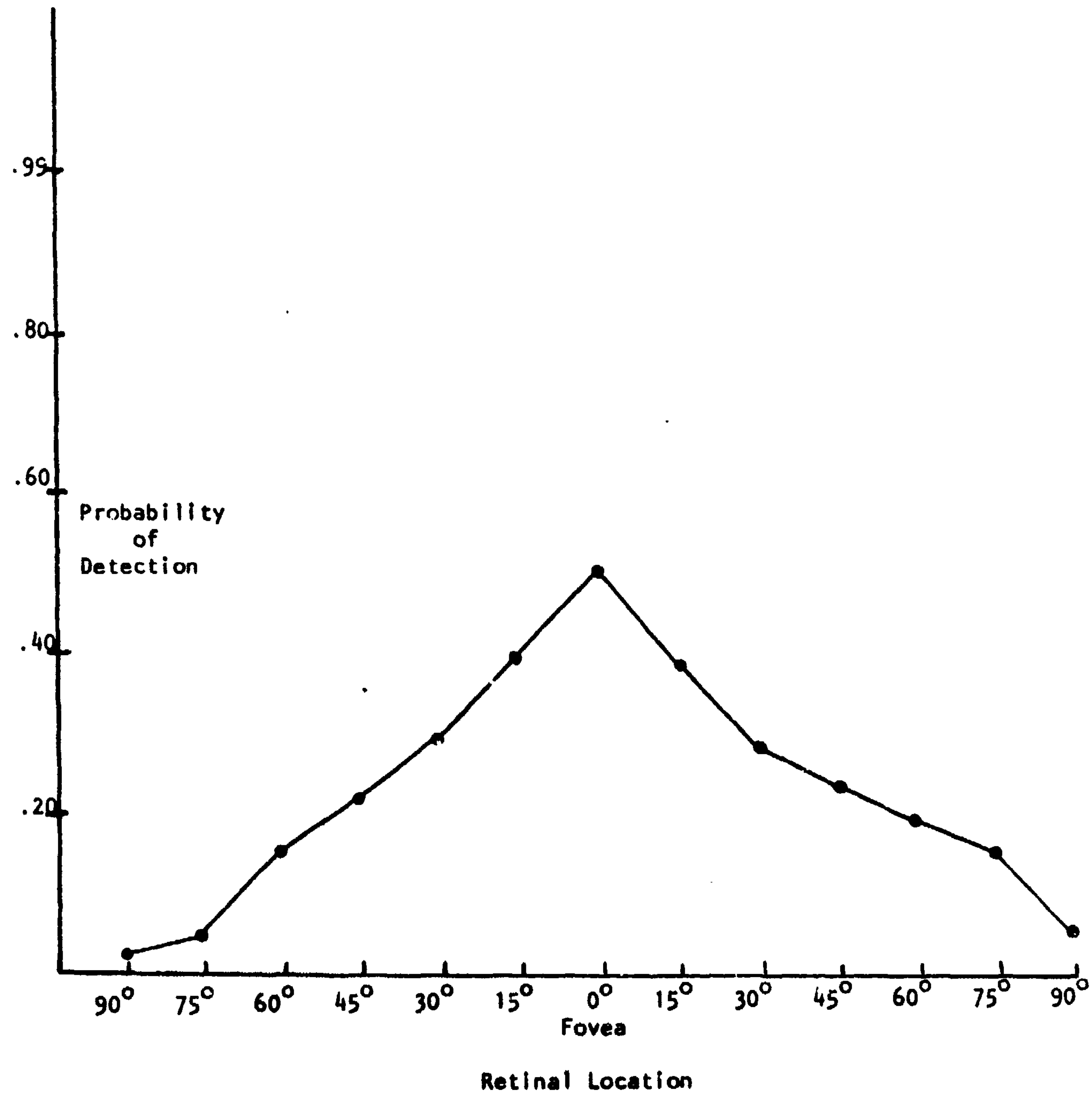

.99
.80
.60
.40
.20
Probability
of
Detection
90°
75°
60°
45°
30°
15°
0°
Fovea
15°
30°
45°
60°
75°
90°
Retinal Location

Figure 50

The distribution is obviously symmetrical, and very similar to the shape of the retinal sensitivity curve. It can be concluded that shorter duration flashes do not result in a higher detectability than equal luminous intensity lights of somewhat longer duration.

With respect to atmospheric transmissivity or visibility the only significant difference detected was between three to five miles and all greater visibilities on pass one. Due to good weather during the data collection period only one and one-half sessions were run at less than five miles visibility. (The half session resulted from a rain storm). Unfortunately, all the three to five mile visibility data were collected at less than 100 Ft.L. background luminance, hence, even this result may be spurious. In general, the data shows no deviation from Allard's Law.

As with all five main effects, range was a significant factor. The overall probability of detection was .28 at the three mile range, and .21 at the five mile range. Although the inverse square law would have predicted a greater spread between the performance at the two ranges (given good visibility which did prevail) the difference is considered to be reasonably in line with theory.

RESULTS - DAYLIGHT SESSIONS

Table 19 shows the obtained F statistics and degrees of freedom for the Main Effects for the daylight sessions. Background luminance at the horizon was always above 1000 ft.L. during these sessions and occasionally approached 3000 ft.L. No difference in performance was observed as background luminance increased above 1000 ft.L. Since there was only one level of background luminance for daylight sessions, B is not a factor in Table 19.

TABLE 19. MAIN EFFECTS F STATISTICS
DAYLIGHT SESSIONS

	F			
	Pass 1 R.T.	Pass 2 P_C	df	F Statistic For Significance
L	163.10	875.85	3,7	8.45
V	35.09	3.89	3,1	34.12
R	35.72	76.88	3,1	34.12
E	15.52	3.04	3,12	5.95

On pass one all effects reach significance at the 0.01 level, while on pass two both eye position and visibility are not significant. In general, performance during the daylight session was so poor over all conditions that it is not surprising that differences were not detected for all main effects. For example, on pass one, the overall mean R.T. for day sessions was 9.7 seconds. The mean at the foveal eye position was 8.9 seconds, and of course, the worst possible performance was ten seconds, which occurred at one 90° position. There was, therefore, very little difference in performance because the results were uniformly poor over all test levels.

The Scheffe test for lights indicates that only the 36,000 E.Cd. strobe differs from all others during daylight sessions. The P_C for 36,000 E.Cd. was 0.15, while for 10,000 E.Cd. it was 0.09. The mean P_C for all strobes during daylight sessions was 0.05.

The Scheffe test for range is statistically significant, although the actual difference in P_C is 0.04 for five miles as opposed to 0.06 for three miles. Although one is 1.5 times the other, the difference is hardly of any practical significance.

With respect to visibility it is likely that the significant F statistic for pass one is spurious, in that it is, in part, based on a very few trials at visibility of three to five miles.

In general, the only important conclusion which can be drawn for the analysis of the daylight session is that strobe lights of practical intensities aren't effective in enhancing visual conspicuity of aircraft under most daylight flight conditions. Even strobe lights of very high intensities, which are not practical to mount on Air Force aircraft, would be of little, if any, practical benefit.

RESULTS - NIGHT SESSIONS

Since the daylight sessions contributed little variance to the total, it would be expected that the night sessions would result in significant effects. Table 20 shows the obtained F statistics and degrees of freedom for the main effects for the night sessions.

TABLE 20. MAIN EFFECTS F STATISTICS - NIGHT SESSIONS

	F			F Statistic
	Pass 1 R.T.	Pass 2 P_C	df	for Significance
L	104.42	313.32	3,7	8.45
V	58.78	22.87	3,2	30.81
B	345.54	317.65	3,3	29.46
R	141.85	100.24	3,1	34.12
E	58.78	22.99	3,12	5.95

As was the case for all sessions, all main effects are significant at the 0.01 level, except for V on pass two. Again, lights and background luminance contribute greatly to deviation from the model, but the effect of range seems to be greater for the night sessions.

Table 21 shows the results of the Scheffe test for lights.

TABLE 21. RESULTS OF SCHEFFE TEST FOR LIGHTS - NIGHT SESSIONS

Pass 1 R.T.		Pass 2 P_C	
1000 Red	7.7831	1000 Red	.3416
2000 Red	7.4559	1000 White	.3842
1000 White	7.1199	2000 Red	.3857
2000 White	6.4736	2000 White	.4606
3500 White	6.0821	3500 White	.5362
10,000 White	5.6247	10,000 White	.5950
36,000 White	4.9254	36,000 White	.6767

The results for P_C for night sessions are identical to the results for all sessions. The results for R.T. are similar, but accent the superiority of White over Red strobe lights for threshold detectability. The 2000 E.Cd. White is significantly better than

2000 E.Cd. Red and the 1000 E.Cd. White is significantly better than the 1000 E.Cd. Red as shown in pass one. The 1000 E.Cd. white is almost identical to 2000 E.Cd. Red in P_C.

Although significantly different on the P_C criterion, the 10,000 E.Cd. strobe did not result in significantly shorter R.T.s than the 3500 E.Cd. strobe in the night sessions. The significant difference in R.T. between 2000 and 1000 E.Cd. white strobe may give a "hint" of breakpoint in performance, but is not reflected on the P_C criterion.

As stated above, these data are biased toward background luminance below 10 ft.L., because there are more trials under this condition. Although it was hoped that the experiment would have produced results for the specification of strobe lights for dawn/dusk operations, this is not possible due to the bias toward dark backgrounds, the fact that the background levels were too coarse, and the possibility that the light levels were too coarse.

Despite these limitations, further analysis of the effect of background luminance is in order. There were approximately 2000 data points under the 100-1000 ft.L. background condition, approximately 2000 at 10-100 ft.L. and approximately 7000 data points below 10 ft.L. The P_C plot for lights for these backgrounds appears as Figure 51. The Scheffe test shown in Table 17 showed that the $<$10 ft.L level was significantly different than the other two background luminances, which did not differ significantly. This is reasonably evident from Figure 51, which, incidentally, also reveals the lack of interaction between L and B.

To the extent that it is possible to draw any conclusion from this finding, it may be that strobe lights of the luminous intensities used in this study are of less value in dawn/dusk operations and against dark clouds than has been suspected. (Recall that these are threshold data and all subjects knew the location of the light.)

A more refined investigation of the region of one to 300 ft.L. background luminance would be required with more levels of white strobe luminous intensity in order to specify the characteristics required for effective dawn/dusk protection.

With respect to the other, main effects the results are similar to those for all sessions. The three to five mile visibility is markedly inferior to both five to ten mile and 10 miles, which do not differ. Most of the three to five mile visibility data were obtained in night sessions, which accounts for the difference being greater than for all sessions.

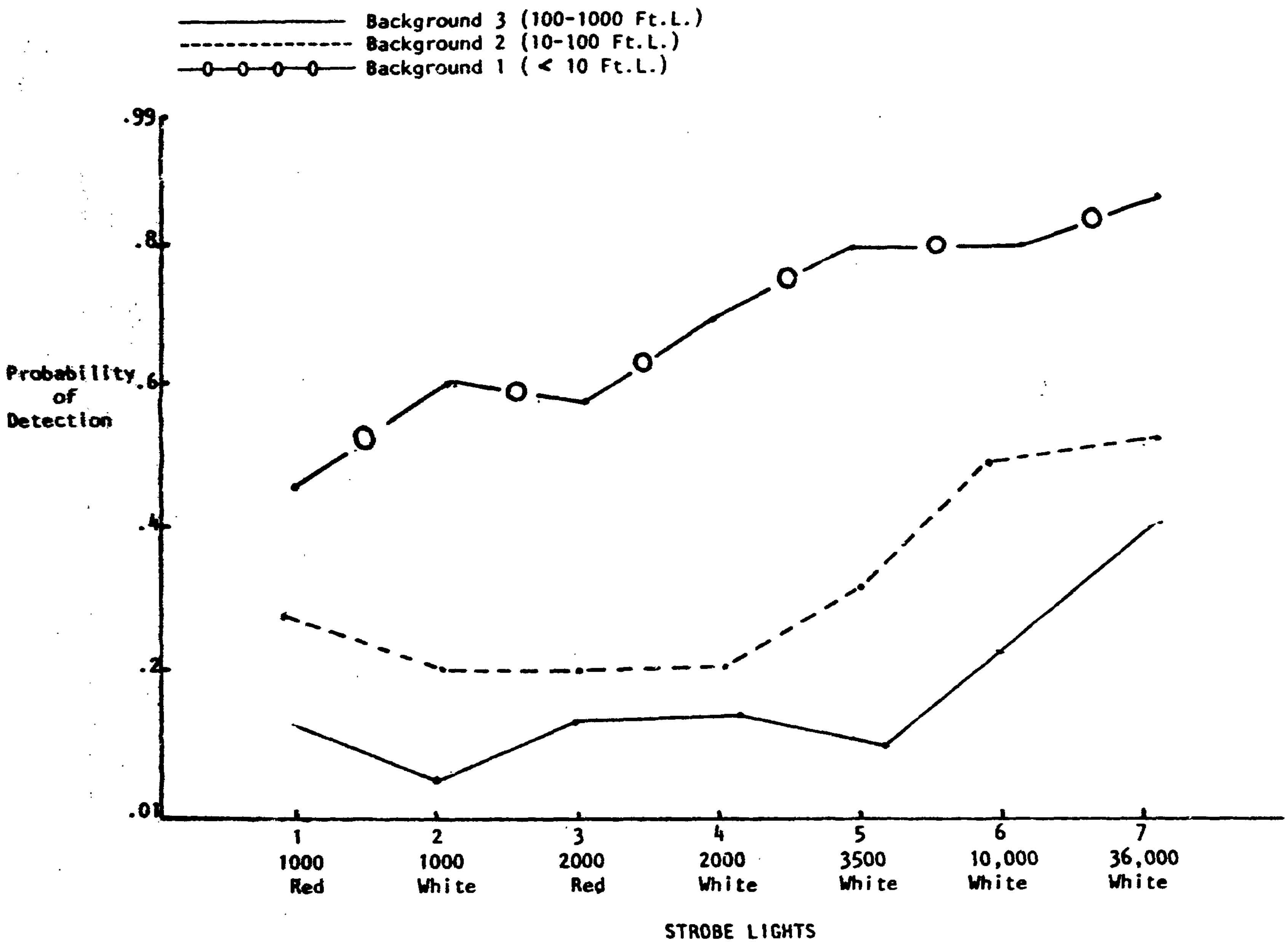

Background 3 (100-1000 Ft.L.)
Background 2 (10-100 Ft.L.)
Background 1 (< 10 Ft.L.)
.99
.8
Probability of Detection
.6
.4
.2
.01
1
1000
Red
2
1000
White
3
2000
Red
4
2000
White
5
3500
White
6
10,000
White
7
36,000
White
STROBE LIGHTS

Figure 51

Range contributes more to the rejection of the model for night sessions than for either all sessions or day sessions, although the difference in P_C between three and five miles was only .59 vs .38, less than would be predicted by the inverse square law for point sources.

Eye position (retinal location of strobe) is almost identical with all sessions because, as mentioned above, the majority of the detections occurred during night sessions, hence the night sessions account for the symmetry of eye position for all sessions.

Again, it is concluded that the short duration flash of the strobe offers no advantage in peripheral detection.

3.6 PROBLEM AREAS

3.6.1 ELECTRICAL EFFICIENCY

In terms of power conversion, the incandescent lamp is the most efficient and straightforward method. It is possible to operate a ten to 28 volt filament from the 115 volt 400 Hz bus through a step-down transformer with a typical efficiency of 90%.

Strobe lights require much more complicated power supply and control circuits. Several typical types are discussed here relative to their electrical efficiency.

a. Voltage Multiplier Circuit - The voltage multiplier circuit is one of the most efficient power supplies used in strobe light systems as efficiencies of 65 to 70 are achieved. A limiting factor to this approach is that the capacitors are charged to multiples of the input voltage (two times, four times, etc.). With each increase in multiplication the circuitry and charging network becomes more complex and efficiency decreases.

b. R-C Charging - This type is not too prevelant and should only be considered in low power applications as the power dissipated in the lamp head is equivalent to that dissipated in the resistor. Efficiencies of 45% can be achieved.

c. D.C. "Flyback" Transformer Method - The "flyback" transformer method uses a single transformer operating in conjunction with a transformer with multiple windings for both output and feedback. (This is the same type circuit used in most battery operated photographic strobes.) This type conversion will give efficiencies approaching 50% and is used in many low power applications where input currents remain small.

d. Transistor DC to DC Converter - This type circuit is a two transistor DC to DC converter with a saturable core type transformer. Most power supplies of this type have efficiencies of no more than 35 to 45%.

3.(.2 ENVIRONMENT

a. Temperature. Temperature can greatly affect the operation of strobe light systems. The energy storage capacitor is probably the most temperature sensitive component in the strobe system. As discussed in the previous paragraph strobe power supplies are lower in efficiency than incandescent systems. Inefficient use of the energy results in heating of the power supply. If the capacitors are overworked or there temperature environment becomes excessive, their leakage current begins to increase. The capacitor leakage current represents power that is being dissipated inside the capacitor in the form of heat, resulting in a further increase in temperature, more leakage, etc. If this cycle goes unchecked or if thermal equilibrium cannot be attained, the capacitors will be destroyed.

Temperature can also adversly affect the gas discharge tube. Heating of the flash tube will increase the required field to initiate ionization of the gas in the tube. Since the tube adds heat to the fixture every time it flashes, achievement of thermal equalibrium is important.

b. Vibration. Due to its construction, (no filament) the flash tube is far better in high vibration environments than the incandescent lamp when properly mounted. Due to the mass involved and storage capacitor construction, the power supply is more susceptible to vibration than the flash tube.

c. EMI/EMC. EMI/EMC requirements are well specified in MIL-STD-461/462 and MIL-E-6051. Strobe light systems meeting these requirements should not interfere with other aircraft avionic systems designed to these same requirements. There is no known strobe light system that can meet the EMI/EMC requirements and produce the 3500 E.Cd. or greater intensity level. EMI/EMC experts at ASD continue to insist that complete compliance with MIL-STD-461/462 is required.

4.0 FUTURE ANTICOLLISION LIGHTING POSSIBILITIES

4.1 REQUIREMENTS DEVELOPMENT

To enhance the conspicuity of an aircraft by the use of a light source requires system compromises to remain within a reasonable power and size range. These compromises must be handled in an informed manner so that the concepts and design are directed so as to provide the best solution within present technology and offer a viable anticollision device.

The problem is not simply determination of required intensity from the source to provide sufficient detectability, but must also address the ability of manufacturing a system which is compatible with size, weight, power, maintainability, and cost considerations.

The required intensity problem is much more complex than one would initially suspect. The theoretical performance of point source lights (see para 3.2) has typically been examined at threshold. But, light sources well above threshold will be required for effective detection. As an example, tests using a telescope in the daytime to find stars [32:886], it was shown that when the illumination from a star was five to ten times the threshold value for the existing conditions, it was easy to find; when two and one-half to five times threshold, it was moderately hard to find; for two times threshold it could be found with difficulty (usually several minutes of search were necessary even though the star was in the field of the telescope); and at threshold it was necessary to know exactly where to look and even then to spend some time in searching.

The shortcomings of the literature in matching the conditions of this problem would be of little consequence if providing higher and higher intensity sources were not a technical problem. A multiplication factor of 1000 could be used for assurance. This is not the case, however, and as a result, a data base is needed which can provide informed guidance in the various areas of expertise required to make the best compromises in providing a system to solve the problem.

A data base is needed to establish the intensity of a point source vs probability of detection vs off axis angle with the observer's eye. The tests should be conducted in ambient brightness levels consistent with aircraft flight environments. The tests should also address the question of flash duration and spacing. Once the required levels are known for visual performance, the trade offs in a light system design can be made in a knowledgeable manner. Field tests, though valuable in evaluating a final system configuration, are cumbersome and contain too many uncontrolled variables for this type of testing. Much of this work could be done with visual simulators. It may very well be that once needed intensity levels are determined anticollision light development can stop. It may be that required levels are many times greater than those that can be produced.

4.2 ELECTRONIC AIDS IN DETECTION

As was pointed out in several of the tests of aircraft and strobe light detectability (see paras 2.5.4 and 3.4) a pilot knowing where to look can detect aircraft at much greater range than an uninformed pilot.

An electronic system to aid in visual detection of aircraft should at least meet the following basic requirements.

a. It must inform the pilot of the presence of another aircraft. Relative bearing and relative elevation will give the pilot the same advantage as the "informed" observers in paragraph 2.5.4.

b. The system must be able to operate in an automatic mode, thereby providing continuous protection without increasing pilot workload.

Pilot Warning Indicator (PWI) systems have been proposed using strobe lights as an infrared emitter. One such system used a lamp head with two flash tubes. The dual lamp strobe system is a cooperative PWI in which the strobe carried by the intruder would be encoded with the altitude of that aircraft. The method of encoding simply operated the strobe system so that it would emit two closely spaced flashes rather than a single flash each second. The spacing of the flashes would be a function of the aircraft's altitude, (pulse position modulation) and would be spaced so that the pair of flashes had the same visual appearance as a single flash (i.e., a maximum separation of 12 milliseconds between pulses in a flash pair). Relative bearing is determined by the detector array.

The altitude of the threat aircraft is compared with the altitude of the aircraft being protected and a visual display presents the pilot with a direction and relative altitude (higher than, the same as, or below his own) to be searched. Such a system may greatly improve the detectability of aircraft in bright daylight conditions when strobe lights are not visible.

Systems such as those described above were examined in the late 1960s. Major problems encountered were caused by false alarms from infrared sources other than the strobe lights. It is proposed that reexamination of these systems is warranted. Development of single chip microprocessors has given the designer much more advanced logic and threat recognition criteria (false alarm rejection) at less cost than was previously available.

4.3 NON-STROBE HIGH INTENSITY ANTICOLLISION LIGHTS

One of the major problems facing the anticollision light designer is lamp efficiency. Typical aircraft strobe lamps are operated so as to obtain approximately 15 lumens per watt (lum/w). Strobe lamps can give much better luminous efficiencies when operated at higher power loading but then they must be forced air or even water cooled to operate at 60 flashes per minute.

One type lamp which can provide increased efficiencies is the relatively new "short-arc" lamp being used by some movie projector manufacturers. Since it is desirable to make anticollision lights as small as possible (to minimize aerodynamic problems) we find another argument for short-arc lamps.

In order to collect effectively the output of a source into a relatively small beam with a small reflector, the source size must be small. This is where the continuous wave (CW) short-arc type lamps show an advantage. The source size for these sources is typically a sphere on the order of one to two millimeters in diameter. There are a number of reasons why short arc lamps can provide better conversion efficiencies from electrical to luminous light energy. The plasma arc in flash lamps is wall stabilized. This means that the plasma is in contact with the flash lamp envelope. In the interest of long life, the energy per unit area of the envelope is kept low, which in turn results in a poor conversion of the energy input to luminous light output by the plasma. For a short arc lamp, however, the plasma arc does not come in contact with the envelope and as a result the temperature of the plasma can be run at higher temperatures thus giving better luminous conversion. Since short-arc lamps are a CW, higher temperature plasma device, various metals and halides can be added which vaporize and enhance the luminous efficiency of these sources. This technique is not available to a pulsed flash lamp (strobes). As an example, mercury added to xenon in a short-arc lamp gives a luminous efficiency of 40 lum/w. A thallium iodide xenon short-arc lamp can give up to 75 lum/w. This is considerably better than the 15 lum/w sighted above for xenon flash lamps.

This short discussion is intended to indicate that there may be alternates to strobe anticollision lighting which should be examined before final decisions are made.

5.0 FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

As pointed out early in this report, the literature review, study effort, and testing described in this document were conducted to determine parameters for a specification on strobe anticollision lights. The following findings consolidate the findings of the separate sections of this report. The conclusions and recommendations reflect the decision by the Air Force not to initiate a fleet wide retrofit of strobe lights for daytime midair collision avoidance and hence not to publish the proposed specification.

5.1 FINDINGS

a. USAF midair collisions were found to occur during the following phases of flight:

(1) Formation flying (56.4%)

(2) Associated flying (20.1%)

(3) Non-associated flying (23.5%)

Of these, strobe lights may only be expected to affect significantly the potential for non-associated flying midair collisions.

b. Almost all midair collisions involve at least one aircraft flying VFR.

c. 86.9% of the non-associated flying Air Force midair collisions occurred during daylight flying.

d. Two-thirds of the non-associated Air Force midair collisions occurred with other military aircraft during takeoff, initial climb, descent, or landing.

e. General aviation aircraft comprise the largest non-military collision threat to the Air Force while collisions with large commercial aircraft are the least threat.

f. Aircraft can be detected at ranges three times greater when the pilot knows the approximate location of the intruding aircraft.

g. Strobe lights will not significantly reduce the potential for midair collisions involving Air Force aircraft. The visibility enhancement characteristics of the strobe light when compared to the midair threat environment, offer very little, if any, added protection against midair collisions.

h. Of the previous tests reviewed, only two (the Army helicopter test - paragraph 3.3.5, and the IG evaluation - paragraph 3.3.8) concluded that strobe lights could be effective daylight anticollision devices. ASD's Quick Look Flight Test and Tower Test (paragraph 3.4 and 3.5) could not support the Army or IG data and in fact are in direct conflict.

5.2 CONCLUSIONS

a. Analysis fails to support high intensity strobes for the reduction of the daytime midair collision potential with present day technology.

b. Further action to develop a strobe light specification for daytime midair collision avoidance is not warranted at this time.

c. Some strobes, optimized for night visual intensity levels may be appropriate if they can be shown to be life-cycle-cost effective.

d. Strobe lights used in conjunction with electronically aided detection devices may provide a viable collision avoidance system and should be investigated as a future task.

5.3 RECOMMENDATIONS

a. Continue selective installation of strobe lights optimized for night visual intensity when a life-cycle-cost savings can be realized.

b. Future work should address the midair collision problem from a systems point of view. This approach will allow consideration of high intensity lighting coupled with electronically aided detection as part of the overall solution to the Air Force's midair collision problem.

LIST OF REFERENCES

1. Problem Summary Report on USAF Strobe Light Evaluation. Deputy Inspector General for Inspection and Safety, USAF, Norton Air Force Base, California. (AFISC/SEFB)

2. USAF Midair Collisions 1965-1975 Final Report. Deputy Inspector General for Inspection and Safety, USAF, Norton Air Force Base, California. (AFSIC/SEY)

3. Murray, J.P., Rucker, R.A., Simpson, T.R., Civil Aviation Midair Collision Analysis January 1964 - December 1971. May 1973, FAA-EM-73-8, Office of Systems Engineering Management, Department of Transportation, Federal Aviation Administration, Washington, DC (The Mitre Corporation).

4. Boyd, P.R., Curtis, B.R., Orr, R.H., Tibbs, A.M., Near Midair Collision Report of 1968. 15 July 1969, Department of Transportation Federal Aviation Administration, Washington, DC.

5. Blackwell, H.R., Contrast Thresholds of the Human Eye. J. Opt. Soc. Amer., 1946, Vol. 36.

6. Duntley, S.Q., The Visibility of Distant Objects. J. Opt. Soc. Amer., 1948, Vol. 38.

7. Hecht, S., Ross, S. & Mueller, C.G., Visibility of Lines and Squares at High Brightness. J. Opt. Soc. Amer., 1947, Vol. 37.

8. Lamar, E.S., Hecht, S., Shlaer, S. & Hendley, C.D., Size, Shape and Contrast in Detection of Targets by Daylight Vision. I. Data and Analytical Description. J. Opt. Soc. Amer., 1947, Vol 37.

9. Middleton, W.E.K., Vision Through the Atmosphere. Toronto: U of Tornoto Press, 1958.

10. Applied Psychology Corporation. Field Study of Threshold Ranges for Aircraft Detection and Color Identification. Tech. Rept. No. 4, under Federal Aviation Administration contract FAA/BRD-127, 1961.

11. Howell, W.D., Determination of Daytime Conspicuity of Transport Aircraft. Tech. Dev. Rept. No. 304, Civil Aeronautics Administration, Technical Development Center, Indianapolis, Indiana, May 1957.

12. Fisher, R.B., Marshall, P.R., Determination of the Daytime Conspicuity of a Small Airplane in a Terminal Area. Tech. Dev. Rept. No. 382, Federal Aviation Agency, Technical Development Center, Indianapolis, Indiana, January 1959.

13. Calvert, E.S., The Use of Aircrew-interpreted Devices for Preventing Collisions in the Air. J. Inst. of Navigation, Vol XI, No. 4, Oct 1958.

14. Howell, W.D., Edwards, T.M., Determination of Some Geometric Relationships Pertaining to Collision Flight Paths. Tech. Dev. Rept. No. 259, Civil Aeronautics Administration, Technical Development and Education Center, Indianapolis, Indiana, June 1955.

15. IES Lighting Handbook - Fifth Edition.

16. Knoll, H.A., Tousey, R., & Hullburt, E.O. Visual Thresholds of Steady Point Sources of Light in Fields of Brightness from Dark to Daylight. J. Opt. Soc. Amer., 1946, Vol 36, No. 8.

17. C.I.E. Technical Committee 3.3.2.1. Aviation Ground Lighting, C.I.E. Proceedings, Vol. II, Committee Report, 1955.

18. Stiles, W.S., Bennett, M.G., & Green, H.N. Visibility of Light Signals with Special Reference to Aviation Lights. Aeronautical Research Committee Reports and Memoranda No. 1793, Brittish Air Ministry, May 1937.

19. Gilbert, M.S., & Pearson, H.J.C. A Study of the Visibility and Glare Ranges of Slope-line Approach Lights. Civil Aero. Admin., Tech. Dev. Center, Tech. Dev. Report No. 150, Nov. 1951.

20. Adrian, W., & Jainshi, P. Experimental Studies on the Reliability of the Visual Threshold Internationally Agreed Upon for the Calculation of Luminous Intensities of Light Signals. Report No. 5-4-4, Sixth International Technical Conference on Lighthouses and Other Aids to Navigation, U.S. Coast Guard, 1960.

21. de Boer, J.B. Visibility of Approach and Runway Lights, Phillips Research Reports, 6 June 1951.

22. Tousey, R. and Kooman, M.J.: The Visibility of Stars and Planets during Twilight, J. Opt. Soc, Amer., Vol 43, March 1953.

23. Breckenridge, F.C. and Douglas, C.A.: Development of Approach and Contact - Light Systems, Illum, Eng., Vol XL, Nov. 1945.

24. Blondel, A. and Rey, J.: The Perception of Lights of Short Duration at Their Range Limits. Trans. of Illum. Eng. Society Vol VII, No. 8, Nov 1912, pp 625-662.

25. Douglas, C.A.: Computation of the Effective Intensity of Flashing Lights. National Bureau of Standards Report 4554, March 1956.

26. Projector, T.H.: Effective Intensity and Efficiency of Flashing Lights. Sixth Int. Tech. Conf. on Lighthouses and Other Aids to Navigation. USCG, 1960.

27. Crosley, J.K., McLean, W.E., Tabak, R.G., Bailey, R.W., The Use of High Intensity Xenon Lighting to Enhance US Army Aircraft Day/Night Conspicuity. U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, January 1971.

28. Specific Item Report No. P-117 FB-111 Strobe Light Evaluation. Headquarters Strategic Air Command, Aircraft Engineering Division, Carswell AFB, Texas. 30 September 1971.

29. Letter of 11 May 1972 entitled T-38 Aircraft Beacon/Strobe Light Visibility Test Results to ATC/DOTF from Headquarters San Antonio Air Material Area (AFLC)/MMEN-8.

30. Goldsmith, Dr.C.T. Final Report - Strobe Light Tower Test. Decilog, Inc. Technical Report 146-2, 10 September 1976, Decilog, Inc., Melville, New York, 11746

31. Connors, M. Conspicuity of Target Lights: The Influence of Color. NASA TN D-7960, NOV. 1975

32. Tousey, R. and Hulbert, E.O. The Visibility of Stars in the Daylight Sky. J. Opt. Soc. Am. Vol 31, No. 10, Oct 1948.

APPENDIX 1

PROPOSED MILITARY SPECIFICATION FOR
AIRCRAFT ANTI-COLLISION STROBE LIGHTS

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO
ATTN OF: ENEG

27 FEB 1976

SUBJECT: Review of Proposed Military Specification for Aircraft Anti-Collision Strobe Lights

TO: SEE DISTRIBUTION LIST

1. A preliminary draft specification (Atch 2) for Strobe Anti-Collision Aircraft Lights has been prepared. In order for us to prepare a useful document, we request that your organization review our draft. No paragraph of this specification should be considered as an absolute requirement of the Air Force and is provided only as a preliminary proposal for review and comment. As such, the proposed specification is subject to extensive modification and may not be used for procurement purposes. Your review, comments and recommendations are requested on or before 1 April 1976.

2. Comments and recommendations relative to the proposed specification should be addressed to the project engineer, Phillip Schmidlapp, ASD/ENEGE, Wright-Patterson AFB OH 45433. Mr. Schmidlapp may be contacted by telephone commercially at (513) 255-5192/4708 and by Autovon at 78-55192/54708. Questions and comments relative to strobe light program being conducted by the Air Force should be addressed to the program manager, Major Donald Drinnon, ASD/AEAI, Wright-Patterson AFB OH 45433. Major Drinnon may be contacted by telephone commercially at (513) 255-6168/6169 and by Autovon at 78-56168/56169.

3. Each reviewer is requested to provide a telephone number(s) where he/she may be reached so that questions relative to submitted comments may be resolved. Current plans are to submit the proposed specification (with appropriate changes from your recommendations and comments) to our specification branch for formal comment cycling by 16 April 1976.

4. The specification consists of a main body, i.e., a general requirement specification and specification sheets covering specific systems. System categories (para 1.2.1) are defined in terms of aircraft parameters such as allowable weight, size, power consumption, etc. Specification sheets are specific solutions to the requirements of the general specification. This means that the large aircraft category (KC-135, C-130, etc.) may have associated with it several specification sheets (for example, one for a wing-tip lighting system and one for a fuselage system). The sample specification sheet provided is not in its final form. The Army has purchased the data to the described system and this data will be used to specify more exactly the helicopter system described. Recommendations for

specification sheets and system category descriptions are of primary interest to this office.

5. Hopefully, this comment cycle will significantly shorten the formal comment cycling of our specification branch and result in a timely release of a final specification. Your timely review and comments will enhance the quality of the specification and help fulfill a critical need at an early date.

FOR THE COMMANDER

FRANK MICKA
Chief, Ground Support Equipment Division
Directorate of Equipment Engineering

2 Atch
1. Distribution List
2. Specification

<u>DISTRIBUTION LIST</u>

AFSC/DOSO Andrews AFB DC 20334	1
TAC/DOOO Langley AFB VA 23665	1
MAC/DOQST Scott AFB IL 62225	1
CINCSAC/EPHV Offutt AFB NE 68113	1
ATC/DO Randolph AFB TX 78148	1
ADC/DOOT Ent AFB CO 80912	1
CINCPACAF/DOOQ APO San Francisco 96553	1
CINCUSAFE/LGMA APO New York 09012	1
NGB/XOS Wash DC 20310	1
AFRES/DOXS Robins AFB GA 31098	1
AAC/DOOA APO Seattle 98742	1
AFCS/FFO Richards-Gebaur AFB MO 64030	1
AFLC/MMA Wright-Patterson AFB OH 45433	65
Defence General Supply Center Richmond VA 23297	1
U. S. Army Aviation Systems Command Attn: AMSAV-ERR (Mr. Garrett) P. O. Box 209 St Louis MO 63166	1

Atch 1

Naval Air Systems Command 1
Attn: Mr. Conaway
AIR-53353A - Electrical Branch
Dept. of Navy
Wash DC 20360

Federal Aviation Administration 1
FAA, AFS-130
Attn: Mr. Chuck Jones
800 Independence Avenue
Wash DC 20592

National Bureau of Standards 1
Div. 221.12, Room A307
Attn: Mr. Tom Twist
Wash DC 20234

CAI - Bourns, Inc. 1
Attn: Mr. W. E. Nickel
550 West Northwest Highway
Barrington IL 60010

Vought Corporation 1
Attn: Mr. R. D. Nicolaysen
P.O. Box 5907
Dallas TX 75222

Kopp Glass, Inc. 1
Attn: Mr. W. A. Provost
P.O. Box 8255
Pittsburg PA 15218

Electronic Brazing Co., Inc. 1
P.O. Box 448
Harrison Street
Dover NJ 07801

Pacer Industries, Inc. 1
Attn: Mr. M. A. Huber
1428 Hayden Avenue
Altoona WI 54720

Multi Electric Mfg.,Inc. 1
Attn: Mr. M. A. Mongoven
4223-43 West Lake Street
Chicago IL 60624

Swiss Controls, Inc. 1
Attn: Carol S. Witek
P.O. Box 567
2603 E. Barker Avenue
Michigan City IN 46360

Hughy & Phillips, Inc. 1
Attn: J. H. Ganzenhuber
3050 North California Street
Burbank CA 91505

Optical Radiation Corporation 1
Attn: R. Goodwin
6352 North Irwindale Avenue
Azusa CA 91702

Aero Marine, Inc. 1
Attn: D. Castetter
18076 Tulsa
Granada Hills CA 91344

Grimes Manufacturing Company 1
Attn: Mr. Glenn Henson
515 North Russell Street
Urbana OH 43078

General Electric Company 1
P.O. Box 2143, Kettering Branch
Dayton OH 45429

R. B. Gale 1
Suite 620, 333 W. First St
Dayton OH 45402

Bren-Tronics, Inc. 1
104 Bellerose Avenue
East Northport NY 11731

Chromalloy Electronics Division 1
Attn: W. E. Williams
3901 North 29th Avenue
Hollywood FL 33020

Soderberg Mfg. Co., Inc. 1
Attn: Lloyd P. Appelman
20821 Currier Road
Walnut CA 91789

Sawyer Camera Company 1
6820 Santa Monica Blvd.
Hollywood CA 90038

Telectro Systems Corporation 1
96-18 43rd Avenue
Corona NY 11368

G.T.E. Sylvania 1
Attn: Mr. D. I. Coggins
Lighting Products Group
60 Boston Street
Salem MA 01970

Symbolic Displays, Inc. 1
1762 McGraw Avenue
Irvine CA 92714

Julian A. McDermott Corporation 1
1639 Stephen Street
Ridgewood NY 11227

L. L. Rowe Company 1
70 Hichborn Street
Boston MA 02135

MIL-L-XXXX (PROPOSED)

MILITARY SPECIFICATION

LIGHT, AIRCRAFT, ANTI-COLLISION, STROBE

This draft prepared by Aeronautical Systems Division, Wright-Patterson AFB, has not been approved and is subject to modification. DO NOT USE FOR PROCUREMENT PURPOSES.

Atch 2

INDEX

LIST OF FIGURES

TABLES

MILITARY SPECIFICATION

LIGHT, AIRCRAFT, ANTI-COLLISION, STROBE

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

1.0 SCOPE.

1.1 This specification establishes performance, configuration, test and acceptance requirements for Strobe, Anti-Collision Aircraft Lighting Systems. Specific systems are covered in specification sheets to this specification.

1.2 Classification. Strobe Anti-Collision Aircraft Lighting shall be classified as to Category and Type as follows:

Category A - Rotary wing aircraft (Para 3.10.1).

Category B - Large Subsonic aircraft (Para 3.10.2).

Category C - Small Supersonic Aircraft (Para 3.10.3).

Category D - Small Subsonic Aircraft (Para 3.10.4).

Category E -

Type I - For use with a 28 VDC (Volt Direct Current) aircraft power source

Type II - For use with one phase of a three phase 115 VAC (Volt Alternating Current) 400 Hertz aircraft power source.

1.2.1 Category-Type Designation. Each Category shall be designated as either a Type I or Type II system per paragraph 1.2.

2.0 APPLICABLE DOCUMENTS.

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal(s) form a part of this specification to the extent specified herein:

DRAFT

SPECIFICATIONS

MILITARY

MIL-B-5087	Bonding, Electrical, and Lightning Protection, for Aerospace Systems
MIL-W-5088	Wiring, Aircraft Selection and Installation of
MIL-L-6503	Lighting Equipment, Aircraft, General Specification for Installation of
MIL-L-6723	General Specification for Aircraft Lights
QPL-6723	Qualified Products List (QPL) for MIL-L-6723
MIL-S-7742	Screw Threads, Standard, Optimum Selected Series, General Specification for
MIL-S-8805	
MIL-C-25050	Color, Aeronautical Lights and Lighting Equipment, General Requirements for

STANDARDS

FEDERAL

FED-STD-595	Color, Requirements

MILITARY

MIL-STD-100	Engineering Drawing Practices
MIL-STD-130	Identification Marking of US Military Property
MIL-STD-143	Specification and Standards, Order of Precedence for the Selection of
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Interference Characteristics, Requirements for Equipment

MIL-STD-462	Electromagnetic Interference Characteristics Measurement of
MIL-STD-704	Electric Power, Aircraft, Characteristics and Utilization of
MIL-STD-781	Reliability Tests: Exponential Distribution
MIL-STD-810	Environmental Test Methods
MIL-STD-889	Dissimilar Metals

2.2 Other Publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal(s) shall apply:

AFSC Design Handbook No. 1-4

3.0 REQUIREMENTS

3.1 Item Definition. The Strobe Anti-Collision Aircraft Lighting System shall provide the anti-collision lighting required by MIL-L-6503 "Specification for Installation of General Aircraft Lighting." The system shall consist of the lamp heads, power supplies, and control circuitry required to meet the requirements specified herein.

3.1.1 Specification Sheets. The individual requirements for each aircraft category shall be as specified herein and in accordance with the applicable detail specification sheet.

3.2 Qualification. The system furnished under this specification shall be a product which has been inspected and has met the requirements of Section 4.0, "Quality Assurance Provisions" specified herein, and has been listed on or approved for listing on the applicable Qualified Products List, QPL-6723. Compliance with the requirements of Section 4.0 herein shall be sufficient to qualify the system for listing in QPL-6723 as all requirements of this specification equal or exceed those of MIL-L-6723, "General Specification for Aircraft Lights." Inspection documentation shall be presented as evidence of compliance with MIL-L-6723 to obtain listing on the QPL.

3.3 Materials. Materials shall conform to applicable specifications as specified herein and on the application standards. Materials which are not described herein shall be of the best quality and suitable for the purpose intended.

DRAFT

3.3.1 Metals. Metals shall be of a corrosion-resistant type or shall be suitably protected to resist corrosion. Dissimilar metals as defined in MIL-STD-889 shall not be in direct contact with each other unless appropriately protected against electrolytic corrosion.

3.3.2 Protective Treatment. Materials subject to deterioration when exposed to climatic or environmental conditions shall be protected against deterioration in a manner that will in no way prevent compliance with the performance requirements specified. Protective coatings that will chip, crack, or scale with age or extremes of climatic or environmental conditions shall not be used.

3.3.3 Selection of Materials. Specifications and standards for all materials, parts, and Government certification and approval of processes and equipment, which are not specifically designated herein and which are necessary for the execution of this specification, shall be selected in accordance with MIL-STD-143.

3.3.3.1 Use of Commercial Parts. Standard aircraft industry parts shall be used whenever they are suitable for the purpose and shall be identified on the drawings by their commercial part numbers. Commercial utility parts, such as screws, bolts, nuts, cotter pins, etc., may be used provided they possess suitable aircraft use properties, are replaceable by the standard aircraft industry parts without alteration, and provided the corresponding standard aircraft industry part numbers are referenced in the qualified parts list and, if practicable, on the contractors' drawings. In the event there is no suitable corresponding standard aircraft industry part in effect on date of solicitation, commercial utility parts may be used provided they conform to all requirements of this specification.

3.4 Design.

3.4.1 System. Each system shall be capable of operation in accordance with the requirements specified herein. The system shall be designed using solid state electronics with no moving parts except for the power supply which may incorporate an electro-mechanical device(s) in the power control circuit if determined by design criteria to be more suitable. The design shall incorporate a modular concept where subassemblies of the major assemblies are more easily replaceable as a complete module. The system shall provide sufficient light sources, each capable of producing both a low level mode and a high level mode which meets the intensity requirements of paragraph 3.5.1 and 3.5.2. Either mode shall be selectable utilizing a remotely located (cockpit mounted) switch. Additionally, a squat switch capability shall be provided which when depressed (aircraft on the ground), the low level mode will operate when either intensity mode is selected. When extended (aircraft in flight), the intensity mode selected will operate. A squat switch override shall be provided in a location that will facilitate maintenance and pre-flight check.

DRAFT

3.4.1.1 Mode Selection. The cockpit mounted switch shall be the three (3) position type specified in MS 27408-1A. The MS 27408-1A switch will be used for selection of the "High," "Off," or "Low" modes with the center position of the switch "Off." The system shall provide for a rapid connect/disconnect capability between the switch interconnecting wiring and each type power supply assembly. The switches and their interconnecting wiring with mating connectors shall not be furnished as components of the system. The mode selector switch shall be totally compatible with and completely interchangeable with the Type I and Type II systems defined in paragraph 1.2. Main aircraft power shall not be routed through the cockpit selector switches.

3.4.1.2 Interface Design. System design shall include the interface and installation data required to mate the specific system with the aircraft. However, the interconnecting wiring and electrical connector mating halves for the aircraft shall not be furnished components of the system. All wiring shall meet the applicable requirements of MIL-W-5088.

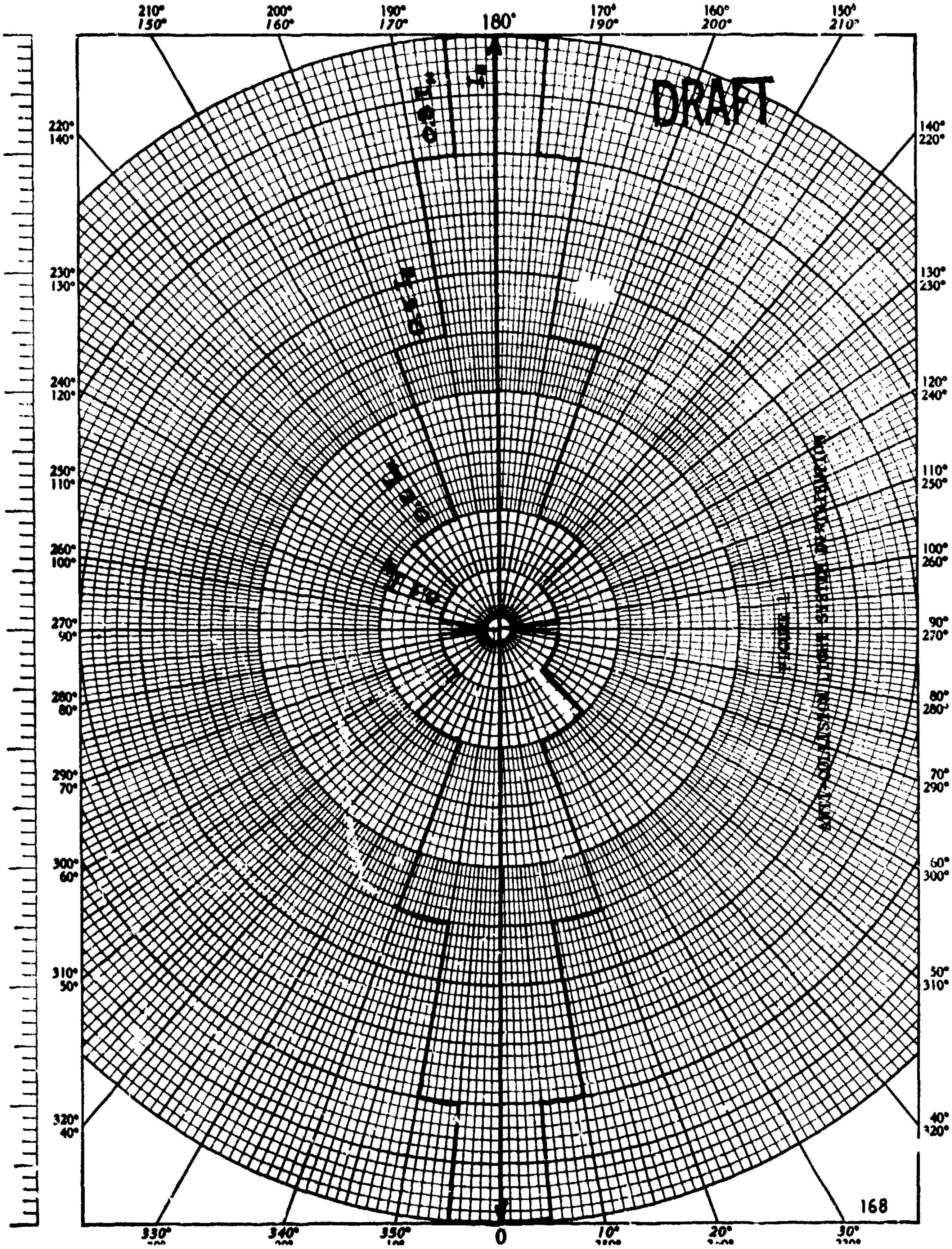
3.4.2 Safety. The system shall be designed to provide for maximum personnel safety in accordance with the applicable requirements of MIL-STD-454, Requirement No. 1. Additionally, when power is removed from the system by any means the system will be rendered "electrically safe" to facilitate maintenance personnel handling of system components. Electrically safe shall be defined as the removal of all electrical shock hazard to the maintenance technician. Provisions for the system squat switch shall be as specified in paragraph 3.4.1.

3.4.2.1 Grounding. Grounding systems shall comply with MIL-B-5087.

3.4.3 Shelf Life. Each system shall be capable of operating as specified after a minimum storage time of ten (10) years.

3.5 Performance.

3.5.1 Intensity. The minimum luminous intensities emitted by the system shall be in accordance with Figure 1 in all vertical planes (hemispherically) for both the high and low modes. I_H for each type system is defined in Table 1. The minimum luminous intensities shall be measured, with the appropriate lens in place, per National Bureau of Standards requirements and described in terms of "EFFECTIVE" intensities. The effective intensities in Figure 1 shall be met at each of the power inputs cited for normal operating ranges of paragraph 3.1.1. The following Blondel-Rey Equation relationship shall apply:


DRAFT
180°
0

FROM HORIZONTAL	MINIMUM INTENSITY REQUIRED
-45° TO -85°	I_H
-20° TO -45°	$0.2\ I_H$
-10° TO -20°	$0.5\ I_H$
-5° TO -10°	$0.8\ I_H$
0° TO -5°	I_F
0° TO $+5^\circ$	I_H
$+5^\circ$ TO $+10^\circ$	$0.8\ I_H$
$+10^\circ$ TO $+20^\circ$	$0.5\ I_H$
$+20^\circ$ TO $+45^\circ$	$0.2\ I_H$
$+45^\circ$ TO $+85^\circ$	$0.1\ I_H$

TABLE 1A: Vertical Distribution
(SEE FIGURE 1)

SYSTEM TYPE	I_H (HIGH MODE)	I_H (LOW MODE)
A-I	3500 e.cd.	150 e.cd.
A-II	3500 e.cd.	150 e.cd
B-I	5000 e.cd.	150 e.cd
B-II	5000 e.cd.	150 e.cd.
C-I		
C-II		
D-I		
D-II		

TABLE 1B: Required I_H

DRAFT

TABLE 1 INTENSITY REQUIREMENTS

PRELIMINARY DRAFT
NOT TO BE USED FOR PROCUREMENT PURPOSES

DRAFT

$$I_e = \frac{1}{0.2+(t_2-t_1)} \int_{t_1}^{t_2} I(t)\, dt$$

where: Ie = effective intensity is candelas, and is the maximum value of the right-hand side of the equation. $I(t)$ = instantaneous intensity as a function of time. t_2-t_1 = flash time interval in seconds.

Note: The maximum value of Ie is obtained when t_2 and t_1 are so chosen that the effective intensity is equal to the instantaneous intensity at t_2 and t_1.

3.5.2 Field of Coverage. The light emitted by the total system shall have a vertical field of coverage above and below the "horizontal plane" of the aircraft as specified in Figure 1. The horizontal field of coverage of the system shall be 360 degrees. "Horizontal plane" of the aircraft is defined by the longitudinal and lateral axes of the aircraft. When the required coverage cannot be met due to blockage caused by aircraft structure, stores, etc., additional lights shall be installed to provide coverage in the deficient areas.

3.5.3 Orientation. Each type system shall operate as specified while in any attitude.

3.5.4 Shielding. The lights shall be positioned or shielded, or both, to prevent light beams from being directly or indirectly projected into the cockpit or other areas that would interface with operating personnel. When the shielding or positioning is such that the light will not provide the required coverage, additional lights shall be installed to provide coverage in the deficient areas.

3.5.5 Flash Rate. The flash rate shall be 100-120 flashes per minute for the complete system. The flash rate shall be maintained throughout the bands of power input specified in paragraph 3.5.9.1. When any of the light sources are deactivated, the flash rate from any remaining sources in either mode shall continue to flash at its individually required rate.

3.5.6 Reliability (Mean Time Between Failure, MTBF)/Service Life. Reliability for each type system shall be in accordance with Test Plan III and Test Level F of MIL-STD-781 except as otherwise specified herein. Each type system shall have a minimum acceptable MTBF of 1000 hours, a specified MTBF of 2000 hours, with Decision Risks of 10% and a Discrimination Ratio of 2/1. Failure of the system is deemed to have occurred if a system fails optically, breaks, arcs, sparks, burns, misfires, crossfires between modes anytime during operations, performs erratically or otherwise displays

DRAFT

evidence of not conforming to conditions specified in this specification. Specific reliability test requirements are identified by paragraph 4.4.1.2.5. Crossfiring shall be defined as the electrical shorting or arcing of electrical current anywhere in the system total operation (start-up, running and shut down) during which triggering of any non-selected mode occurs.

3.5.6.1 Optical Failure of the High Mode. A failure of the High Mode will be deemed to have occurred when I_e (paragraph 3.5.1) falls below 0.85 I_H (I_H defined in Table 1) effective candelas in the horizontal plane, for the purpose of reliability computations.

3.5.6.2 Optical Failure of the Low Mode. A failure of the Low Mode will be deemed to have occurred when I_e (paragraph 3.5.1) exceeds 1.15 I_H or falls below 0.85 I_H (I_H defined in Table 1) effective candelas in the horizontal plane, for the purpose of reliability computations.

3.5.6.3 Optical Failure Day/Night Mode Computational Data Base. For system reliability computation, a seventy percent (70%) high mode and thirty percent (30%) low mode usage relationship shall be assumed.

3.5.7 Environmental. Each type system shall operate as specified herein over the ranges specified for each system category (see Table 2). Both high and low modes of each system shall comply with the total environmental requirements of this specification.

3.5.7.1 Altitude. Performance requirements of this specification shall apply over the altitude ranges specified in Table 2 for each system category. In all cases the minimum altitude range required shall be 0 feet (sea level) to 50,000 feet.

3.5.7.2 Temperature. Performance requirements of this specification shall apply over the temperature ranges specified in Table 2 for each system category. The system shall be designed to withstand the non-operating temperature ranges specified in Table 2 and shall operate as specified when the system is returned to the operating temperature range of Table 2.

3.5.7.3 Atmospheric Degradation. Each type system shall be designed to withstand the effects of sunshine, rain, humidity, salt fog, dust, and any other atmospheric degradation which may be encountered during use or storage of the system. The system shall operate properly, when exposed to those conditions of atmospheric degradation in which the aircraft using the system will operate. Sealing shall be per paragraph 3.6.1.

3.5.7.4 Explosive Atmosphere. The system shall not cause ignition of an ambient explosive gaseous mixture with air, when thoroughly operated in such an atmosphere after having been in such an atmosphere for a period long enough to be permeated by such an atmosphere.

SYSTEM CATEGORY	ALTITUDE RANGE	TEMPERATURE RANGE		
		OPERATING		NON-OPERATING
		CONTINUOUS	INTERMITTENT	
A	SEA LEVEL TO 50,000 ft.	-54° TO $55^\circ C$	55° TO $71^\circ C$	-62° TO $85^\circ C$
B	SEA LEVEL TO 70,000 ft.	-54° TO $71^\circ C$	71° TO $95^\circ C$	-62° TO $95^\circ C$
C				
D				
E				

TABLE 2

ALTITUDE AND TEMPERATURE REQUIREMENTS

PRELIMINARY DRAFT
NOT TO BE USED FOR PROCUREMENT PURPOSES

DRAFT

DRAFT

3.5.7.5 Vibration. The equipment shall meet the performance requirements of this specification when subjected to the vibration environments of Table 3. Table 3 outlines the vibration environments expected to be encountered by each aircraft category and represents the vibration levels each category is expected to withstand.

3.5.7.6 Acoustics. The equipment shall meet the performance requirements of this specification when subjected to the acoustic environments listed in Table 3.

3.5.8 Electromagnetic Interference. The light shall be designed to meet the requirements of MIL-STD-461, test methods CE03, CS01, CS06, REOZ, and RS04. The frequency range of 14K Hertz and 1 M Hertz shall be used for test method REOZ. AFSC Design Handbook 1-4 shall be used for design guidance.

3.5.9 Electrical Power Interface. Each type system shall operate in accordance with the requirements specified in this specification utilizing the applicable aircraft power having characteristics as defined in MIL-STD-704 for Category B equipment. Performance requirements of this specification shall be met over interconnecting wiring from the power supply(s) to the light sources represented by a maximum of 0.188 ohms resistance for each mode.

3.5.9.1 Power Consumption. Power consumption will be as specified per the applicable category.

3.5.10 Maintainability. Each type system shall provide for ease of system maintenance as specified herein. Major assemblies and their modules shall incorporate a capability for removal and replacement within fifteen (15) minutes. Removal/installation of major assemblies or modules shall not cause system/circuit detuning, degradation or instability and shall not require any subsequent adjustments. There shall be no capability for field adjustments of the system to maintain compliance with performance parameters of this specification. Operational checkout of the system shall consist of a squat switch as in MIL-S-8805 for the light sources with "test" mode, and visual inspection of assemblies or modules. System maintenance shall consist only of assembly/module, fuse replacements, or resetting circuit breakers when such circuit protection is used. When self-locking nuts are used in the assembly where module(s) replacements are anticipated and the nuts cannot be replaced with the module(s), provisions must be made for appropriate safety wiring of the bolt and/or nut.

3.6 Construction. Construction shall be such as to take full advantage of the design for minimum size and weight, long life, maximum reliability and minimum electromagnetic interference per the applicable category.

3.6.1 Sealing. Environmental sealing shall be used in lieu of hermetic sealing in the construction of the system or major assemblies to provide conformance with the requirements of this specification.

DRAFT

TABLE 3

VIBRATION AND ACOUSTIC NOISE REQUIREMENTS

PRELIMINARY DRAFT
NOT TO BE USED FOR PROCUREMENT PURPOSES

DRAFT

3.6.2 Electrical Connectors. The electrical connectors used in conjunction with system wiring shall be military qualified quick connect/disconnect type. Electrical connectors shall be selected and installed so that contacts on the "live" or "hot" side of the connector are socket type rather than pin type. Electrical connectors used for power circuits, control circuits, and light source circuits shall be dissimilar to the extent that electrical connections cannot be made which would electrically damage any portion of the equipment.

3.6.3 Interchangeability. All parts having the same manufacturer's part number shall be directly and completely interchangeable with each other with respect to installation and performance. Changes in manufacturer's part numbers shall be governed by the drawing number requirements of MIL-STD-100.

3.6.4 Screw Threads. Screw threads shall be in accordance with MIL-S-7742.

3.6.5 Thermal Design. The system shall be designed to incorporate within each assembly any necessary thermal devices required to comply with the environmental requirements of this specification, provided such devices are automatically activated/deactivated. The design of each type system shall not require any externally supplied heating or cooling devices such as fans, blowers, or ducting, etc.

3.7 Details of Major Assemblies.

3.7.1 Light Source Assemblies.

3.7.1.1 Modules. The light source assembly shall be designed to provide a light source module(s) incorporating high and low modes, and a base module for aircraft interfacing. The light source module and the base module shall be independently replaceable as separate modules requiring no more than fifteen (15) minutes of effort to remove and replace and requiring no special tools.

3.7.1.2 Interchangeability. The light source assemblies shall be designed to allow full interchangeability of modules between light sources in any aircraft position. This interchangeability shall require not more than fifteen (15) minutes of effort and no special tools.

3.7.1.3 Transparent Cover(s). The transparent cover(s) of the light source shall be glass which shall not craze, crack, discolor or dimensionally distort as a result of operational/environmental temperatures or other conditions. Further, the transparent cover(s) assemblies shall not deteriorate from ultra-violet radiation or aircraft cleaning chemicals. The transparent cover(s) shall not in any manner degrade color emission requirements as per 3.7.1.4. Plastics shall not be used in any optical portions of the system.

DRAFT

3.7.1.4 Chromaticity. The chromaticity of the light emitted by each light assembly shall be aviation white light, and/or aviation red, conforming to MIL-C-25050 revised to reflect FAS revisions for strobe light applications, except that the "X" chromaticity coordinate for aviation white light shall not be less than 0.285.

3.7.1.5 Dimensions. Dimensions shall be specified as per applicable category.

3.7.1.6 Mounting. Each light source shall be designed to mate with a mounting flange if needed and shall incorporate any necessary mounting provisions required to comply with the requirements specified. The mounting flange shall not be furnished as a component of the system.

3.7.2 Power Supply Assembly.

3.7.2.1 Modularization. The power supply assembly for each system shall be designed to provide maximum use of modular construction. The power supply assembly and the separate power supply module(s) shall be independently replaceable requiring not more than fifteen (15) minutes of effort to remove and replace, requiring no special tools.

3.7.2.2 Mounting. The power supply assembly design shall incorporate the necessary mounting provisions required to comply with the requirements specified for any mounting attitude including interior and exterior airframe mounting.

3.7.2.3 Dimensions. Dimensions shall be specified as per applicable category.

3.7.2.4 Finish. The finish of the power supply assembly shall be Lusterless Black, Color No. 37038 in accordance with FED-STD-595.

3.7.2.5 Circuit Overload/Electrical Damage Protection. The system design shall be such that, in case of either an open or short circuit of any light source in either the high or low mode, any other light source shall continue to operate and the system provided protection from impending electrical damage. Where fuses, circuit breakers, or such devices are used, these devices shall be located in an assessible service location and replaceable and resettable within fifteen (15) minutes with no special tools while on the ground.

3.7.2.6 Marking. The marking requirements specified herein apply to power supply assemblies for each system and shall conform to MIL-STD-130.

3.7.2.6.1 Fuse Holders. Where fuses are used, the current rating shall be identified adjacent to the fuse holder.

DRAFT

3.7.2.6.2 Circuit Breakers. Where circuit breakers are used, the current rating shall be identified adjacent to the breaker.

3.7.2.6.3 Electrical Connectors. Marking adjacent to electrical connectors shall identify the connected circuit to preclude improper connections.

3.8 Identification Marking. Equipment, assemblies, and parts shall be marked for identification in accordance with MIL-STD-130.

3.9 Workmanship. The system shall be constructed and finished to produce an item free from all defects which would affect proper functioning in service. Particular attention shall be given to neatness and thoroughness of soldering, wiring, marking of parts and assemblies, finish, alignment of parts, tightness of screw assemblies, and freedom of parts from burrs and sharp edges.

3.10 System Categories. A System Category consists of a grouping of aircraft which have similar limitations relative to strobe light installation. Categories may be expanded or added by the Government to provide for additional and or changing aircraft limitations. It is understood that the categories described herein may be applicable to aircraft outside of the defined category. Specification sheets are a specific implementation of category requirements. Each specification sheet for the category and type desired should be reviewed prior to the generation of additional systems. The categories are as follows:

DRAFT

3.10.1 Category A. Rotary Wing Aircraft.

3.10.1.1 System Description. Each type system shall consist of the following assemblies:

a. Two (2) each light sources, each with high (white) and low (red) modes.

b. One (1) power supply assembly.

3.10.1.2 Power Consumption. The system shall not require more than 300 watts of electrical power from an aircraft power source, averaged over each flash cycle.

3.10.1.3 Weight. Each system shall weigh a maximum of fifteen (15) pounds, exclusive of assembly interconnecting wiring and remote switches.

3.10.1.4 Light Source Location. One source shall be located to provide "top half hemisphere" coverage and the other source shall be located to provide "bottom half hemisphere" coverage.

3.10.1.4.1 Field of Coverage. The light emitted by the system shall have a vertical field of coverage as specified in paragraph 3.5.1 with I_H = 3500 e.cd. high mode and 150 e.cd. low mode, except that the 20^o to 45^o (and -20^o to -45^o) sector shall be 0.25 I_H and 45^o to 80^o (and -45^o to -80^o) sector shall be 0.03 I_H. Table 4 lists the Category A distribution. The horizontal field of coverage for each light source shall be 360 degrees. Figure 2 graphically represents this distribution.

3.10.1.5 Flash Rate. Each type system shall emit 100 to 120 flashes per minute with each flash alternating between light sources in either the red or white light modes. Light sources in either mode shall be synchronized to flash 180 degrees out of phase.

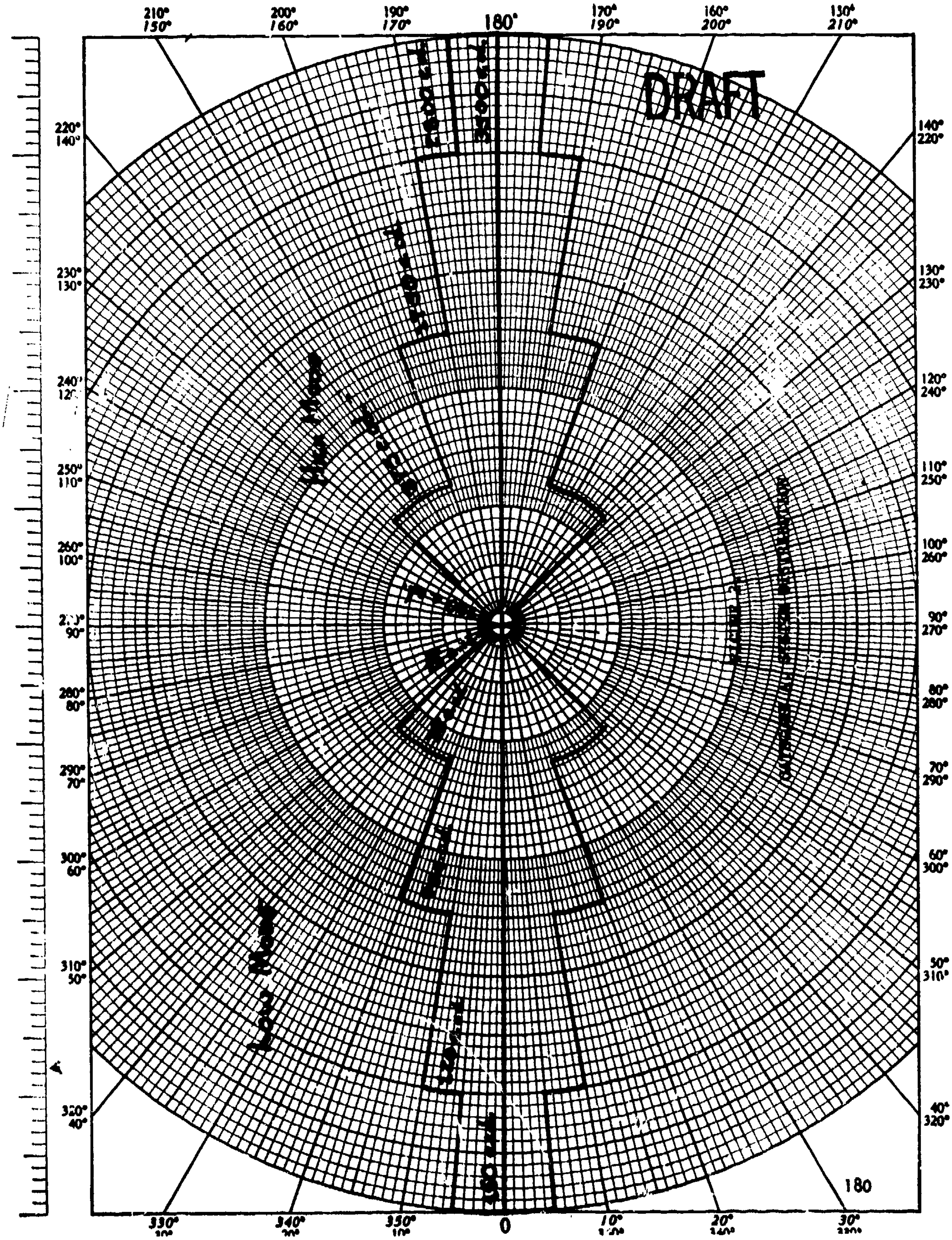
3.10.1.6 Dimensions. The light assembly shall conform to the maximum dimensional requirements depicted in Figure 3. The power supply assembly shall conform to the following dimensional requirements: length, width, and height including mounting provisions and connectors shall not exceed fourteen (14) inches each and the total volume shall not exceed 1120 cubic inches.

DRAFT

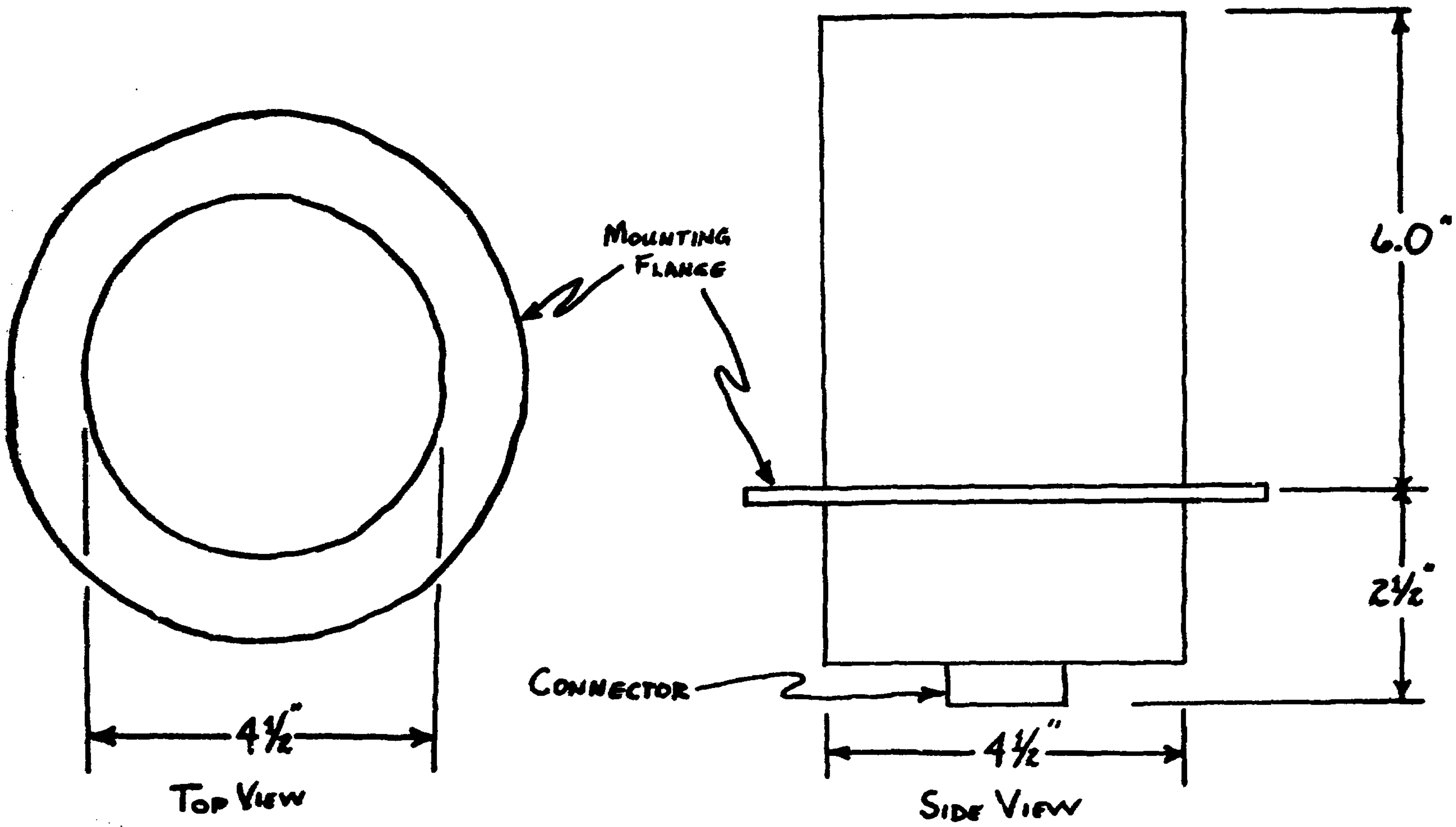
FROM HORIZONTAL	MINIMUM INTENSITY REQUIRED
-45° TO -80°	100 e.cd.
-20° TO -45°	875 e.cd.
-10° TO -20°	1750 e.cd.
-5° TO -10°	2800 e.cd.
0° TO -5°	3500 e.cd.
0° TO 5°	3500 e.cd.
5° TO 10°	2800 e.cd.
10° TO 20°	1750 e.cd.
20° TO 45°	875 e.cd.
45° TO 80°	100 e.cd.

TABLE 4

CATEGORY A DISTRIBUTION REQUIREMENTS



180°
DRAFT
210° 150°
200° 160°
190° 170°
170° 190°
160° 200°
150° 210°
220° 140°
230° 130°
250° 110°
260° 100°
280° 80°
290° 70°
300° 60°
310° 50°
320° 40°
140° 220°
130° 230°
120° 240°
110° 250°
100° 260°
90° 270°
80° 280°
70° 290°
60° 300°
50° 310°
40° 320°
330°
340°
350°
0
10°
20°
30°



DRAFT

FIGURE 3

CATEGORY A LIGHT ASSEMBLY MAXIMUM DIMENTIONAL REQUIREMENTS

DRAFT

3.10.2 Category B.

DRAFT

3.10.3 Category C.

PRELIMINARY DRAFT
NOT TO BE USED FOR PROCUREMENT PURPOSES

DRAFT

3.10.4 Category D.

DRAFT

3.11 System Types.

3.11.1 Type I. The Type I system shall be a strobe light system operated from a 28 VDC (Volt Direct Current) aircraft power source. The Type I system shall operate without damage within the following limits:

Low Limit	16 VDC
High Limit	28.5 VDC

Performance requirements specified herein apply only to the range 24 VDC to 28 VDC.

3.11.2 Type II. The Type II system shall be a strobe light system operated from a 115 VAC (Volt Alternating Current), 400 Hertz aircraft power source. The Type II system shall operate without damage within the following limits:

Low Limit	102 VAC at 380 Hz
High Limit	124 VAC at 420 Hz

Performance requirements specified herein apply only to the range 115 $\pm$ 5% VAC at 400 Hz $\pm$ 5%.

4.0 Quality Assurance Provisions.

4.1 General. This section shall be the basis for determining the extent of compliance with requirements specified herein. The term "inspection(s)" used herein shall be defined as the examination and testing required by this specification to demonstrate compliance as specified herein.

4.2 Responsibility for Inspection. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or purchase order, the contractor may use his own or any other facilities suitable for the performance of the inspection requirements specified herein. Inspection records shall be kept complete and available to the Government. All data not delivered to the Government as specified in the contract or purchase order shall be maintained in an orderly fashion to allow review by the Government upon demand. The Government reserves the right to perform any of the inspections set forth in this specification where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.3 Facilities. The contractor shall furnish any facilities, equipment, or personnel that the Government may require to insure that the system(s) meets the requirements of this specification. The facilities must be reviewed and approved by the Government prior to their use for the performance of the inspection requirements specified herein. The Government shall reserve the right to accept or reject an item as a result of such inspections if such inspections indicate the requirements of this specification have not been fulfilled.

4.4 Classification of Inspections. The inspections of the system shall be classified as follows:

a. Qualification inspections (4.4.1)

b. Acceptance inspections (4.4.2)

(1) Individual inspections (4.4.2.1)

(2) Sampling inspections (4.4.2.2)

4.4.1 Qualification Inspections. Qualification inspections shall be conducted by the Government or by the vendor, as determined by the Government, to insure that candidate equipment fully complies with requirements herein. Ten (10) candidate systems shall be submitted to qualification inspections cited herein. Satisfactory compliance with all qualification inspections shall form a basis for acceptance of candidate systems as qualified. The qualification inspections shall consist of the following:

4.4.1.1 Qualification Examinations. Each system shall be examined to determine conformance to the requirements specified herein with respect to materials, workmanship (assembly, construction, dimensions, tolerances, etc.), painting and marking. Each system shall be examined to determine that it is correctly assembled as evidenced by visual or other examination as required.

4.4.1.2 Qualification Testing. The candidate system shall, on the sampling basis described by paragraph 4.4.1, be subjected to the following operational tests prior to qualification acceptance. Physical mounting for these operational tests shall simulate typical aircraft installations, i.e., "Top" and "Bottom" of fuselage, "Wingtip," tail, etc.

4.4.1.2.1 Flash Rate. The flash rate of the candidate system shall be measured for compliance with normal operating ranges of 3.5.5.

4.4.1.2.2 Effective Intensity and Distribution. The intensity of each light source shall be photometrically measured under a complete and normal system interconnected configuration to insure compliance with intensity and distribution requirements specified by 3.5.1, 3.5.2, 3.5.3.

4.4.1.2.3 Chromaticity. The system shall be photometrically measured to insure that chromaticity of light for the system in all modes is in accordance with 3.7.1.4.

4.4.1.2.4 Electrical Tests.

DRAFT

4.4.1.2.4.1 Power Consumption. The power consumption shall be monitored throughout qualification testing to insure that power consumption of the system does not exceed the value specified in 3.5.9.1.

4.4.1.2.4.2 Electrical Malfunctions. The system shall be monitored throughout qualification testing for electrical short and open circuits. In the event of such malfunctions in the system, aircraft protection shall have been incorporated consistent with requirements of 3.7.2.5.

4.4.1.2.4.3 High/Low Voltage Survivability Tests. The candidate system shall be tested to insure it will operate without damage at the following voltage limits:

Type I System Test Requirements

Low DC Test Limit	16 VDC
High DC Test Limit	28.5 VDC

Type II System Test Requirements

Low AC Test Limit	102 VAC, Single Phase at 380 Hz
High AC Test Limit	124 VAC, Single Phase at 420 Hz

4.4.1.2.4.4 Normal Test Input Voltages. Qualification shall be performed at nominal input voltages for each type system, except where otherwise specifically required herein. Nominal voltage for Type I system shall be 28.0 VDC $^{+0\text{ VDC}}_{-1.5\text{ VDC}}$ and nominal voltage for Type II systems shall be 115.0 VDC $\pm$ 5%, Single Phase, 400 Hz.

4.4.1.2.5 Reliability Testing.

4.4.1.2.5.1 Reliability. Reliability testing to insure compliance with 3.5 shall be in accordance with Test Plan III and Test Level F of MIL-STD-781 except as otherwise specified herein. These system(s) shall have a minimum acceptable MTBF of 1000 hours, a specified MTBF of 2000 hours, with Decision Risks of 10% and a Discrimination Ratio of 2/1. The Reliability Duty Cycle shall have a seven (7) hours operation in the high mode followed by three (3) hours operation in the low mode with the system deactivated by the mode switch for one minute after each duty cycle. Vibration shall be applied continuously during the equipment "on" time. Temperature cycling shall be in accordance with the Alternative Method of Temperature Cycling (para 5.2.3.2 of MIL-STD-781). The time for stabilized equipment operation at both the lower temperature and higher temperature shall be the time required for one complete Reliability Duty Cycle. The time required for equipment to stabilize at either the lower temperature or higher temperature shall be no more than one (1) hour. Input voltage shall be at

DRAFT

the applicable nominal voltage. Input voltage cycling shall not be performed. There shall be no adjustments, preventive maintenance or replacement of assemblies, modules or components during the reliability testing except as specified in MIL-STD-781. Environmental tests shall be run concurrently with and the time included as part of the reliability testing time. Candidate systems shall be tested in complete normal operating configurations.

4.4.1.2.5.2 Reliability Test Failures. For each type system a failure is defined as having occurred when the system breaks, burns, cross-fires, fails optically, fails to meet flash rate requirements, performs erratically or otherwise displays evidence of not conforming to conditions specified in this specification which results during its normal operation. Failure of the cockpit control switche(s) shall not be counted as a failure of the system unless the failure is determined to be the result of inherent system design deficiencies.

4.4.1.2.5.2.1 Optical Failure of the High Mode. A failure of the high mode shall have occurred in the high mode when the light intensity falls below .85 I_H in the horizontal plane.

4.4.1.2.5.2.2 Optical Failure of the Low Mode. A failure of the low mode shall have occurred in the low mode when the light intensity exceeds 1.15 I_H or falls below .85 I_H or falls below .85 I_H in the horizontal plane.

4.4.1.2.5.2.3 System Failure Basis. All systems' failure criteria is predicated in normal voltages of 28.0 VDC or 115.0 VDC, respectively, unless specifically otherwise required herein (per paragraph 4.4.1.2.4 4).

4.4.1.2.6 Grounding Systems Tests. Grounding systems tests shall be performed to determine compliance with commercial aviation grounding standards. Compliance with paragraph 3.4.2.1 shall be demonstrated.

4.4.1.2.7 Environmental Tests. The following environmental tests shall be performed to assure durability and reliability of the materials and components under the environmental extremes specified in paragraph 3.5.7. Tests shall be conducted with candidate systems in their normal operating configuration.

4.4.1.2.7.1 Temperature-Altitude Test. Each type system shall be subjected to a temperature-altitude test in accordance with MIL-STD-810, method 504, procedure I, and shall demonstrate that the system meets the requirements of paragraphs 3.5.7.1 and 3.5.7.2.

4.4.1.2.7.2 Rain Test. Each type system shall be subjected to a rain test in accordance with MIL-STD-810, method 506, procedure I. Pretest data is required per MIL-STD-810, paragraph 3.2.1. The system shall be operated during the test. Data shall be collected before, during,

DRAFT

and after the test to demonstrate operation as specified in paragraph 3.5.7.3.

4.4.1.2.7.3 Humidity Test. Each type system shall be subjected to a humidity test in accordance with MIL-STD-810, method 507, procedure I. Pretest data is required per MIL-STD-810, paragraph 3.2.1 The system shall be operated during the test. Data shall be collected before, during, and after the test to demonstrate operation as specified in paragraph 3.5.7.3.

4.4.1.2.7.4 Fungus Test. Each type system shall be subjected to a fungus test in accordance with MIL-STD-810, method 508, procedure I. Pretest data is required per MIL-STD-810, paragraph 3.2.1. The system shall be operated at the end of the incubation period.

4.4.1.2.7.5 Salt Fog Test. Each type system shall be subjected to a salt fog test in accordance with MIL-STD-810, method 509, procedure I. Pretest data and post test data is required per MIL-STD-810, paragraph 3.2.1 and 3.2.4.

4.4.1.2.7.6 Dust Test. Each type system shall be subjected to a dust test in accordance with MIL-STD-810, method 510, procedure I. Pretest data is required per MIL-STD-810 paragraph 3.2.1. The system shall be operated during the test. Step 3 of the test shall be performed immediately after reaching stabilization of the temperature requirements of Step 2.

4.4.1.2.7.7 Explosive Atmosphere Test. Each type system shall be subjected to an explosive atmosphere test in accordance with MIL-STD-810, method 511, procedure I, and shall demonstrate that the system meets the requirements of paragraph 3.5.7.4.

4.4.1.2.7.8 Vibration Test. Each type system shall be subjected to vibration testing in accordance with MIL-STD-810, method 514 and table herein, and shall demonstrate that the system meets the requirements of paragraphs 3.5.7.5 herein.

4.4.1.2.7.9 Acoustical Noise Test. Each type system shall be subjected to acoustical noise testing in accordance with MIL-STD-810, method 515 and table herein, and shall demonstrate that the system meets the requirements of paragraph 3.5.7.5 herein.

4.4.1.2.7.10 Shock Test. Each type system shall be subjected to a shock test in accordance with MIL-STD-810, method 516, procedure I. Pretest data is required per MIL-STD-810 paragraph 3.2.1. The shock pulse shall be as shown in MIL-STD-810 figure 516.2-1 for flight vehicle equipment.

4.4.1.2.8 Electromagnetic Interference Test. Electromagnetic interference tests shall be conducted in accordance with tests procedures established by MIL-STD-462 to assure conformance to this specification. Minimum Test Requirements are as follows:

DRAFT

4.4.1.2.9 Extent of Testing and Test Conditions Not Covered Herein. The extent of testing and test conditions required to determine quality assurance for any component/module or subassembly of the system shall be determined by the Government. Joint Government/Contractor agreement shall prevail for cases where such criteria has not been included in this specification.

4.4.1.2.10 Material to Accompany Systems. Systems submitted by the Contractor for Government qualification inspections shall be accompanied by preliminary installation and operating instructions. Such instructional data shall include interconnection and operational specifications.

4.4.2 Acceptance Inspections. Acceptance inspections shall consist of individual inspections (those inspections performed on each and every system) and Sampling inspections (those performed on two (2) randomly selected samples of every one hundred (100) production systems) as follows:

4.4.2.1 Individual Inspections. Individual inspections shall be conducted to insure that each production system conforms to the requirements and standards established by this specification. Individual inspections consist of:

a. The Qualification Examinations defined in paragraph 4.4.1.1.

b. As a confidence test, the light output of at least a single radial vector will be selected and tested on each light source demonstrating that the source being tested meets the requirements of paragraphs 4.4.1.2.1 and 4.4.1.2.2. This confidence test will be conducted with a power supply having identical characteristics as defined for the light source under test.

c. Each power supply will be functionally tested to demonstrate required output.

4.4.2.2 Sampling Inspections. Sampling inspections shall be conducted to insure that production systems conform to requirements and standards established by this specification. Inspections shall consist of the qualification inspections of paragraph 4.4.1. Failure of any sample shall be grounds for increasing rate of sampling and/or cessation of production until failure cause has been determined and corrected. This shall be at the discretion of the Government.

DRAFT

4.5 Disposition of Test Samples. When the Government has contracted for candidate systems, the Government shall retain equipment tested. When candidate systems have been acquired for required testing at no cost to the Government, the equipment will be returned to the vendor at the end of scheduled test series. If equipment has performed in a manner at any time during testing which would disqualify it for further consideration within the test series and time frame scheduled, it will also be returned to the vendor.

4.6 Demonstrations. When specified in this specification or contract, reliability, environmental and maintainability compliance demonstrations shall be conducted by the Contractor and shall commence following the satisfactory completion of inspections and testing of the anti-collision strobe system at the site agreed to by the Government.

4.6.1 Reliability Demonstration. This demonstration shall be performed in accordance with the Government approved, Contractor prepared, demonstration plan. Proof of Contractor compliance with the demonstration plan shall include the necessary collection of operation and failure data in order that the Government may assess the extent reliability requirements specified herein have been achieved.

4.6.2 Maintainability Demonstration. This demonstration shall be performed in accordance with the Government approved, Contractor prepared, demonstration plan. Proof of compliance with maintainability requirements specified in this specification shall include the necessary collection of maintainability data in order that the Government may assess the extent that maintainability requirements have been achieved.

4.6.3 Environmental Compliance Demonstration. This demonstration shall be performed in accordance with the Government approved, Contractor prepared, demonstration plan. Proof of Contractor compliance with the demonstration plan shall include the necessary collection of operation and failure data in order that the Government may assess the extent environmental requirements specified herein have been achieved.

4.6.4 Necessary Test and Demonstration Data Collections. The data shall include names and identification of Government witnesses approved by the procuring activity.

5.0 PREPARATION FOR DELIVERY.

5.1 Preparation for delivery will be in accordance with the instructions of the procuring activity.

6.0 NOTES.

6.1 Operational Considerations. The anti-collision system shall be designed to replace the existing anti-collision system as a means for

DRAFT

detecting aircraft to avoid mid-air collisions during visual meterological conditions.

6.2 Essential Characteristics. To eliminate risks to the Government in procuring a proven capability, no equivalent will be accepted for the parameters forming essential characteristics of the system as described by this performance specification.

6.3 International Standardization Agreements. When amendment, revision, or cancellation of this specification is proposed which will affect or violate any international agreement, the preparing activity will take appropriate reconciliation action through international standardization channels including departmental standardization offices, if required.

PRELIMINARY DRAFT
NOT TO BE USED FOR PROCUREMENT PURPOSES

DRAFT

MIL-L-XXXX/1

MILITARY SPECIFICATION

LIGHT, HELICOPTER, ANTI-COLLISION, STROBE

This specification is approved for use by all Departments and Agencies of the Department of Defense.

This specification sheet describes a Cateogry A, Type I and Category A, Type II Strobe Anti-Collision Aircraft Light. The complete requirements for procuring Strobe Anti-Collision Helicopter Lights described herein shall consist of this document and the latest issue of MIL-L-XXXX.

APPLICABLE DOCUMENTS

The following documents of the issue in effect on date of invitation for bids or request for proposal(s) form a part of this specification to the extent specified herein:

SPECIFICATIONS

REQUIREMENTS

1. System Design. The system shall provide two (2) light sources, each consisting of both a red light mode (low) and a white light mode (high), either red or white mode being selectable utilizing remotely located (cockpit mounted) switches. The squat switch required in paragraph 3.4.1 of MIL-L-XXXX is not required.

PRELIMINARY DRAFT
NOT TO BE USED FOR PROCUREMENT PURPOSES

DRAFT

2. Mode Selection. In addition to the "white," "off," or "red" mode selection per MIL-L-XXXX paragraph 3.4.1.1 a second MS27408-1A switch shall be used for selection of either aircraft topside ("TOP") or aircraft bottom side ("BOTTOM") light source in the high or low modes with upper position being "BOTH," center position being "UPPER," and lower position being "LOWER."

3. Field of Coverage. The Field of Coverage shall be per paragraph 3.10.1.4.1 of MIL-L-XXXX. Each light shall have the vertical coverage shown in Figure 1.

4. System Description. The system described herein consists of either a Type I (NSN 6220-00-361-0644) or a Type II (NSN 6220-00-361-0614) system as designed by the U.S. Army Aviation Systems Command (AVSCOM) for use on their helicopters. Figure 2 shows the system assemblies and modules described herein.

4.1 Light Assembly. (AVSCOM P/N 1680-EG-035-9/NSN 6220-00-433-7175) The light assembly consists of three (3) modules and two (2) retained bands. The modules are as follows:

a.	Light Housing	AVSCOM P/N 1680-EG-035-17
b.	White Module	1680-EG-035-19
c.	Red Module	1680-EG-035-21
d.	Retainer band (for White Module)	1680-EG-035-23
e.	Retainer band (for Red Module)	1680-EG-035-25

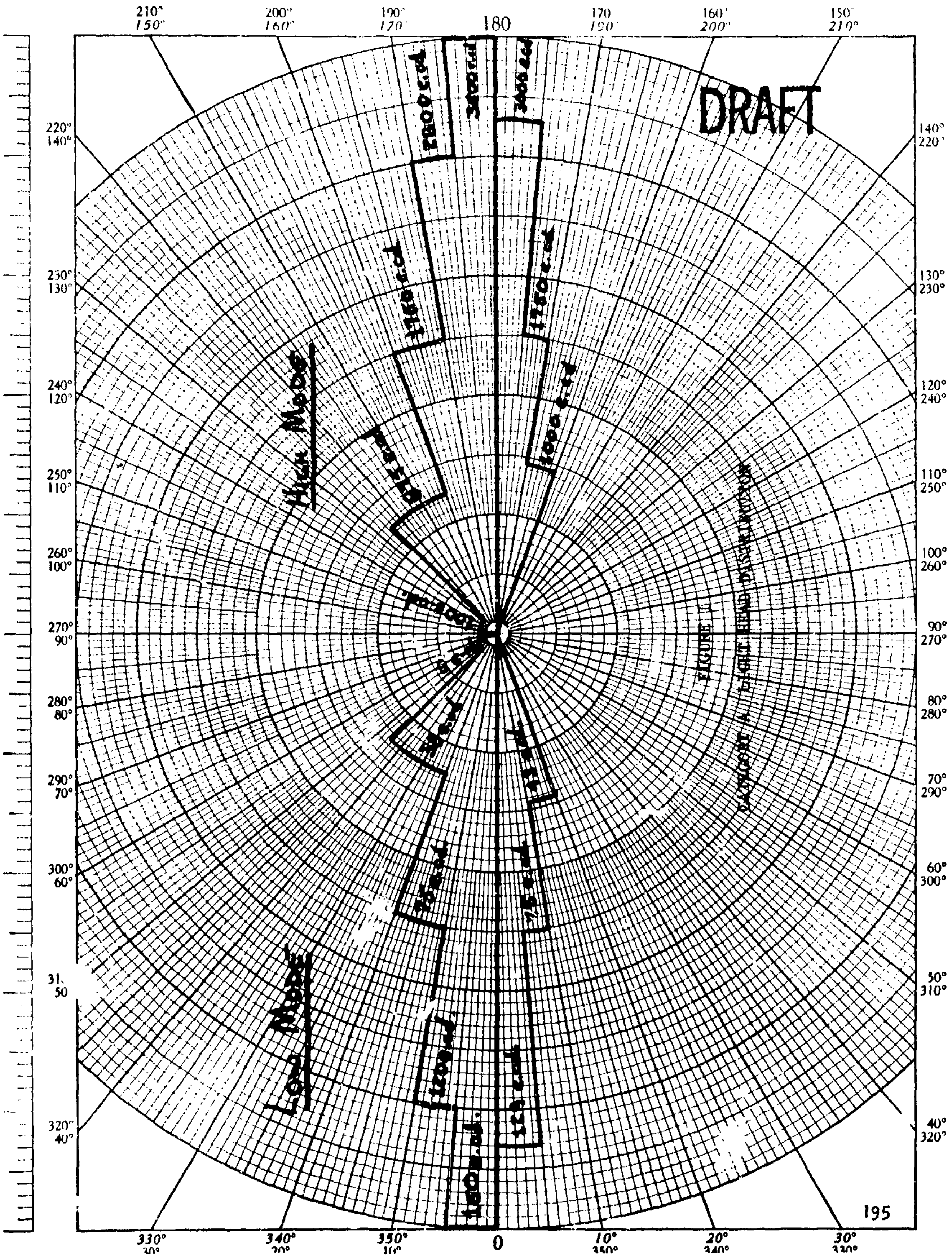
NOTE: The 1680-EG-035-9 Light Assembly consists of the 1680-035-17,-19,-21, -23, and -25 modules.

4.1.1 Light Housing. The Light Housing forms the base of the light assembly, contains the two trigger coils used to fire their respective light modules, and the MS 3122E14-5P connector to allow connection to the system supply.

4.1.2 White Module. The White Module forms the high or daylight mode of the light system. The module requires 100 joules and produces a minimum I_H (see paragraph 3.5.1 of MIL-L-XXXX) of 3500 e.cd.

4.1.3 Red Module. The Red Module forms the low or night more of the light system. The module requires 45 joules and produces a minimum I_H (see paragraph 3.5.1 of MIL-L-XXXX) of 150 e.cd.

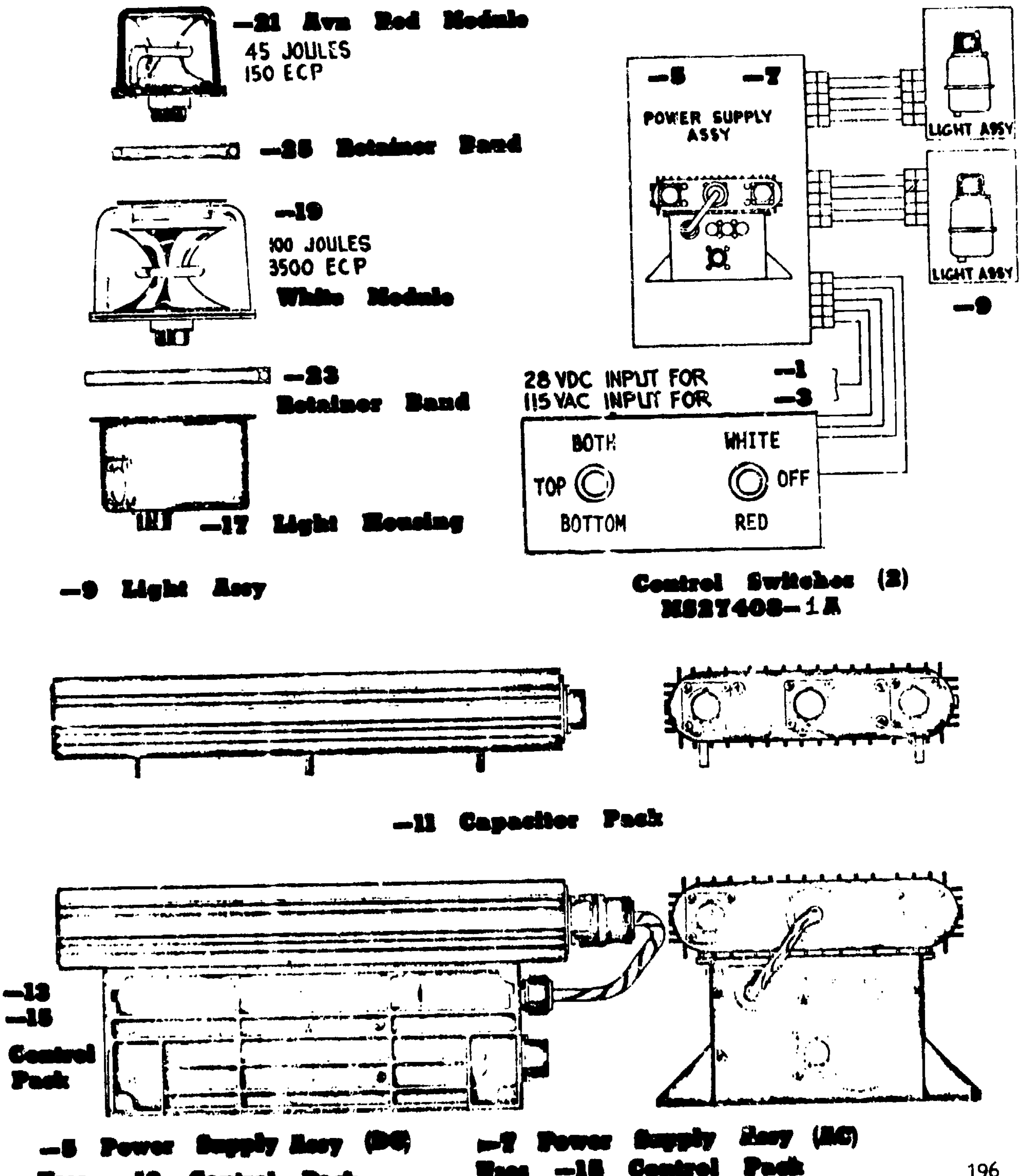
4.1.4 Retainer Band-White Module. The Retainer Band for the White Module is used to secure the White Module to the Base Module and allows for easy


DRAFT
180
0
High Mode
Low Mode
3400 cd
2800 cd
1760 cd
1000 cd
1200 cd
180 cd

ARMY AIRCRAFT ANTICOLLISION LIGHT SYSTEM

DRAFT

Type I Systems P/N 1680—EG—035—1*
Type II Systems P/N 1680—EG—035—3



*U. S. Army Aviation Systems Command (AVSCOM) Part Nos.

FIGURE 2

DRAFT

replacement during repair.

4.1.5 Retainer Band-Red Module. The Retainer Band for the Red Module is used to secure the Red Module to the White Module and allows for easy replacement during repair.

4.2 Power Supply Assembly. The Power Supply Assembly consists of two (2) modules (a Capacitor Pack and either a Type I or Type II Control). The complete Power Supply Assembly is either a Type I (28 VDC input) AVSCOM P/N 1680-EG-035-5/NSN 5945-00-475-9125 or Type II (115 VAC input) AVSCOM P/N 1680-EG-035-7/NSN 5945-00-475-9117. The modules are as follows:

a.	Capacitor Pack	AVSCOM	P/N 1680-EG-035-11
b.	Type I Control	AVSCOM	P/N 1680-EG-035-13
c.	Type II Control	AVSCOM	P/N 1680-EG-035-15

NOTE: The 1680-EG-035-5 Power Supply Assembly consists of the 1680-EG-035-11 and -13 modules. The 1680-EG-035-7 Power Supply Assembly consists of the 1680-EG-035-11 and -15 modules.

4.2.1 Capacitor Pack.

4.2.2 Type I Control.

4.2.3 Type II Control.

4.3 Related Components. The following components are required for complete system's installation but are not included in the procurement of the strobe light system. The components are as follows:

a. Switches and/or Control Panel

b. Mounting Flange

c. Cable(s)

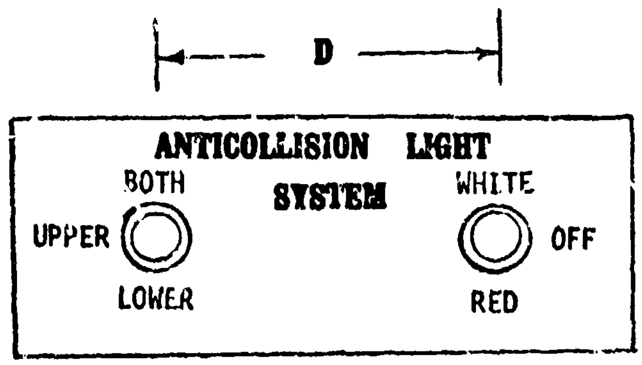
4.3.1 Switch and/or Control Panel. Two MS 27408-1A switches are required to operate the system (see paragraph 2 of this specification sheet). Figure 3 depicts a typical control panel.

PRELIMINARY DRAFT
NOT TO BE USED FOR PROCUREMENT PURPOSES

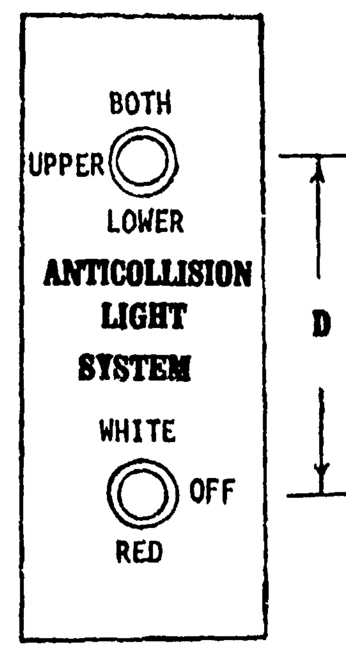
FIGURE 3

DRAFT

SWITCH ORIENTATION
FOR ARMY AIRCRAFT ANTICOLLISION
LIGHT SYSTEM
PART NUMBERS 1680-EG-035-1 AND -3



HORIZONTAL MOUNTING



VERTICAL MOUNTING

D - DIMENSIONED FOR ONE HAND, ONE MOTION POSITIONED SENSING AND OPERATION. (APPROX. 1.25 - 1.75 INCHES)

Switches shall be MS27408-4A, MS equivalent or composite switch panel, Control Assy, P/N 75-0310-1 & -3 for Type I and Type II Systems.

PRELIMINARY DRAFT
NOT TO BE USED FOR PROCUREMENT PURPOSES

DRAFT

4.3.2 Mounting Flange. A mounting flange must be provided to attach the Light Assembly to the aircraft. A typical Mounting Flange is depicted in AVSCOM Drawing No. 1680-EG-035-27.

4.3.3 Cables. Four cables are required for installation of the system described.

4.3.3.1 Power Supply to Light Assembly. Two cables conforming to MIL-W-81044 shall be provided to connect the appropriate power supply output to the light assembly (top and bottom). The cable shall be five (5) color coded stranded unshielded conductors. Three (3) conductors shall be #16 gage and two (2) conductors shall be #20 gage. All conductors shall be bundled in a braided shield and sheathed. Each cable shall have a MS 3126F14-5P connector on the power supply end and a MS 3126F14-5S connector on the light assembly end.

4.3.3.2 Power Supply to Control Switches. One cable conforming to MIL-W-81044 shall be provided to connect the appropriate power supply input to the cockpit control switches. The cable shall be four (4) color coded stranded unshielded #20 gage conductors. Conductors shall be bundled and overall sheathed. The power supply end shall have a MS 3126F14-5S Connector.

4.3.3.3 Power Supply to Power Bus. One cable conforming to MIL-W-81044 shall be provided to connect the power supply to the power supply bus. The cable shall be one (1) conductor color coded #16 gage and terminate in the connector of paragraph 4.3.3.2.

☆U.S. Government Printing Office: 1977 — 757-001/97