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INTEGRATED TEST AND EVALUATION OF AIRCRAFT
EXTERIOR LIGHTING

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Glenn Scott Kinney
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DEDICATION

This thesis is dedication to
my wife Jayne,
my son Justin,
and my parents Bill and Prue
whose support never ends and are my future

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I would like to thank Dr. Ralph Kimberlin, Dr. Ted Paludan, and Mr. Robert Richards my major professors and committee members for guidance and assistance. I would also like to thank the United States Navy for providing me the opportunity to further develop my education and work on some of the most advanced weapons systems in the world.

DISCLAIMER

The information presented in this thesis does not reflect the views of the Naval Air Warfare Center, Naval Air Systems Command, or the United States, it is the sole opinion of the author.

ABSTRACT

The integration, test, and evaluation of U.S. Navy military aircraft exterior lighting over the past ten years have created several unanswered questions. Attribute this to the development and integration of new lighting technology, Night Vision Imaging Systems (NVIS), and changes in operational performance requirements of military aircraft. Federal Aviation Regulations and Military Specifications specify current exterior lighting system performance requirements. The latest significant update to the performance requirements was in the mid-60's. This update was due to the development of supersonic aircraft and the relative increases in closure speeds (1). The purpose of this thesis is to provide technical information based on the research of current Navy aircraft exterior lighting performance requirements, existing exterior lighting military specification requirements, and aircraft exterior lighting test and evaluation procedures.

Existing Navy and military specification requirements establish baseline exterior lighting configuration requirements for both fixed wing and rotary wing aircraft. These specifications are generic providing general design guidance for the procurement or "detailed" specification. The detailed specification contains tailored military specification requirements defining specific design criteria

to fulfill current and unique operational and mission requirements for a particular aircraft. These tailored procurement specifications provide the ability to better define aircraft exterior lighting performance requirements. A key element that must be considered prior to defining a performance requirement is the ability to test it. It is impractical to define a performance requirement if it is not testable.

Advanced military aircraft like the U.S. Navy V-22, F/A-18E/F and Air Force F-117 are examples of the latest military aircraft with unique operational mission requirements. The integration of NVIS, advanced avionic systems and stealth technology is changing the look, shape and design of military aircraft. The primary impacts to conventional aircraft exterior lighting are new integration requirements due to current aircraft "system" integration requirements. Existing conventional exterior lighting performance requirements have not changed significantly, but the systems integration requirements have degrading lighting performance. The new system integration requirements are challenging to the aerospace lighting industry, emphasizing the significance of an integrated military aircraft exterior lighting system.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
1.1 BACKGROUND	1
1.2 SUMMARY	2
II. AIRCRAFT EXTERIOR LIGHTING SYSTEMS	4
2.1 OVERVIEW.	4
2.2 AIRCRAFT EXTERIOR LIGHTING.	6
2.3 U.S. NAVY AIRCRAFT EXTERIOR LIGHTING.	7
2.3.1 ANTICOLLISION LIGHTS	8
2.3.2 POSITION LIGHTS	8
2.3.3 LANDING, TAXI AND SEARCH LIGHTS	9
2.3.3.1 FIXED WING AIRCRAFT	9
2.3.3.2 ROTARY WING AIRCRAFT.	10
2.3.4 FORMATION LIGHTS	10
2.3.5 WING INSPECTION AND ICE DETECTION LIGHTS	11
2.3.6 AIR REFUELING LIGHTS.	11
2.3.6.1 REFUELING PROBE LIGHT	11
2.3.6.2 TANKER RECOGNITION LIGHT	12

2.4	NIGHT VISION IMAGING SYSTEMS	
	AIRCRAFT EXTERIOR LIGHTING. .	12
2.4.1	AIRCRAFT NIGHT VISION IMAGING	
	SYSTEMS	12
2.4.2	NVIS AIRCRAFT LIGHTING . . .	14
2.4.3	NVIS AIRCRAFT EXTERIOR	
	LIGHTING.	15
2.4.4	NVIS AIRCRAFT EXTERIOR	
	LIGHTING INTEGRATION. . . .	16
2.5	AIRCRAFT EXTERIOR LIGHTING	
	REQUIREMENTS AND SPECIFICATIONS	18
2.5.1	MILITARY AIRCRAFT EXTERIOR	
	LIGHTING.	19
2.5.2	NAVY AIRCRAFT EXTERIOR	
	LIGHTING INTEGRATION ISSUES .	21
2.5.3	NVIS AIRCRAFT EXTERIOR	
	LIGHTING REQUIREMENTS . . .	22

III. AIRCRAFT EXTERIOR TEST PROCEDURES AND

	INTEGRATION TOOLS.	23
3.1	OVERVIEW.	23
3.2	QUANTITATIVE EXTERIOR LIGHTING	
	GROUND TEST PROCEDURES . . .	24
3.2.1	GENERAL	24
3.2.2	UNITS OF MEASURE	26

3.2.2.1	VISIBLE LIGHT	26
3.2.2.2	NVIS RADIANT ENERGY	30
3.2.3	TEST PROCEDURES AND TEST EQUIPMENT	33
3.2.3.1	GENERAL	33
3.2.3.2	RADIATING POINT SOURCE	35
3.2.3.2.1	FLASHING POINT SOURCE	36
3.2.3.3	DIFFUSE SOURCE.	38
3.2.4	DATA ANALYSIS	39
3.2.4.1	ATMOSPHERIC ATTENUATION.	39
3.2.4.2	WINDSCREEN ATTENUATION	41
3.2.4.3	VISUAL PERSPECTIVE OF A DIFFUSE SOURCE.	43
IV	CONCLUSIONS AND RECOMMENDATIONS	45
4.1	CONCLUSIONS.	45
4.2	RECOMMENDATIONS	46
4.2.1	INTRODUCTION	46
4.2.2	JOINT ARMY, AIR FORCE, MARINES, AND NAVY AIRCRAFT EXTERIOR LIGHTING TEAM	47
4.2.3	NVIS EXTERIOR LIGHTING	47

BIBLIOGRAPHY	49
VITA.	52
APPENDIX	53

LIST OF TABLES

TABLE

1.	Comparison of Photometric Units and NVIS	
	Radiant Units	33
2.	Atmospheric Attenuation	41

LIST OF FIGURES

FIGURE

2.1 - Visual Representation of Electromagnetic Energy Emitted from a Diffuse Light Source	54
2.2 - Visual Representation of Electromagnetic Energy Emitted from a Point Source	54
2.3 - Colormetric Chart Defining Standard Aviation.	55
2.4 - Coverage Requirements for the Wing and Tail Position Lights: (a) Horizontal Plane, (b) Vertical Plane	56
2.5 - F/A-18 Formation Lights	57
2.6 - Refueling Probe Light: (a) Illumination Requirements, (b) Distribution Requirements	58
2.7 - NVIS Class A and Class B, and Eye Response .	59
2.8 - NVIS Type I Class A: (a) Helmet Mounted (b) NVIS Device.	60
2.9 - NVIS Type II Class B: (a) Helmet Mounted (b) NVIS Device.	61
3.1 - Illuminance Meter (Incident Power)	62
3.2 - Incident Power: (a) Photometer Cosine Receptor (b) Theoretical and Actual Relative Response Curves	63
3.3 - Luminance Meter (Radiant Meter)	64
3.4 - Spectraradiometer (PR-713/M)	65

3.5 - Anticollision Light Sample Test Data	
(T-45 Aircraft)	66
3.6 - Formation Light Reduction in Visual Area . .	67

LIST OF ABBREVIATIONS

cd	- Candela
cm	- Centimeter
C.I.E.	- International Commission on Illuminance
EL	- Electroluminescent
FAA	- Federal Aviation Administration
fc	- Footcandle
fL	- Footlambert
ICAO	- International Civil Aviation Organization
JACG	- Joint Aeronautical Commanders Group
LED	- Light Emitting Diode
lm	- Lumens
lx	- Lux
m	- meter
m-L	- Meterlambert
nm	- Nanometers
nmi	- nautical mile
NI	- NVIS Irradiance
NR	- NVIS Radiance
NRI	- NVIS Radiant Intensity
NVIS	- Night Vision Imaging System
r	- radius
sr	- Steradian
T	- Transmission

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Since 1986, the author has been an aircrew systems test and evaluation engineer of the Systems Engineering Test Directorate at the Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland. During the first three years the author was an assistant test engineer conducting aircrew station and cockpit evaluations. Since then the author has been a crew systems program performance monitor, and test and evaluation engineer. These duties involve writing detailed specification requirements, monitoring technical engineering design progress, technical report writing and briefings, preparation of test plans and cost estimates, and the development of new or advanced test and evaluation procedures. His experience includes single and multi year programs on helicopters, fixed wing patrol and cargo aircraft, and fixed wing fighter and attack aircraft.

New cockpit and crew station integration issues evolve due to the development of advanced technology in the aerospace industry. The integration test and evaluation of aircraft exterior lighting systems became a technical engineering issue during the author's participation of the U.S. Navy's A-12 program. This issue raised several unanswered questions; with

several remaining unanswered upon cancellation of the program. As a result, the author conducted technical research focusing on aircraft exterior lighting technology, test and evaluation procedures, and integration techniques and tools. This effort supported empirical laboratory and field tests, the development of test procedures, and identification of unique performance characteristics of aircraft exterior lighting.

1.2 SUMMARY

The primary objective of this thesis is to discuss the development of test procedures to evaluate aircraft exterior lighting subsystems as installed on Navy aircraft and lighting mockups. In addition, an objective was to provide a general overview of military aircraft exterior lighting subsystems and military specifications. The test procedures include a combination of laboratory and aircraft ground test techniques and equipment. Additionally, this thesis summarizes technical research of existing exterior lighting systems and requirements, and integration issues associated with U.S. Navy military aircraft exterior lighting. Initially some history behind the evolution of aircraft exterior lighting is discussed and the six primary aircraft exterior lighting subsystems are defined. Then a general overview of the military aircraft exterior lighting Military Specifications is presented. Once the conventional exterior lighting subsystems

are described, some significant design and integration issues are identified. New integration issues are due to technology advances in the aerospace industry, specifically the use of Night Vision Imaging Systems (NVIS). In continuing, a detailed description of developmental integration techniques, and test and evaluation procedures developed to quantify aircraft exterior lighting performance will be presented. The thesis is completed with the conclusions and specific recommendations.

Detailed integration requirements and operational mission requirements discussed are limited due to potential release of sensitive proprietary information. This work is primarily associated with the integration of NVIS aircraft exterior lighting. NVIS exterior lighting is a supplement to conventional military aircraft exterior lighting; the integration specifics and the use of these systems are not within the scope of this discussion. The primary emphasis of this thesis is how to test and evaluate military aircraft exterior lighting subsystems based on the lighting technology used and associated performance characteristics of common exterior lighting requirements.

CHAPTER II

AIRCRAFT EXTERIOR LIGHTING SYSTEMS

2.1 OVERVIEW

During the evolution of aircraft there was a time in history that recognized the significance of installing aircraft exterior lighting. The first aircraft exterior lights were navigation or position lights. Installation of the first position lights occurred in the late 20's and early 30's (2). The configuration of the position lights was copied after ship navigation lights. A green light was put on the right wing tip (starboard), a red light on the left wing tip (port), and a white light on the tail of the aircraft (2). During World War II the U.S. Navy and Army developed an aircraft exterior lighting standard to improve logistics and establish performance criteria. Installation of the first anticollision lights occurred in the mid-50's at the beginning of the "jet age" (2). The skies have become more crowded and the possibilities of midair collisions have increased as the development of the aircraft has progressed. In addition the integration of various navigation aides has made it possible to fly at night and during bad weather. As the technological advances in aircraft performance evolved, aircraft exterior lighting requirements have evolved as well.

Currently exterior lighting requirements are usually low on the priority list. Once conventional exterior lighting requirements were mastered in the mid-60's, consideration of aircraft exterior lighting performance requirements was minimal. Until the early 90's the aircraft exterior lighting industry had been complacent and minimal technological advances were made. In the civilian and commercial aviation industry the Strotek Corporation revealed evidence of this. The Strotek Corporation specializes in measuring the light output of anticollision lights. They conducted tests identifying that the vast majority of strobe type anticollision lights on civilian and commercial aircraft do not meet the 400 candelas Federal Aviation Administration (FAA) intensity standard (4). Strotek concluded that this was due to maintenance being performed only when the lights looked dim, or ceased to function. Strotek notified the FAA and recommended increasing the maintenance and testing of anticollision lights to avoid a potential safety problem. To date the FAA has not enforced or incorporated any significant procedural changes (4).

The integration test and evaluation of Navy aircraft exterior lighting systems became a technical engineering issue during the U.S. Navy's A-12 program. With the introduction of advanced technology, changes in military aircraft requirements, and the use of Night Vision Imaging Systems (NVIS) military aircraft exterior lighting integration is

changing. To date these issues raise several new and unanswered questions resulting in an elevated awareness of aircraft exterior lighting.

2.2 AIRCRAFT EXTERIOR LIGHTING

To attain military aircraft exterior lighting system performance requires the use of various types of lighting technology. The lighting subsystems used for specific exterior lighting functions are defined based on various operational performance priorities and trade study decisions. There are two primary categories of aircraft exterior lighting subsystems: 1. signaling systems 2. illumination lighting systems (2). Dependent upon the functional utility of the light, the exterior lighting systems will fall into one of these two categories. If lights positioned on the aircraft provide information or cuing, it is performing a signaling function (2). An example would be position lights, which are color coded signal lights intended to provide aircraft positioning or orientation information. In contrast, if the use of light illuminates or sheds light on to a surface to improve visibility, it is performing an illuminating function (2). An example would be landing lights, which illuminate the runway during takeoff and landing.

There are two types or divisions of lighting "technology" used for aircraft exterior lighting subsystems: 1. radiation

point sources 2. diffuse sources (5). The type of emission of the light energy is the primary difference. A radiating point source emits a uniform distribution of light energy and a diffuse source emits a nonuniform or scattered dispersion of light energy (see Figures 2.1 and 2.2). Examples of a radiating point source are Position Lights (signaling lights) and Landing Lights (illumination lights). Both categories of exterior lighting subsystems (signaling and illumination) consist of radiating point source type of light. An example of the second type of lights, diffuse sources, are formation lights (signaling lights). Diffuse light sources do not have good illumination qualities, due to the scattered dispersion of light energy, thus are limited in utility for aircraft exterior lighting use.

2.3 U.S. NAVY EXTERIOR LIGHTING SUBSYSTEMS

The U.S. Navy aircraft exterior lighting system consists of several lighting subsystems. There are primarily six categories of exterior lighting subsystems for fixed and rotary wing aircraft: anticollision lights, position lights, landing, taxi and search lights, formation lights, wing inspection and ice detection lights and air refueling lights. The following paragraphs provide general definitions of the functional utility, color, and coverage requirements.

2.3.1 ANTICOLLISION LIGHTS

Anticollision lights are signal lights intended to provide initial indication or position information of aircraft in airspace. It is a high intensity flashing Aviation Red or White light. The use of the term Aviation to define specific color boundaries is presented on the 1931 International Commission on Illumination (C.I.E.), chromaticity diagram (see Figure 2.3) (6). The boundaries define and identify chromaticity or color coordinates for Aviation Red, Green and White light to assure unambiguous color identification by a standard observer. The flash rates of anticollision lights are approximately 90 flashes per minute. Anticollision lights are usually placed on the top and bottom of the aircraft. The design is to provide complete coverage 360° around the aircraft and 30° above and below the horizontal plane of the aircraft (7). The only exception to this design and integration requirement is that the emitting light should not enter the cockpit and degrade the pilot's vision.

2.3.2 POSITION LIGHTS

Position lights are signal lights providing aircraft relative position or orientation information with respect to other aircraft. They consist of wing position and tail position lights. Wing position lights require installation at

the extremities of the wings, providing coverage in the horizontal plane forward and to the left and right 110° (7). The color requirements of the position light on the port (left) wing is Aviation Red. The color requirements of the starboard (right) position light is Aviation Green. The tail position light must be installed on the extreme aft of the aircraft providing coverage aft and to the left and right 70° (7). Color requirements for the tail position light is Aviation White. The wing and tail position light system provides 360° degree coverage around the aircraft in the horizontal plane. The vertical plane coverage requirements are 40° up and 40° down. (see Figure 2.4).

2.3.3 LANDING, TAXI AND SEARCH LIGHTS

2.3.3.1 FIXED WING AIRCRAFT

Landing and taxi lights are illumination lights that effectively provide high intensity light to illuminate runways and obstructions during landing and taxiing. The mounting of landing lights is typically on the wing or landing gear struts. These lights provide a narrow beam of light, 10° to 13° of angular-diameter (3), about the centerline and final approach path of the aircraft. Mounting of taxi lights is commonly on the nose gear strut (3). The primary function of this light is to illuminate any obstacles within the wing span

of the aircraft. A single landing taxi light is acceptable on U. S. Navy fighter and attack aircraft (e.g., F-14, A-6, & F/A-18) when space and weight limitations are an issue (7).

2.3.3.2 ROTARY WING AIRCRAFT

The helicopter search and hover lights are illumination lights. The primary function of these lights is to provide high intensity lighting to illuminate the ground or water under and forward of the aircraft. Common locations or positioning of the lights is below the cargo hatch and the cockpit. Functionally, search and hover lights are adjustable 15° in any direction from the installation position (7).

2.3.4 FORMATION LIGHTS

Formation lights are signal lights that provide a visual unambiguous orientation of the lead aircraft during formation flight. These lights are typically diffuse Electroluminescent lights, 36 inches in length and 2 inches wide. The design applications of the formation lights are to highlight critical points on the aircraft to provide attitude and position reference information (7). Integration requirements dictate the location of formation lights on both sides of the aircraft. Typical locations of individual formation lights include the outer edge of the wing tip, along the fuselage

forward of the wing root, along the rear quarter of the fuselage, and on the vertical stabilizer (see Figure 2.5).

2.3.5 WING INSPECTION AND ICE DETECTION LIGHTS

Wing inspection lights or ice detection lights are illumination lights. The primary function of these lights is to illuminate the wing leading edge for aircrew inspection of ice build up (7). These lights may also be used to illuminate the air intakes of engines mounted on the wings.

2.3.6 AIR REFUELING LIGHTS

2.3.6.1 REFUELING PROBE LIGHT

The refueling probe light is an illumination light located on the receiving aircraft. Color requirements for the probe light is Aviation Red or Aviation White. The function of the probe light is to illuminate the probe nozzle and the drogue of the tanker aircraft (7). The drogue, commonly called the basket, connects to the end of the tanker aircraft refueling hose. To receive fuel from the tanker aircraft the refuel-probe is inserted into the drogue. Distribution of the probe light should provide a 40° cone of light at the probe tip and be inclined 10° above the probe nozzle (see Figure 2.6).

2.3.6.2 TANKER RECOGNITION LIGHT

The tanker recognition light is a signal light. It replaces or is a modification of the existing anticollision lights. An Aviation Green light replaces at least one Aviation Red anticollision light (7). The primary function of this light is to emphasize the identity of the tanker aircraft.

2.4 NIGHT VISION IMAGING SYSTEMS AIRCRAFT EXTERIOR LIGHTING

2.4.1 AIRCRAFT NIGHT VISION IMAGING SYSTEMS

Night Vision Imaging Systems (NVIS) evolved from devices initially designed for ground troops to devices designed for aviator use. NVIS are passive helmet-mounted binocular devices that use image intensifier tubes. They are extremely sensitive to near infrared radiated energy between 600 and 930 nm of the electromagnetic spectrum, referred to as NVIS Radiance (NR). This energy is just beyond the visible range of the human eye that is sensitive between 400 and 700 nm (see Figure 2.7). At night with minimal levels of visible light and a relative high degree of NR energy, NVIS devices improve the ability of military aircrew to see in the dark. NVIS devices improve the operational performance of nap-of-the-earth flying and additional mission requirements (5).

There are various designs of aviation NVIS devices defined by Type and Class. The following is a description of the various Types and Classes:

- a. Type I: Direct view image NVIS using Generation III image intensifier tubes.
- b. Type II: Projected image NVIS using Generation III image intensifier tubes.
- c. Class A: NVIS using a 625 nm minus blue objective lens filter.
- d. Class B: NVIS using a 665 nm minus blue objective lens filter.

Type I Class A NVIS, (see Figure 2.8) is primarily used by the helicopter community. Type II Class B NVIS, (see Figure 2.9) is primarily used in the fixed wing community (5). The Class, 625 nm or 665 nm, defines sensitivity of the lower end of the electromagnetic spectrum for NVIS devices. The Class of NVIS device primarily establishes the design criteria for interior and exterior lighting systems and the amount of NR energy to be radiated from individual light sources.

2.4.2 NVIS AIRCRAFT LIGHTING

The integration of NVIS devices into military aircraft imposes several aircraft interior lighting design changes and performance challenges to the aircraft crew station and lighting design engineers. Military specification MIL-L-85762A defines the performance criteria for aircraft interior lighting (9). The basic utility of NVIS devices is to improve visibility of the terrain or physical obstructions for the pilot and aircrew during night operations. NVIS devices amplify low levels of electromagnetic energy ($1.0e^{-10}$ watts/cm²) or NVIS radiance, which is readily available at night, and transforms it into a visual scene for the user (9). The integration of NVIS into aircraft established the requirement to develop NVIS "compatible" interior lighting to optimize performance. NVIS compatible interior lighting consists of filtered light that restricts the emission of NVIS radiant energy into the cockpit environment. Reducing the NVIS radiant energy generated by the cockpit lighting optimizes the performance of NVIS by eliminating any interference between the cockpit lighting and night ambient scene illumination (9).

2.4.3 NVIS AIRCRAFT EXTERIOR LIGHTING

NVIS Aircraft exterior lighting design and integration are different from interior lighting. The design of NVIS exterior lighting is to emit NVIS radiance that is detectable and not overpowering to NVIS. The levels of NVIS radiance emitted by conventional exterior lighting systems are excessive and overpower the sensitivity of NVIS. Excessive NVIS radiance from conventional exterior lighting creates a visual hot spot or a blooming effect degrading NVIS performance and possibly damaging the image intensifier tubes. This occurrence represents the visual effect when looking toward the sun or a bright light with the naked eye. Therefore, NVIS exterior lighting has unique lighting characteristics different from NVIS compatible interior lighting.

There are two Categories of NVIS exterior lighting: NVIS "compatible" and NVIS "viewable" exterior lighting (5). NVIS compatible exterior lights are viewable to the human eye, and detectable but not offensive to NVIS devices. The use of filters restricts the level of NVIS radiance energy emitted and provides lighting visible to the human eye. NVIS compatible exterior lighting improves safety of flight and collision avoidance for NVIS and non-NVIS equipped aircraft. The concept of NVIS compatible exterior lighting is established but there is a significant amount of research and

engineering development that remains. It is a technological challenge to build a high intensity light that is visible to the naked eye and not offensive to NVIS. The filters used to absorb part of the NVIS radiance energy inherently generates a significant amount of heat that tend to crack or break during flight.

NVIS viewable aircraft exterior lighting is invisible to the naked eye and visible through NVIS. The design of NVIS viewable lighting emits prescribed amounts of NVIS radiant energy used to specifically meet operational mission requirements. The advantage of NVIS viewable exterior lighting is that the lights are invisible to the naked eye while providing signaling cues visible through NVIS devices. NVIS viewable lighting technology is further along than the NVIS compatible exterior lighting. This is attributed to the demand for NVIS viewable lighting; it was requested and envisioned first. The design and development of current NVIS exterior lighting technologies emit NVIS radiant energy and minimal, if any, visible light. The lighting technologies used are Light Emitting Diodes (LED) and Electroluminescent (EL).

2.4.4 NVIS AIRCRAFT EXTERIOR LIGHTING INTEGRATION

NVIS exterior lighting is a supplement to conventional aircraft exterior lighting meeting specific military operational requirements and applications (5). Typical NVIS

exterior lighting subsystems are NVIS position, anticollision, formation and search lights. The NVIS lighting subsystems are commonly co-located and consistent with the functional application of conventional exterior lighting subsystems. The one exception is the elimination of color coding due to the limited capability of NVIS (9). NVIS devices do not generate a multicolor visual image for the user. The visual image generated on a monochromatic display is of various shades of green. This eliminates the capability of using color coding as a coding or signaling technique, specifically position lights. Additional coding methods include alternative flash rates, or the addition of lights creating an asymmetrical configuration to differentiate the port and starboard sides of the aircraft. The utility of integrating NVIS position lights is limited, unless they are of the NVIS compatible category.

To optimize the integration of the NVIS exterior lighting requires additional exterior lighting controls. Additional independent variable brightness and mode selection controls will allow the aircrew turn on and off, adjust, and configure the exterior lighting system as required. These NVIS lighting controls provide the flexibility required to adapt to the various ambient lighting, atmospheric conditions, and operational mission requirements (9).

2.5 AIRCRAFT EXTERIOR LIGHTING REQUIREMENTS AND SPECIFICATIONS

Aircraft exterior lighting has evolved from various aircraft operational and safety requirements. The design of exterior lighting subsystems previously discussed perform specific functions to meet prescribed performance requirements. The military exterior lighting performance requirements are an extension of and primarily based on the civil aviation exterior lighting performance requirements specified in "FAA codes of regulations." The civilian exterior lighting regulations are standardized international agreements per the International Civil Aviation Organization (ICAO) to assure unambiguous visual signature, color and identification requirements (2). The primary purpose of the standardization is to maintain consistency for all aircraft traveling in national and international airspace. The performance requirements specified for Navy aircraft are in "Military Specifications." These Specifications define unique aircraft exterior lighting requirements for rotary wing and fixed wing aircraft, which are above and beyond standard civil aviation requirements. Military standards are design requirements approved by the Department of Defense and are for use by all Departments and Agencies. Specifications are design requirements approved by a Department or Agency of the Department of Defense. Military specifications contain

requirements that are characteristic of a department or agency.

2.5.1 MILITARY AIRCRAFT EXTERIOR LIGHTING

The exterior lighting requirements specified for military aircraft are in several military standards. The primary Navy exterior lighting specification is Military Specification MIL-L-006730 (Lighting Equipment: Exterior Aircraft, General Requirements For, of May 1971. The following is a list of additional military specifications:

- a. MIL-L-21652A Light Beacon, Anticollision, Aircraft, of 1 Jul 1983.
- b. MIL-A-19736A Air Refueling Systems, General Specifications For, of 16 Mar 1966.
- c. MIL-F-26301D Flasher, Aircraft Navigation Light, of 5 Oct 1973.
- d. MIL-L-6503H Lighting Equipment, Aircraft, General Specification For Installation Of, of 2 Apr 1975.

- e. AFGS-87240A Air Force Guide Specification, Lighting Equipment, Airborne, Interior and Exterior, of 31 Dec 1987.
- f. MIL-L-85314 Lighting Systems, Anticollision, Strobe, Red and White Mode, Wing, Fuselage, Vertical Stabilizer Mounted, of 27 Dec 1982.

Military aircraft as a minimum must meet FAA aircraft exterior lighting regulations. The military specifications contain FAA regulations and provide standardized exterior lighting performance requirements for various types of military aircraft. The current procurement procedures permit the flexibility of modifying and tailoring existing military standards and specifications in the detailed procurement specifications for new and upgraded aircraft. This procurement guidance is due to the number of military standards and specifications that are not current or up to date, and the lack of funding to generate new or updated ones.

The primary Navy aircraft exterior lighting specification (MIL-L-006730) was last updated in the late 1960's (5). This update was necessary due to technological advances and the development of supersonic aircraft. The primary justification was the relative increases in aircraft closure speeds. In 1965 and 1966 North American Aviation, Inc. conducted this research

for the U.S. Navy. A significant number of changes made to MIL-L-006730 were a result of this research.

2.5.2 NAVY AIRCRAFT EXTERIOR LIGHTING INTEGRATION ISSUES

Over the past thirty years the integration of aircraft exterior lighting has been a low priority. With the introduction of stealth technology, new lighting technology, and the use of NVIS, the emphasis on aircraft exterior lighting has heightened. Existing conventional aircraft exterior lighting intensity and coverage requirements have not changed significantly. The current changes are associated with new integration and ever changing military mission requirements. There are several technical engineering issues that have performance effect on aircraft exterior lighting: weight, aerodynamics, stealth, and power requirements. Weight requirements force the reduction of the number of lights and size of the individual lights. Aerodynamics and stealth require that the exterior lighting fixtures be contour to the aircraft. Power requirements are comparable to weight, less is always requested to improve efficiency. These issues can have a significant impact on aircraft exterior lighting performance. To resolve engineering design decisions integration engineers conduct trade studies during the preliminary design stage or milestone of a military aircraft program. These integration issues have changed the aircraft

exterior lighting technology and design philosophy. The integration of dual mode (conventional and NVIS) lighting systems specifically have generated several engineering design challenges. The primary system integration issue has been defining units of measure tied to quantitative measures of NVIS exterior lighting performance.

2.5.3 NVIS AIRCRAFT EXTERIOR LIGHTING REQUIREMENTS

NVIS exterior lighting integration requirements do not exist in a formal military standard or specification. Currently, various NVIS aircraft exterior lighting systems are and have been manufactured and integrated into military aircraft. The demand by the military aircraft squadrons supports that there are operational needs. However, there is minimal direction and no quantitative units of measure or measures of effectiveness. The current procedures used to quantify NVIS exterior lighting performance are qualitative flight tests and pilot comments, which require a significant amount of flight time and money. The initial formulation of units of measure and test procedures to collect quantitative data will be presented in Chapter III. The NVIS units of measure, together with aircraft specific operational and mission requirements, will define effective units of measure to support the development, test and evaluation of NVIS exterior lighting.

CHAPTER III

AIRCRAFT EXTERIOR LIGHTING INTEGRATION, AND TEST AND EVALUATION PROCEDURES

3.1 OVERVIEW

During the developmental phase of an aircraft program the use of computer generated models, scale models, engineering analysis and a full scale mockup typically support various engineering trade studies and design decisions. Computer-aided models and scale models are excellent developmental tools to assist in determining the placement and operational control requirements of aircraft exterior lighting subsystems. After establishing the initial aircraft exterior lighting configuration requirements, the next step is to conduct detailed engineering and design analysis of the individual lighting components. Subsequently the creation of a full scale aircraft lighting mockup supports the initial systems integration test and evaluation, and verification of the preliminary engineering and design analysis. The full scale lighting mockup evaluation and demonstration process is a significant milestone event during the development phase of an aircraft program.

The combination of the modeling, engineering analysis, and test and evaluation of lighting hardware is an imperative

process supporting the integration of military aircraft exterior lighting. These processes identify integration problems to assure that the exterior lighting system will meet the operational performance requirements prior to installation on an aircraft. Upon installation of the exterior lighting subsystems on the aircraft, the next step is to conduct ground and flight tests. The ground tests are quantitative test procedures comparable to the test procedures used on a lighting mockup. A combination of laboratory tests and field tests makes up the ground tests to support qualitative flight test results. The use of quantitative ground tests to support the integration of exterior lighting systems is limited. This chapter will discuss quantitative ground test procedures and engineering analysis, and briefly expand upon existing scale modeling and integration tools.

3.2 QUANTITATIVE EXTERIOR LIGHTING GROUND TEST PROCEDURES

3.2.1 GENERAL

The design of the test equipment to evaluate aircraft interior and exterior lighting is typically used in a laboratory environment. But, to verify and quantify the operational performance of integrated systems, testing has to be conducted on equipment installed on the aircraft. It is important to quantitatively evaluate the aircraft lighting

subsystems as installed on the aircraft to verify integrated system performance and to support qualitative flight test results. It is not uncommon to identify system integration problems of aircraft exterior lighting systems due to unforeseen electrical, reliability, obstructed visibility, coverage and light distribution difficulties.

The test and evaluation of aircraft exterior lighting subsystems installed on aircraft consist of collecting initial engineering, laboratory, aircraft ground test and flight test data. The approach to evaluating an exterior lighting system installed on an aircraft is to initially establish the operational performance criteria. The next step is to collect and analyze the engineering data that supports the design of each of the exterior lighting subsystems. It is important to witness the production representative laboratory tests conducted by the manufacturer of the aircraft exterior lighting systems. This is necessary to verify and witness the test procedures and equipment and to analytically relate the laboratory test data to the aircraft exterior lighting performance requirements. The lighting engineering data package should include; design and integration philosophy associated with the aircraft operational and mission requirements, location and placement of the individual light sources in three-dimensional coordinates, light source categories and types, exterior lighting cockpit controls, and subsystem lighting data (intensity, chromaticity and coverage

data). These data are analyzed prior to a mockup or ground test to reduce tests and identify any potential problem areas before testing. It is important to request these data as part of a data item deliverable specified in the procurement contract for an military aircraft program.

3.2.2 UNITS OF MEASURE

3.2.2.1 VISIBLE LIGHT

Aircraft exterior lighting, and light by definition, refer to the portion of the electromagnetic spectrum that the human eye can detect. Visible light covers a small part of the electromagnetic spectrum (10). The range of detection or wavelengths that the human eye is sensitive to are 400-700 nm. The wavelengths or combination of wavelengths depicts the visual sensation of color. The longer wavelengths with lower frequency produce red and the shorter wavelengths with higher frequency produce violet. Representative of other forms of electromagnetic energy, light travels through space at a constant velocity of 300,000,000 meters per second, and has a sinusoidal wave form.

Radiometric measurements relate to the measurement of electromagnetic energy. The energy units commonly used are joules or power units of watts or micro-watts, one joule per second equals one watt (10). The term luminous flux is derived

from units of radiant energy (joules) multiplied by the spectral sensitivity of the eye or "photometric curve" (10). The sensitivity of the eye varies as defined by the photopic curve (see Figure 2.7). Therefore the perception of brightness of equivalent amounts or levels of radiant energy at different wavelengths can vary. The cumulative effect of the photopic curve or sensitivity of the eye depicts the perceived color and relative brightness.

Photometric measuring equipment referred to as photometers have the same spectral sensitivity as the human eye. The use of photometers measures both incident and radiant forms of power (watts). The term, "incident," measures power incident or falling on a surface per unit area (10). It is important to remember that incident energy enters or strikes the photometer (illuminance meter) at a wide range of angles (see Figure 3.1). Thus, parallel incoming incident energy per unit area varies as the cosine of the angle between the incident energy and the normal or perpendicular imaginary line relative to the face of the photometer cosine receptor (10) (see Figure 3.2). Because of this relationship most photometers or illuminance meters have hemispherical diffusers as a receptor (11). These diffusers provide equal sensitivity from all angles of incoming light. This type of measurement generates units in photometric terms referred to as illuminance; power per unit area (watts/m^2 or lumens/m^2).

The second form of measurement, radiant energy, is power per unit area radiated from a surface (11). This energy reflects off a surface like a wall or table, or radiates from a surface like an electroluminescent panel or fluorescent lamp. The photometer used to measure radiant energy is very different from the incident photometer. It has directional characteristics because the measurement is quantifying power per unit area coming from the surface. The photometer receptor consists of an aperture that limits or shields all the energy except that coming from a specific direction through the aperture (see Figure 3.3). This type of measurement generates units in photometric terms referred to as luminance; power per unit area per steradian ($\text{watts/m}^2/\text{sr}$ or $\text{lumens/m}^2/\text{sr}$).

The units of measure to quantify light or the light output is luminous intensity, luminous flux, illuminance and luminance. The use of each of these units, in conjunction with photometric measuring devices discussed previously, quantifies specific characteristics associated with light energy.

Luminous intensity or candlepower is the theoretical intensity or light output of a point source of light. The unit of measure, candela (cd), is an international standard defined by the luminous intensity of $1/600,000 \text{ m}^2$ of a projected area of a black body radiator operating at the temperature of solidification of platinum (2046° K) under a pressure of 101,325 newtons per square meter (11). The unit of

measure candela was originally defined by the amount of light emitted from a candle.

Luminous flux or power is the rate at which light energy is emitted from a source per unit of time. One lumen (lm) is defined as the power present in a unit solid angle (steradian) from a point source of one candela (10). The unit conversion of 1 cd is equivalent to 12.56 lm or 1 cd is equivalent to 1 lm per steradian (11). This conversion factor comes from the total area of the sphere $4\pi r^2$ ($r = 1$ ft) or 12.56 square feet.

The measurement of illuminance is in terms of luminous flux per unit area or incident power. The unit of measure, footcandle (fc), is the measure lumens per square foot or lux (lx) the measure of lumens per square meter (11). Illuminance is measured to quantify the light output from a point source that emits a uniform distribution of light energy. The illuminance varies as a function of the distance from the point source of light. Mathematically illuminance is typically converted to candlepower by a relationship called the inverse square function (12). The inverse square law is defined in the equation that follows.

Inverse Square Law Formula:

$$cp = fc \times D^2$$

cp = candlepower

fc = footcandles

D = Distance from the light source (ft)

The measure of luminance is in terms of the amount of light reflected or radiated from a surface or radiant power. The unit of measure is lumens per square area (ft^2 or m^2) per solid angle (steradian), footlambert (fL) or meterlambert (m-L). This unit of measure relates to the radiometric measurement of radiant energy discussed earlier.

Color as discussed earlier is relative to the wavelength. The combination of wavelengths depicts the visual sensation of color. The use of a tristimulus color or chromaticity measurement technique defines color by numbers based on the photopic response of the human eye (10). The International Commission on Illumination (C.I.E.) establishes the Chromaticity Diagram (see Figure 2.3) as an international standard for measuring chromaticity (12). The process consists of measuring the relative percentage of the three primary colors red (x), green (y), and blue (z) (12). The relative percentages are then plotted on the chromaticity diagram as one chromaticity point. Some photometers are equipped with tristimulus filters to measure color.

3.2.2.2 NVIS RADIANT ENERGY

Units of measure for Night Vision Imaging Systems (NVIS) in comparison to photometric units are very similar. The primary difference is between the response curves. The NVIS response

curve range is approximately 600 to 900 nm, which is just beyond the photopic response curve (see Figure 2.7). The use of radiometric measurements to quantify power in units of watts or microwatts is the same. A tri-service military committee, namely the Joint Aeronautical Commanders Group (JACG) recognized that it was necessary to define a unit of measure to quantify the performance of NVIS compatible cockpit or interior lighting (13). The unit of measure established was NVIS radiance (NR) (13). This unit of measure was modeled after the definition of photopic luminance to represent the amount of energy emitted by a light source that is visible through the NVIS (13). NVIS Radiance is defined as the integral of the curve generated by multiplying the spectral radiance of a light source by the relative spectral response of NVIS (13). The development of NVIS Radiance was specifically to support the method of quantifying the level of NVIS radiance for NVIS compatible cockpit interior lighting. This unit of measure is relative to the measure of radiant power ($\text{watts/m}^2/\text{sr}$) or luminance ($\text{lm/m}^2/\text{sr}$).

To adequately quantify the performance of NVIS exterior lighting requires additional units of measure. The units of measure, NVIS Radiant Intensity (NRI) and NVIS Irradiance (NI), were required to support data analysis and quantitative performance predictions. To derive these units of measure theoretically, they were modeled after the photopic units of measure for luminous intensity and illuminance.

The conversion of NVIS radiance to NVIS irradiance is like the relationship or the conversion of luminance to illuminance. With the use of 100% reflective uniform diffuser the measured luminance ($\text{lm}/\text{m}^2/\text{sr}$) divided by π , an apostilb is equivalent numerically to illuminance (lm/m^2) or a metercandle (14). In English units 1 footlambert ($\text{lm}/\pi/\text{ft}^2/\text{sr}$) is equivalent to 1 footcandle (lm/ft^2). Typically the factor of π is commonly overlooked when using a 100% reflectance diffuser or plaque to convert measured radiance to irradiance because the photometric units of measure inherently contain the factor of π . It is important to remember the conversion of radiance to irradiance requires the multiplication of π times the measured radiance. The factor of π comes from the measuring area or circle ($A = \pi r^2$) of a spot photometer or radiance meter (12). The measurement of raw radiant and irradiant energy multiplied by the NVIS response curve generates the relative units of measure for NVIS radiance, irradiance and radiant intensity. The NVIS exterior lighting units of measure allow the use of the equations that quantify the two different categories or types of conventional or photometric light sources (point sources and diffuse sources). Table 1 provides a comparison of the photometric units and NVIS radiant units.

Table 1. Photometric Units and NVIS Radiant Units Comparison.

PHOTOMETRIC UNITS	NVIS RADIANT UNITS
Luminous Intensity (lm/sr)	NVIS Radiant Intensity (NVIS W/sr)
Illuminance (lm/cm ²)	NVIS Irradiance (NVIS W/cm ²)
Luminance (lm/cm ² /sr)	NVIS Radiance (NVIS W/cm ² /sr)

3.2.3 TEST PROCEDURES AND TEST EQUIPMENT

3.2.3.1 GENERAL

Prior to performing an evaluation of an exterior lighting system that is installed on an aircraft or lighting mockup it is important to analyze the operational performance requirements, engineering design information, and developmental lighting laboratory data as discussed earlier. Reviewing this information will assist in streamlining the aircraft or lighting mockup test procedures by identifying critical test points. The identification of critical test points as a result of preliminary analysis is acceptable to verify and quantify the performance of an exterior lighting system. It is important to recognize that tests conducted in a laboratory are more accurate. This is due to the increased sensitivity of the laboratory test equipment, and the ability to conduct the tests in a controlled environment. But aircraft

ground tests are necessary to verify the performance of the lighting system as installed on the aircraft. It is optimum to use a mix of laboratory, ground, and flight test data for analysis to evaluate the exterior lighting systems as installed or integrated on the aircraft. In addition it is not as effective to evaluate the performance characteristics of each individual light by conducting and analyzing ground or flight tests results only. In instances where there are no laboratory data, ground test may be the only way to collect quantitative data, dictating a more detailed ground test evolution. Additional detail does not require the use of different or more sophisticated test equipment, but requires the collection of additional data. The critical function of a test and evaluation engineer is to identify and define the scope of the tests. This will dictate the level of effort required to conduct and complete the tests efficiently and effectively.

The following paragraphs discuss the basic test procedures and equipment to evaluate the two different types of light (radiating point sources and diffuse sources). The basic test procedures will not change, the primary difference usually is the operational performance requirements and integration aspects of different aircraft. Analysis of the data as it relates to the operational performance requirements is conducted by applying the photometric and NVIS radiance mathematical relationships.

3.2.3.2 RADIATING POINT SOURCE

As defined in Chapter 2 and in the previous paragraphs there are two types of light sources; radiating point sources and diffuse sources. The performance of a point source light is quantified by measuring the light intensity (luminance or NVIS radiant intensity), light distribution or coverage, and color or spectral distribution. The procedures and equipment to collect the performance data are based on the inverse square law. To determine the luminance or radiant intensity requires measurement of illuminance or irradiance at a point in space. After collection of the data, the inverse square law is applied or the illuminance or irradiance is multiplied by the square of the distance in relative units. The inverse square law equation is presented as follows (12):

Inverse Square Law (12)

$$LI = I \times D^2$$

LI = Luminance Intensity or NVIS Radiant Intensity.

I = Illuminance or Irradiance.

D = Distance of the detector from the light source.

The fundamental requirement for the test equipment is that it is capable of defining various points in space relative to the aircraft, and that it measures the relative illuminance or

NVIS irradiance. A recommendation of items to define points in space relative to the aircraft is a detailed schematic of the aircraft, measuring tape, plum bob, angle finder, and a protractor. The schematic of the aircraft defines the location of the exterior lights in three-dimensional coordinates. The remaining items are measuring equipment to identify points in space. To quantify illuminance or NVIS radiance requires the use of a Spectraradiometer, NVIS spot photometer/radiometer and a diffuse reflectance plaque, or illuminance and irradiance meters, and a color-meter (see Figure 3.4). As discussed earlier the amount of data collected is dependent upon the scope of the tests and the detail required to accurately quantify the performance of a light source.

3.2.3.2.1 FLASHING POINT SOURCES

The primary exterior lighting subsystem that flashes is the anticollision lighting subsystem. Flashing lights have unique characteristics and are difficult to test. The evaluation of these lights is in terms of effective intensity, which is, the representative intensity of a fixed (nonflashing) light that appears equally bright (12). The fundamental theorem and application of the Blondel-Rey equation provides the capability to quantify the performance of anticollision lights. The Blondel-Rey equation is as follows:

BLONDEL-REY EQUATION (12)

$$I_e = \frac{\int_{t_1}^{t_2} I_t dt}{0.2 + (t_2 - t_1)}$$

I_e = Effective intensity (candela)

I_t = Instantaneous intensity as a function of time

$t_2 - t_1$ = Flash time interval (seconds)

0.2 = Constant

The data to support the Blondel-Rey equation drives the test procedure to evaluate flashing lights. The instantaneous intensity as a function of time is collected with the use of an illuminance or irradiance meter containing an analog voltage output, an analog to digital converter, a personal computer, and computer software to analyze the data. A sample of representative test data of the T-45 anticollision light is provided (see Figure 3.5). The effective intensity of the T-45 anticollision light was calculated by integrating the area under curve represented mathematically by two separate equations of a line. There are other measurement devices available that are automated specifically to quantify the performance of flashing lights.

3.2.3.3 DIFFUSE SOURCE

The second type of light source, diffuse source (e.g., formation lights), is quantified by measuring luminance or radiance and the surface area of the light source. The visibility or detection of a diffuse light source is not only dependent upon the measured luminance or radiance but is also dependent upon the size of the light. This is based upon the theoretical relationship of spatial summation of a diffuse source. The theoretical relationship is Ricco's Law (15). The product of measured luminance and area equals a constant or "k value." The equation is as follows:

Ricco's Law (15)

$$k = L \times A$$

k = Constant

L = Threshold luminance energy

A = Surface Area

The k value represents the total energy required for detection of a diffuse light source. At a given distance the k value is the same, whether the diffuse light energy is highly concentrated in a small area or the diffuse energy is low and spread out over a large area (5).

3.2.4 DATA ANALYSIS

In addition to the units of measure and the data collection procedures previously discussed it is necessary to analyze the data in relation to the operational performance requirements. If the photometric or radiometric data exceed or fail the specified performance requirement at times it is necessary to answer the question of the operational performance impact. The equations defined in the test procedures and equipment section of this thesis are the framework of analytical methods of quantifying the operational performance of aircraft exterior lighting. There are additional analytical methods to more accurately model or predict the operational performance of aircraft exterior lighting systems. Additional operational and environmental considerations that affect the detection of aircraft exterior lights are atmospheric attenuation, and windscreen attenuation. An additional factor to consider for diffuse sources (formation lights) is the perspective of the visual angle to the light from the observer. These factors are not inclusive, but are contributors that affect visual detection of aircraft exterior lights.

3.2.4.1 ATMOSPHERIC ATTENUATION

The atmosphere absorbs or attenuates a percentage of the electromagnetic energy as it travels at the speed of light

from the source to the observer. Dependent upon the atmospheric conditions, the distance for threshold visibility will vary. As the atmospheric conditions degrade, the attenuation of light energy will increase, degrading detectability of a light source, which is based on Allard's Law (5). This factor can be accounted for and incorporated into the Inverse Square Law equation and Ricco's Law. The formulas are as follows:

Allard's Law (Inverse Square Law) (2)

$$I = (IR \times D^2) / AT^d$$

I = Intensity of light source (cp, NRI)

IR = Threshold Irradiance (fc, NI)

D = Distance (ft, cm)

AT = Atmospheric attenuation per nautical mile (%/nmi)

d = Distance (nmi)

Allard's Law (Ricco's Law)

$$k = (L \times A) / AT^d$$

k = Constant

L = Threshold luminance energy

A = Surface Area

AT = Atmospheric attenuation per nautical mile (%/nmi)

d = Distance (nmi)

The atmospheric attenuation coefficients for the photopic and NVIS visual spectrums are presented in Table 2. As shown in the table, atmospheric attenuation of NVIS is less than attenuation that occurs in the photopic region. The attenuation is higher at shorter wavelengths, toward the ultraviolet region of the photopic spectrum. Allard's Law improves the ability to more accurately quantify the performance of photopic and NVIS exterior lighting subsystems.

Table 2. Atmospheric Attenuation.

Meteorological Conditions Sea-Level	Unaided Eye Visible Attenuation nmi^{-1}	Aided Eye NVIS Attenuation nmi^{-1}
Exceptionally Clear 37 mile visibility	~93%	~95%
Very Clear 25 mile visibility	~90%	~92%
Clear 9 mile visibility	~74%	~80%
Light Haze 5 mile visibility	~55%	~63%
Medium Haze 3 mile visibility	~22%	~40%

3.2.4.2 WINDSCREEN ATTENUATION

The windscreen or windshields on military aircraft are made of different materials and combinations or layers of materials. These materials attenuate photometric and NVIS electromagnetic energy. The range of attenuation can be as

high as 50% varying from one model of aircraft to the next. Windscreen attenuation is quantified simply by measuring the light energy per wavelength of broadband light source, typically white, with a spectroradiometer to establish a baseline spectral distribution. The measurement is repeated with the windscreen placed in the path of the light energy. The measured light energy and spectral distribution of these measurements are compared with the difference or resultant defining windscreen attenuation. The photopic and NVIS attenuation for a particular aircraft is typically available and it is safe to assume worse case. It is simple to visualize the complete scenario of the photopic or NVIS electromagnetic energy traveling through the atmosphere, then at some point passing through the windscreen in to the cockpit and the pilot. Again the electromagnetic energy is attenuated as it passes through the material of the windscreen. The windscreen attenuation factor is applied to the Inverse Square Law and Ricco's Law in conjunction with Allard's Law as presented in the following equation.

Allard's Law (Inverse Square Law)

$$I = ((IR \times D^2) / AT^d) / T$$

I = Intensity of light source (cp, NRI)

IR = Threshold Irradiance (fc, NI)

D = Distance (ft, cm)

T = Atmospheric Transmission per nautical mile (%/nmi)

d = Distance (nmi)

T = Windscreen attenuation (%)

Allard's Law (Ricco's Law)

$$k = ((L \times A) / AT^d) T$$

k = Constant

L = Threshold luminance energy

A = Surface Area

AT = Atmospheric attenuation per nautical mile (%/nmi)

d = Distance (nmi)

T = Windscreen attenuation (%)

3.2.4.3 VISUAL PERSPECTIVE AND ANGLES OF A DIFFUSE SOURCE

Ricco's Law as discussed previously supports the performance quantification of a diffuse light source. It became apparent as a result of flight and ground tests that the visual perspective or visual angle of the light to the observer has an impact on visual detection. Typically diffuse or formation lights are mounted flush to the aircraft surface and the visual perspective of these lights is usually off angle. Rotation of these lights vertically and horizontally reduces the visual area thus reducing the visual detection of the lights. The use of basic trigonometric functions will

determine the reduction in visual area (see Figure 3.6). The configuration of aircraft in formation flight depict a 30° - 45° viewing angle between the aircraft. The reduction of visual area of formation lights is a function of the formation flight configuration requirements. If not accounted for the operational performance predictions will be incorrect.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Aircraft exterior lighting is an operational subsystem that primarily does not improve how the aircraft flies, but it provides signaling and illumination to support the operational environment of civilian, commercial and military aircraft. The integration of aircraft exterior lighting systems can take many forms. The type of aircraft and operational requirements define the integration requirements. Integration is a key word that emphasizes the importance of any subsystem working in conjunction with other subsystems that make up an aircraft. Military aircraft, specifically Navy aircraft, were the primary focus of this analysis because of additional and stringent operational requirements. The basic design guidelines, or requirements, for military aircraft exterior lighting have evolved from international agreements, FAA codes of regulations and the mission requirements defined for a particular military aircraft. The process of designing and integrating exterior lighting systems for today's military aircraft is changing because of new operational requirements.

New operational requirements create a trickle down effect resulting in additional design and integration requirements

affecting the performance of exterior lighting systems. To address new design issues, computer generated models, scale models and analytical research assist in conducting performance trade studies. Upon completion of the preliminary design trades the next step is to conduct tests to evaluate the exterior lighting and subsystem hardware. Preliminary or developmental tests include laboratory and possibly full scale lighting mockup evaluations. At a later phase the exterior lighting hardware is evaluated on an aircraft during ground and flight tests. The use of quantitative units of measure and test procedures for exterior lighting will enhance this design and integration process by establishing quantitative performance requirements, strengthen trade study results, and support ground and flight tests. The primary application of quantifying aircraft exterior lighting performance is to improve safety of flight, while reducing design, manufacturing and flight costs.

4.2 RECOMMENDATIONS

4.2.1 INTRODUCTION

Operational performance requirements of military aircraft exterior lighting systems are being discussed independently by the Army, Air Force, Navy, and Marines, specifically associated with the use of Night Vision Imaging Systems. There

are several integration issues, concerns, and details that need to be addressed. Based on the experience and results of the effort to establish, quantify, and test aircraft exterior lighting two future challenges and recommendations were identified.

4.2.2 JOINT ARMY, AIR FORCE, MARINES, AND NAVY AIRCRAFT EXTERIOR LIGHTING TEAM

Based on this extensive analysis of aircraft exterior lighting requirements and the development of quantitative test and evaluation procedures the author recommends formation of a joint Army, Air Force, Marines, and Navy aeronautical commanders team on aircraft exterior lighting. This group is representative of the Night Visions Imaging Systems cockpit interior lighting group. The joint exterior lighting team will provide a formal process to discuss lessons learned and establish common ground rules. The remaining recommendation is challenge to the exterior lighting industry.

4.2.3 NVIS EXTERIOR LIGHTING

The use of NVIS in military aircraft has rapidly increased in the past ten years. Several midair collisions have occurred with the use of NVIS during peace time operations. This is the primary justification for recommending

the development of NVIS compatible exterior lighting. NVIS compatible exterior lighting is visible to non-NVIS equipped aircraft and does not degrade the performance of NVIS equipped aircraft. This will provide aircraft exterior lighting that is visible to the non-NVIS equipped aircraft and eliminate NVIS degradation to improve safety of flight and collision avoidance.

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VITA

Glenn Scott Kinney was born in Parkersburg, West Virginia on February 6, 1963. He lived in Parkersburg throughout his childhood and graduated from Parkersburg High School in 1981. In that same year he began his college career at West Virginia University. During his tenure at West Virginia University, he pursued a degree in Industrial Engineering and was a member of the football team where he participated in three major Bowls, and received the Dedication Desire Award presented by the Toledo Club North at Toledo Ohio in 1985. After graduating in 1986 with a Bachelor degree in Industrial Engineering, he began working for the Aircrew Systems Department, Systems Engineering Test Directorate at Naval Air Warfare Center Aircraft Division Patuxent River Maryland. During the first three years he was an assistant test engineer conducting aircrew station and cockpit evaluations. Since then he has been a crew systems program performance monitor, and test and evaluation engineer. His experience working with the integration of Night Vision Imaging Systems tied specifically with cockpit lighting lead to the investigation of aircraft exterior lighting performance requirements, and test and evaluation procedures. The experience received at the Naval Air Warfare Center guided the development of this thesis.

APPENDIX

FIGURES

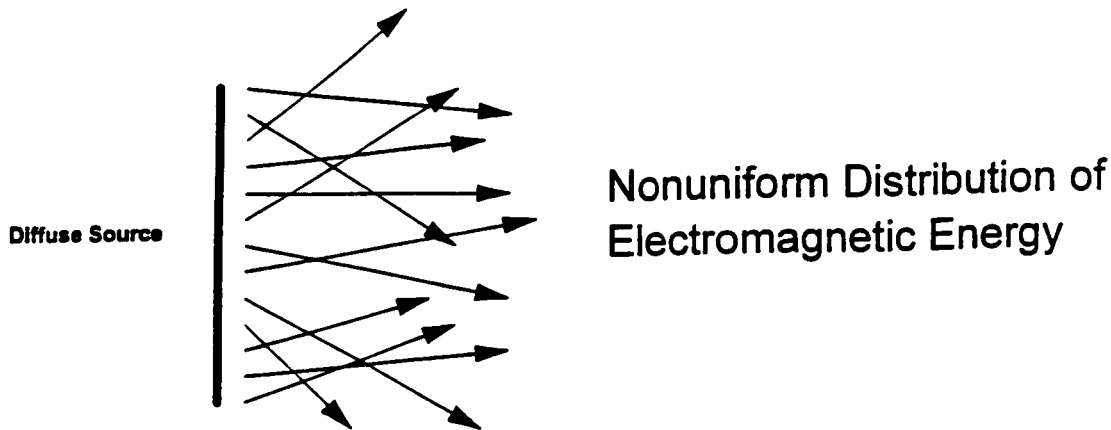


Figure 2.1 - Visual Representation of Electromagnetic Energy Emitted from a Diffuse Light Source.

Source: S. Kinney and R. Simpson, "Quantification of NVIS Exterior Lighting Performance." Technical Memorandum, Naval Air Warfare Center Patuxent River, Maryland, October 1993.

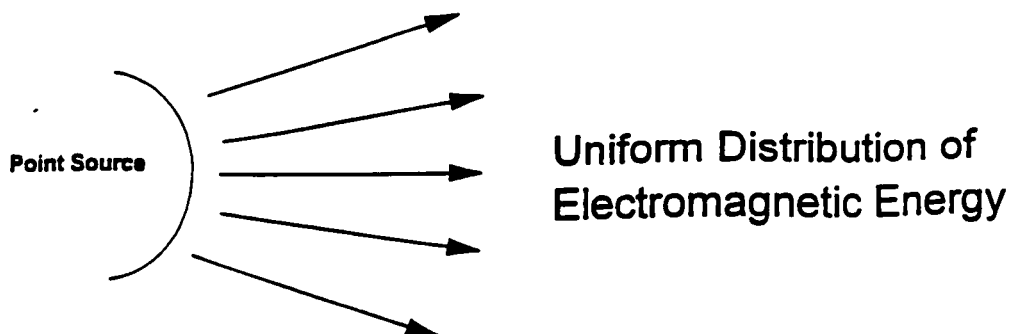


Figure 2.2 - Visual Representation of Electromagnetic Energy Emitted from a Point Source.

Source: S. Kinney and R. Simpson, "Quantification of NVIS Exterior Lighting Performance." Technical Memorandum, Naval Air Warfare Center Patuxent River, Maryland, October 1993.

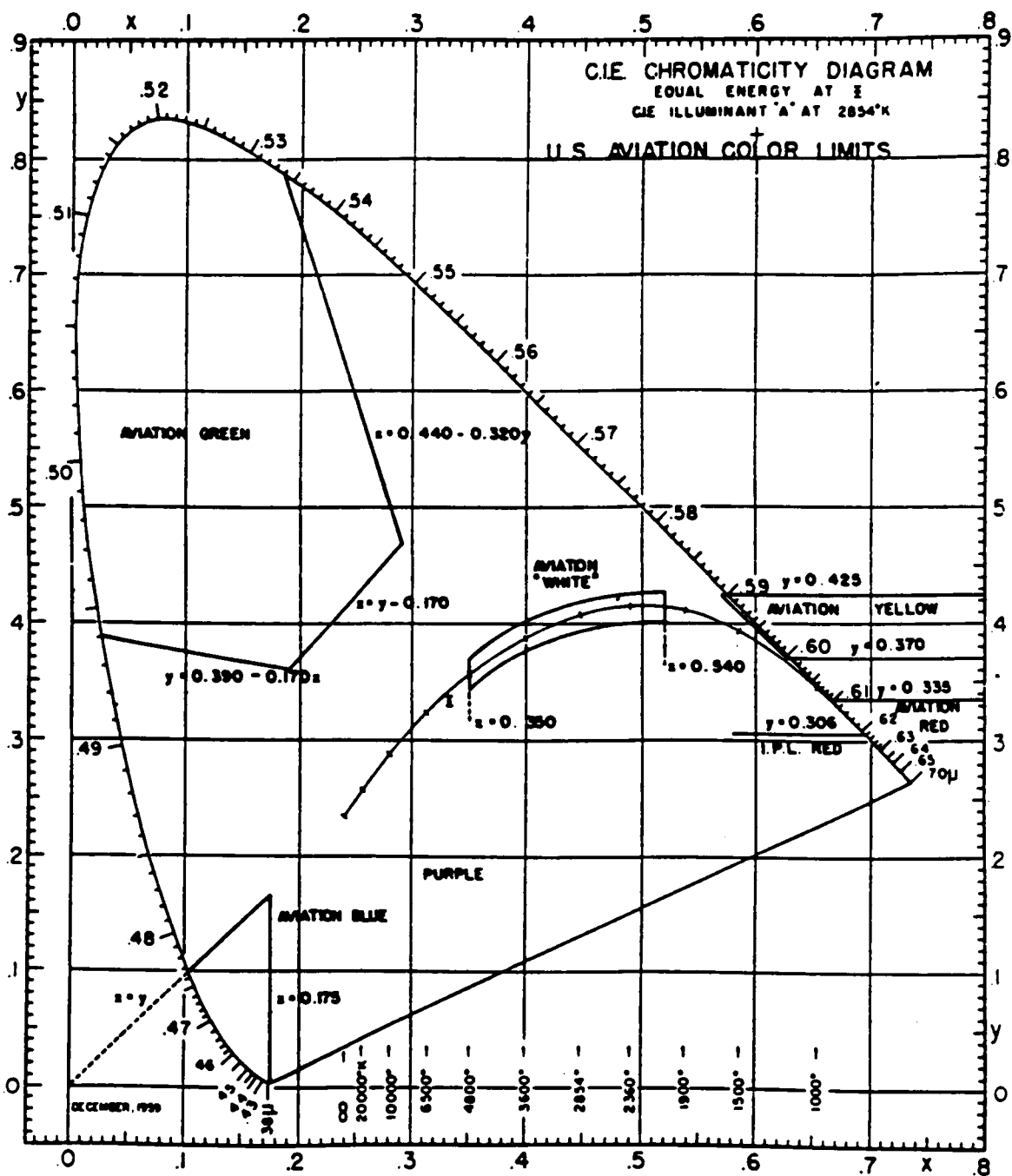


Figure 2.3 - Colormetric Chart Defining Standard Aviation Colors.

Source: Military Specification, "Colors, Aeronautical Lights and Lighting Equipment, General Requirements for", Specification Number MIL-C-25050, December 2 1963.

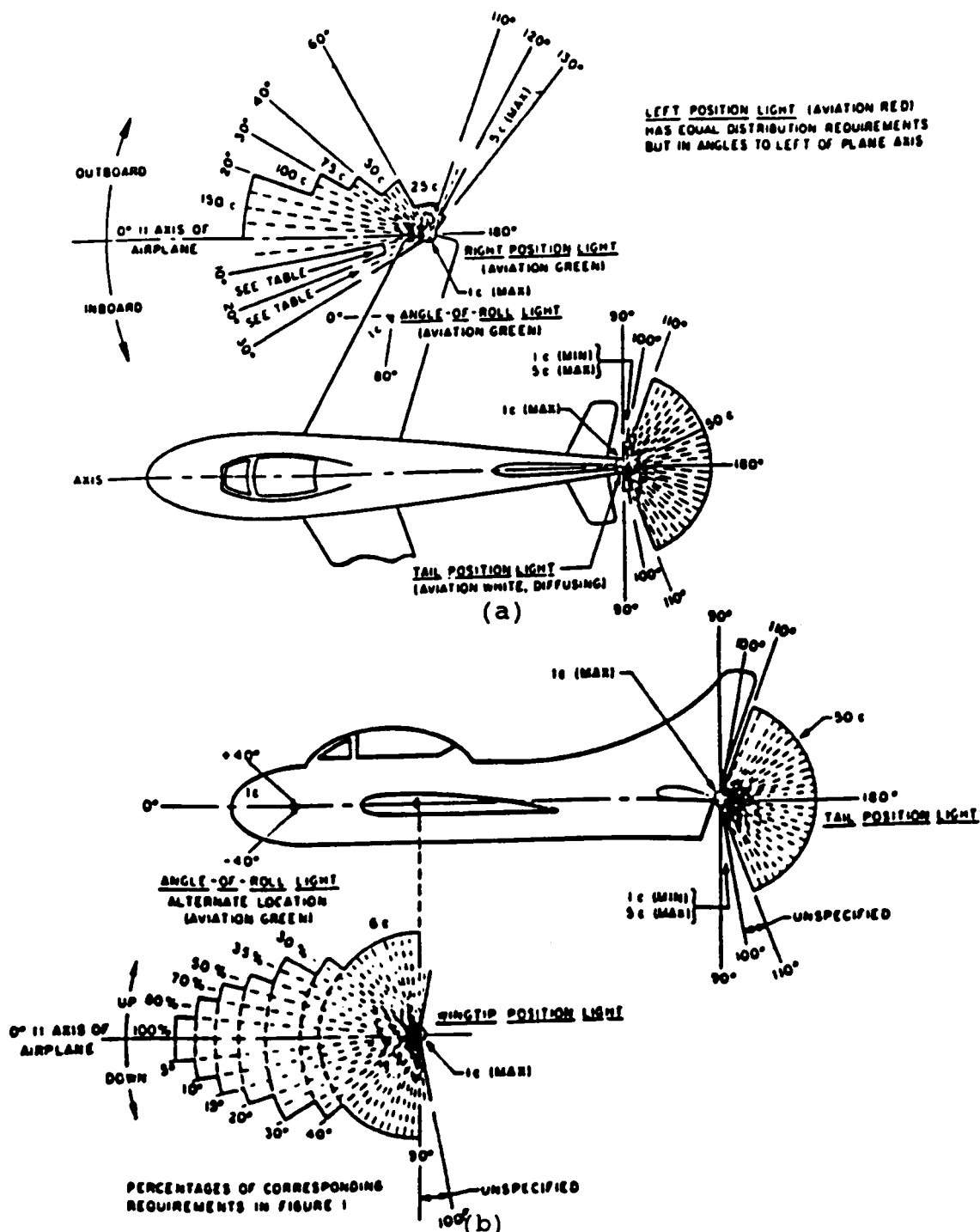


Figure 2.4 - Coverage Requirements for the Wing and Tail Position Lights: (a) Horizontal Plane, (b) Vertical Plane

Source: Military Specification, "Lighting Equipment; Exterior, Aircraft General Requirements for", Specification Number MIL-L-006730, December 2 1963.

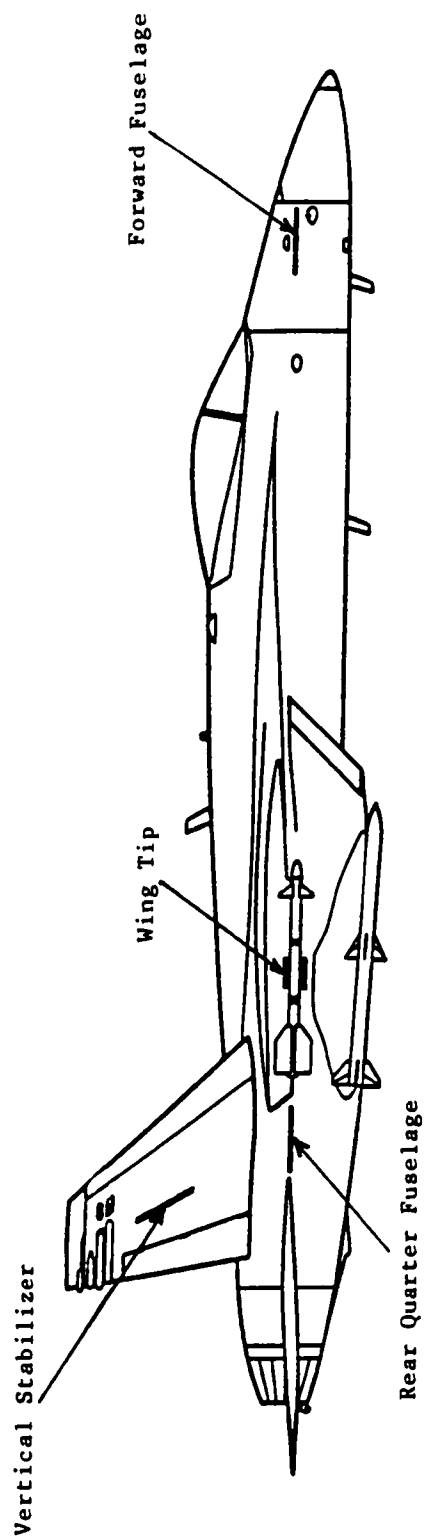
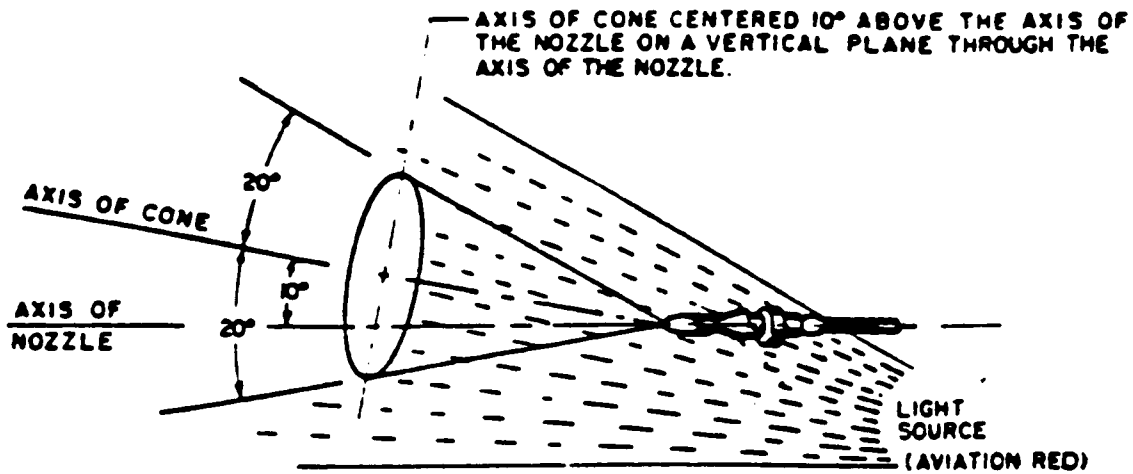
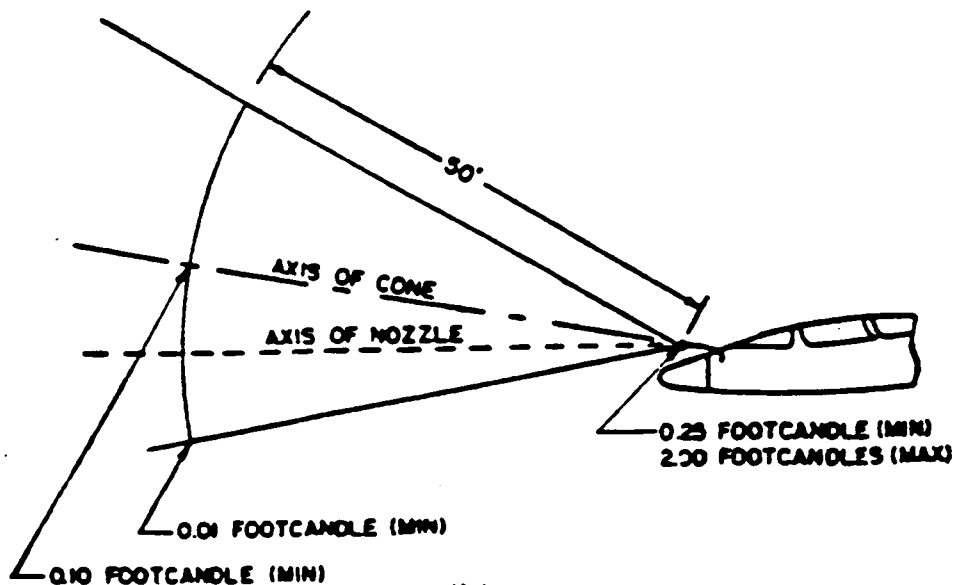


Figure 2.5 - F/A-18 Formation Lights



(a)



(b)

Figure 2.6 - Refueling Probe Light: (a) Illumination Requirements, (b) Distribution Requirements.

Source: Military Specification, "Lighting Equipment; Exterior, Aircraft General Requirements for", Specification Number MIL-L-006730, December 2 1963.

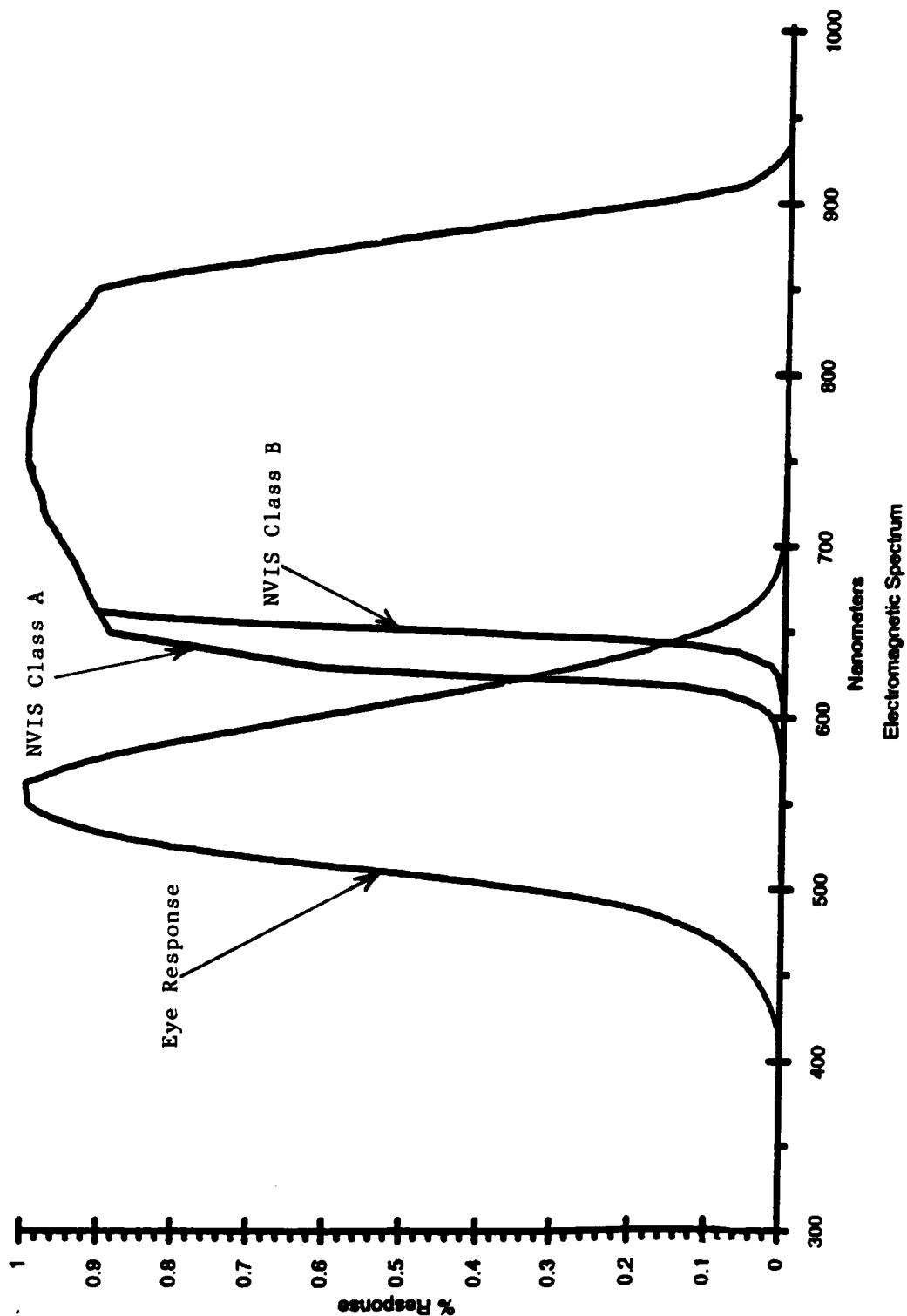
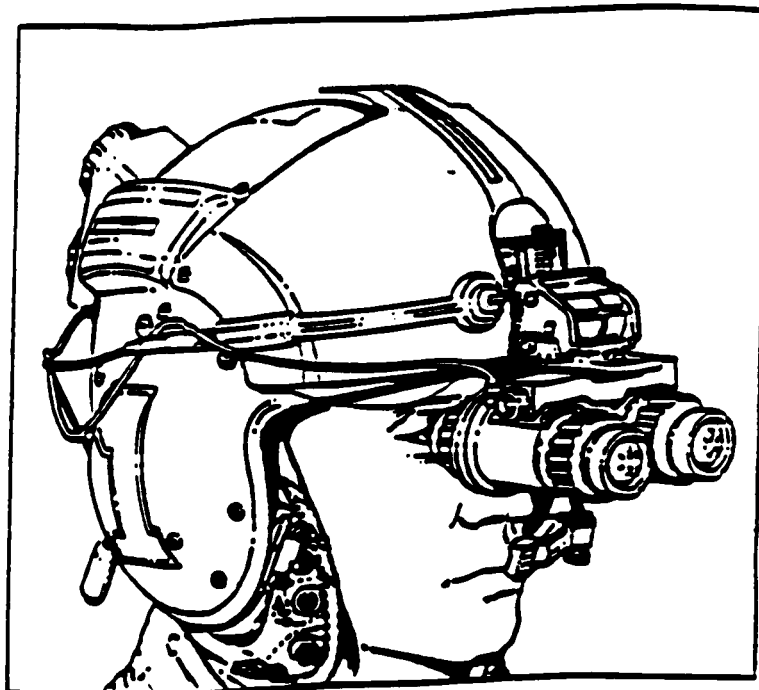
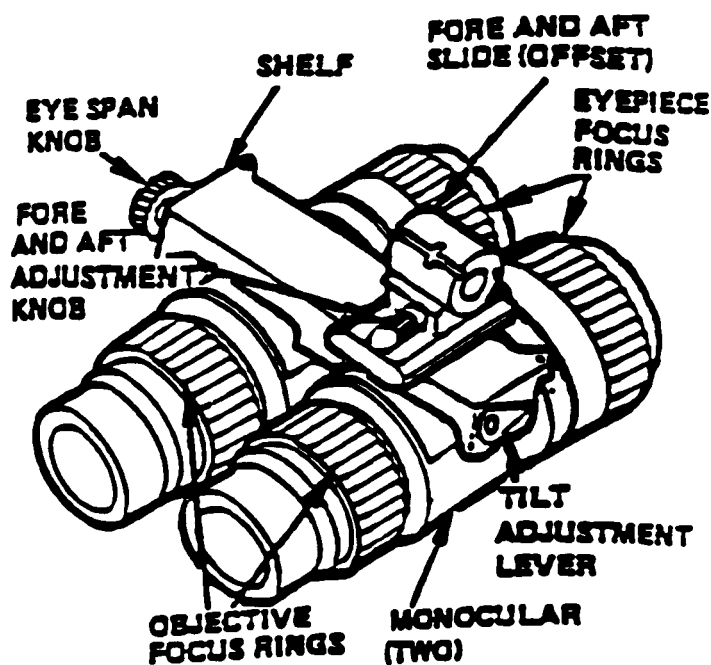


Figure 2.7 - NVIS Class A and Class B, and Eye Response.

Source: S. Kinney and R. Simpson, "Quantification of NVIS Exterior Lighting Performance." Technical Memorandum, Naval Air Warfare Center Patuxent River, Maryland, October 1993.



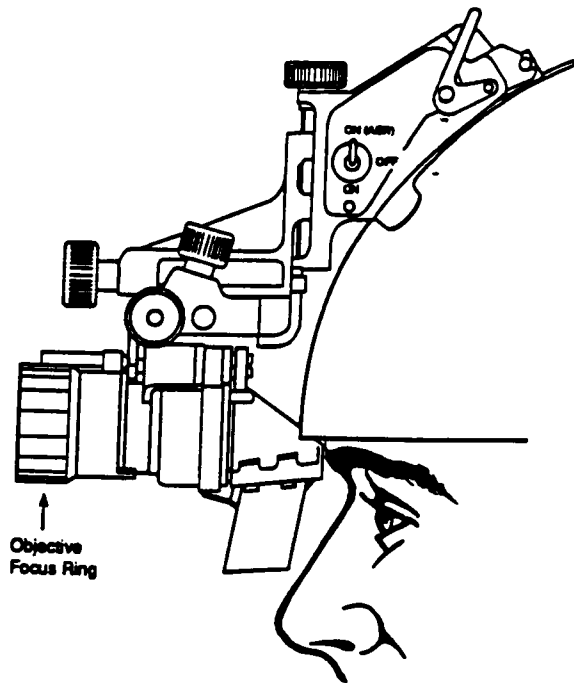
(a)



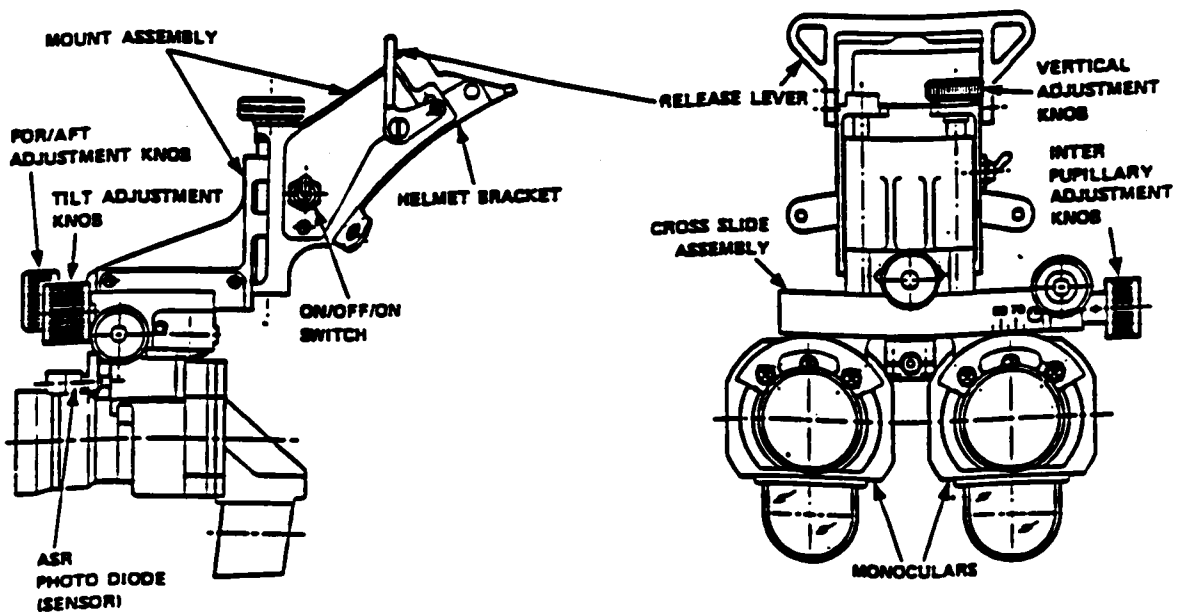
(b)

Figure 2.8 - NVIS Type I Class A: (a) Helmet Mounted (b) NVIS Device.

Source: S. Kinney and R. Simpson, "Quantification of NVIS Exterior Lighting Performance." Technical Memorandum, Naval Air Warfare Center Patuxent River, Maryland, October 1993.



(a)



(b)

Figure 2.9 - NVIS Type II Class B: (a) Helmet Mounted (b) NVIS Device.

Source: S. Kinney and R. Simpson, "Quantification of NVIS Exterior Lighting Performance." Technical Memorandum, Naval Air Warfare Center Patuxent River, Maryland, October 1993.



Figure 3.1 - Illuminance Meter (Incident Power)

Source: Minolta Camera Co., "Illuminance Meter Instruction Manual", Minolta Camera Co. Japan, 1984.

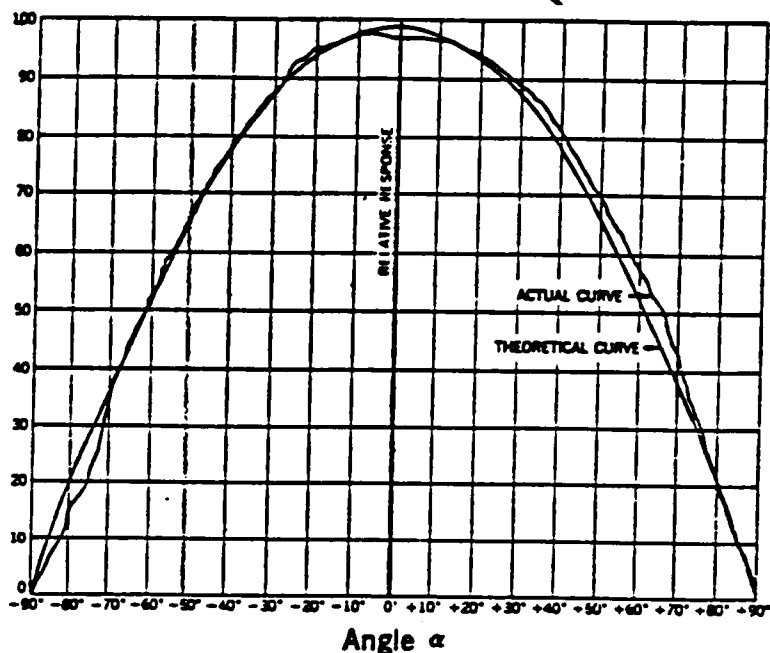
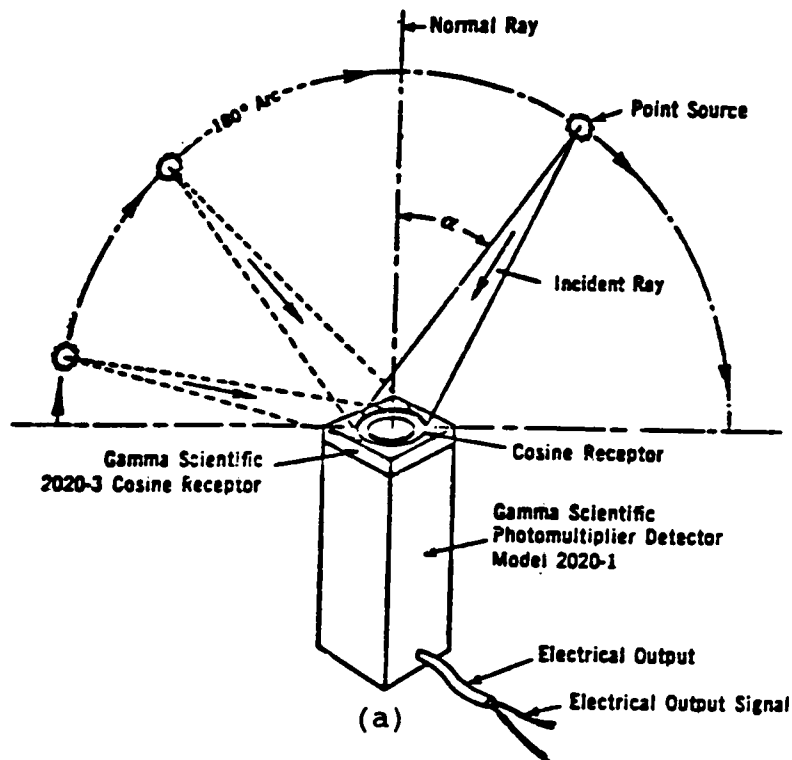
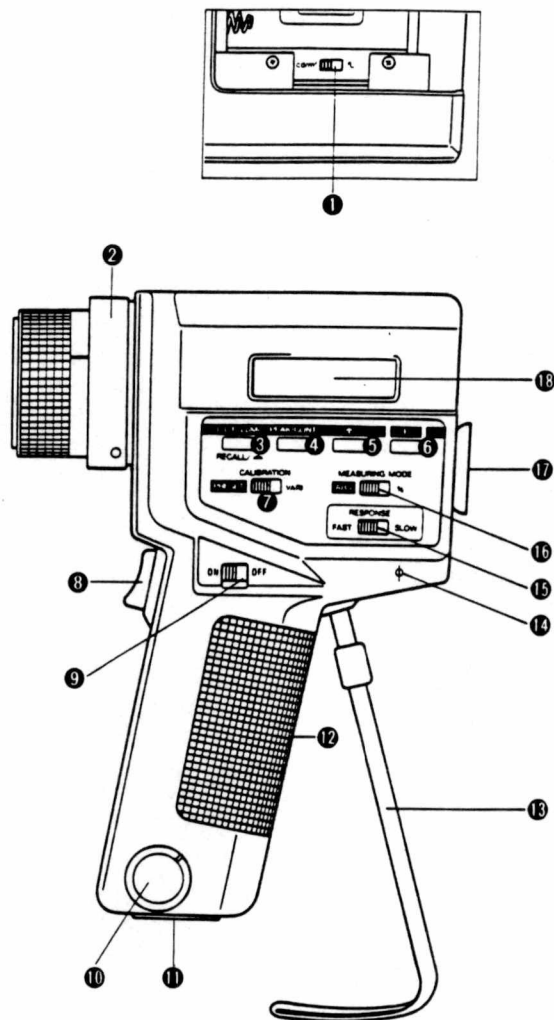


Figure 3.2 - Incident Power: (a) Photometer Cosine Receptor, (b) Theoretical and Actual Relative Response Curves.

Source: Gamma Scientific, Inc., "Handbook of Light Measurement Techniques", Gamma Scientific, San Diego, CA, 1970.



- | | |
|----------------------------------|----------------------------------|
| ① Luminance-unit selector switch | ⑩ Data-output terminal |
| ② Distance scale | ⑪ Tripod socket |
| ③ Data-control key | ⑫ Handgrip |
| ④ PEAK/CONT. key | ⑬ Wrist strap |
| ⑤ Increase key | ⑭ Focal-plane indication |
| ⑥ $\boxed{F}$ key | ⑮ RESPONSE speed selector switch |
| ⑦ CALIBRATION selector switch | ⑯ MEASURING MODE selector switch |
| ⑧ Measuring trigger | ⑰ Eyepiece |
| ⑨ Power switch | ⑱ External display |

Figure 3.3 - Luminance Meter (Radiant Power)

Source: Minolta Camera Co., "Luminance Meter Instruction Manual", Minolta Camera Co. Japan, 1987.



Figure 3.4 - Spectraradiometer (PR-713/M)

Source: Photo Research Division of Kollmorgen Co.,
"Instruction Manual Spectrascan PR-713/M", Photo Research,
Burbank, CA, 1984.

T-45 STROBE 0 Deg Az 5-10 Deg EI

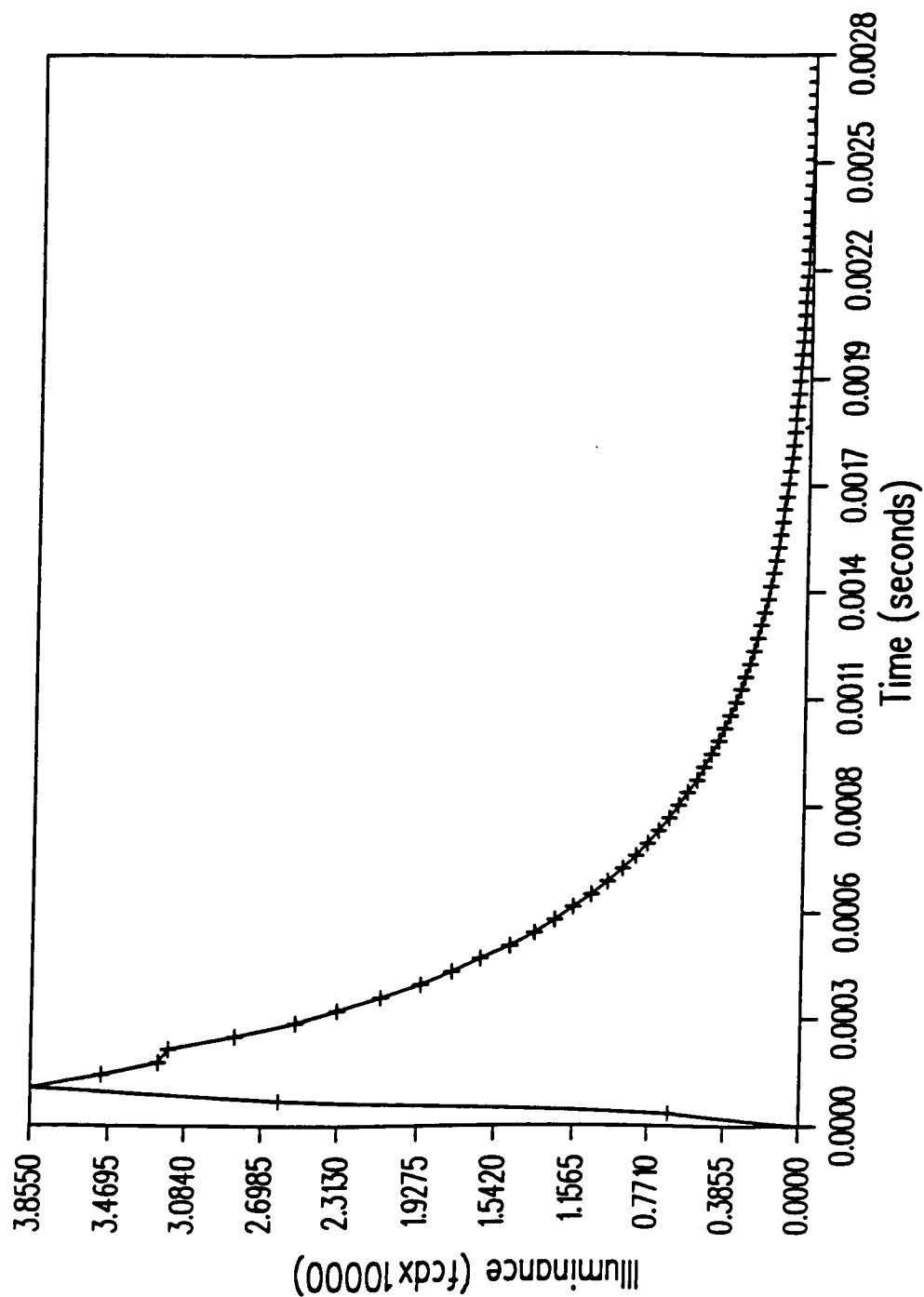


Figure 3.5 - Anticollision Light Sample Test Data (T-45 Aircraft).

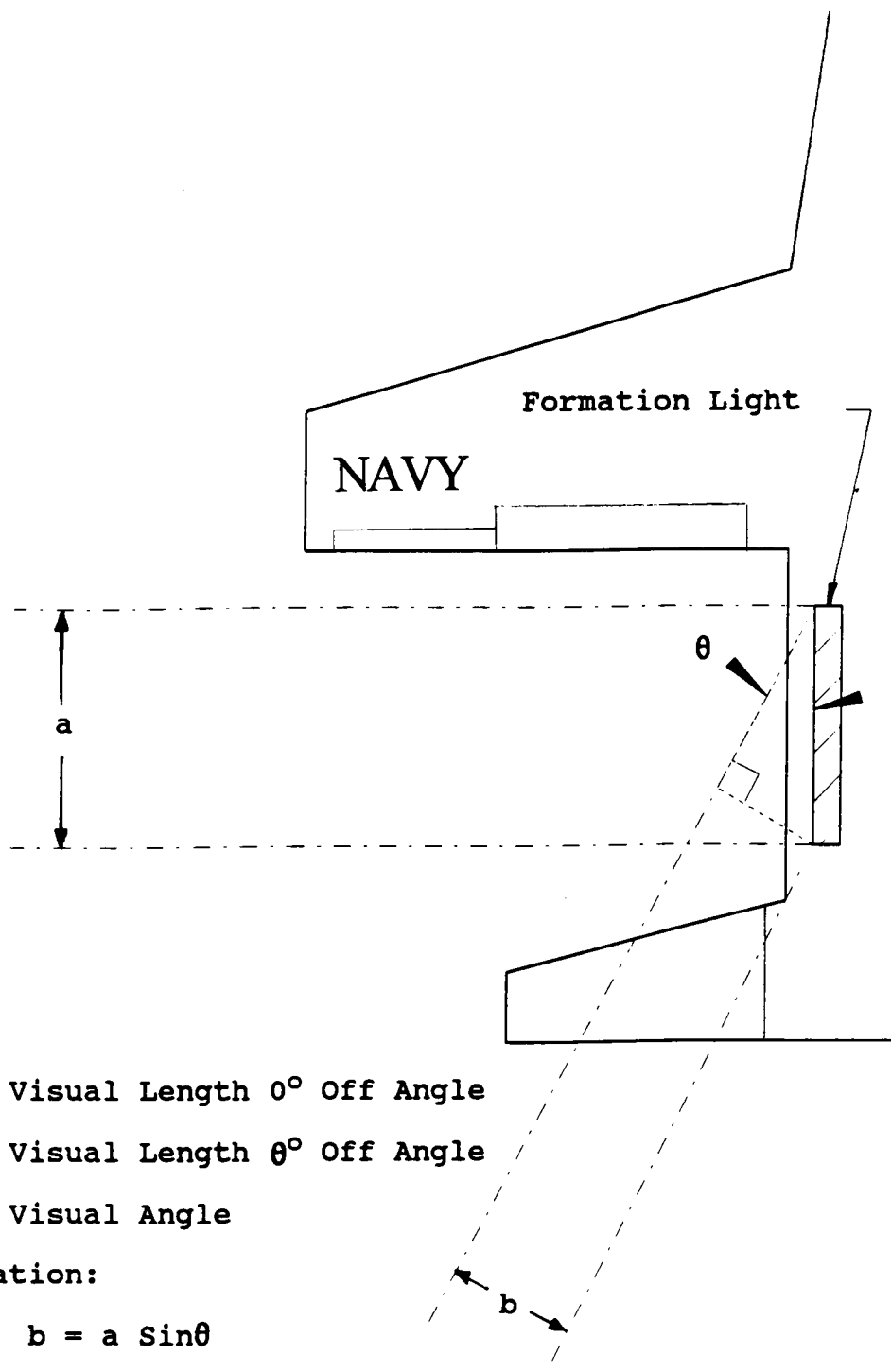


Figure 3.6 - Formation Light Reduction in Visual Area.