SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP5825

Issued 2005-07

Design Requirements and Test Procedures for Dual Mode Exterior Lights

TABLE OF CONTENTS

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: custsvc@sae.org

SAE WEB ADDRESS: http://www.sae.org

1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) contains the general requirements and test procedures for Dual Mode (NVIS Friendly visible and Covert) exterior lighting for most rotorcraft and fixed wing aircraft and could be applicable to ground vehicles that desire a Dual Mode lighting system.

1.1 Purpose:

This document is to define both the basic NVIS Friendly limits for visible exterior lights and the radiance limits for the covert energy sources. In addition, this document will define the test methods and equipment necessary in verifying the measurements.

1.2 Limitations:

This document includes and updates the traditional requirements that cover normal visible exterior lighting and integrate them with Dual Mode exterior lighting design and testing concepts. This document will not attempt to define the environmental qualification, reliability requirements or any of the other tests required that are normally contained in procurement specifications or readily found in other technical documentation. The primary focus of this document is for fixed wing aircraft, but other air frames or ground vehicles can use many of the technical requirements.

1.3 Field of Application:

This document defines three classes of tests. Each test is applicable to the different phases of a products life: for example, engineering development and qualification (CLASS 1), production/quality assurance (CLASS 2), and field service maintenance or flight readiness (CLASS 3). The test requirements for each of these phases differ and hence the test procedures for each test class may differ. Each procedure in this document is CLASS 1 unless otherwise stated.

1.4 Classes of Tests:

CLASS 1 - Laboratory Tests - The objective of tests in this class is to verify the design of the assembly. Tests in this class are most appropriate in an engineering laboratory environment or as part of a certification program.

CLASS 2 - Production/Quality Assurance - The objective of this test class is to verify that every assembly has been manufactured or repaired to meet specified requirements. Tests in this class are most appropriate for acceptance and/or end item tests.

CLASS 3 - Maintenance/Flight Readiness - The objective of tests in this class is to verify that the assembly is within acceptable performance limits. Tests in this class are most appropriate for field service maintenance and flight line inspection.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096 or www.sae.org.

ARP694A	Aerial Refueling Lights - Design Criteria
AS8017A	Minimum Performance Standard for Anticollision Light Systems

2.1.2 U.S. Government Publications: Available from Document Automation and Production Service (DAPS), 700 Robbins Avenue, Philadelphia, PA 19111-5094 or http://assist.daps.dla.mil/online/start/

MIL-L-85762A 26 Aug. 1988	Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible
MIL-STD-3009 2002 Notice 1	Lighting, Aircraft, Night Vision Imaging System 04 Oct. (NVIS) Compatible
MIL-L-6503H March 1996 Notice 2	Lighting Equipment, Aircraft, General Specification 25 for Installation of
MIL-L-006730C 9 Oct. 1996 Notice 2	Lighting Equipment, Exterior, Aircraft (General Requirements for)
FAR 23	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
FAR 25	Airworthiness Standards: Transport Category Airplanes
FAR 27	Airworthiness Standards: Normal Category Rotorcraft
FAR 29	Airworthiness Standards: Transport Category Rotorcraft

2.2 Applicable References:

Aerospace Lighting Institute, February 2002 Advanced Seminar
Tim Bushell, Oxley Presentation

2.3 Definitions:

COVERT: Covert exterior lights cannot be viewed in normal operation by the unaided eye and requires the use of night vision goggles. Covert lighting allows the benefits of exterior lights in mission requirements while in hostile battle area where there is a desire to limit visible detection.

DUAL MODE: Dual Mode exterior lights comprises of two modes; visible and covert. The visible mode can be viewed with the unaided eye whereas the covert mode requires additional sensors (i.e., night vision goggles). In most cases, the visible mode is further divided into two categories; the first one being Aviation (or standard) and the second one being NVIS Friendly (see NVIS Friendly). Dual Mode exterior lights are designed to operate with the use of night vision goggles. Most Standard or Aviation exterior lighting systems do not integrate naturally with night vision goggles. The exception being aviation lights that are naturally NVIS Friendly (this includes aviation green lights in general and selective LEDs that are being used for exterior lights).

NRI: This abbreviation stands for NVIS Radiant Intensity. NRI is the unit used to measure Dual Mode exterior lights. Radiometric energy from a light source is collected and integrated with the response curve of the night vision goggles as defined in MIL-L-85762A. This integration is then multiplied by the distance squared of the energy source to the detector (in accordance to the inverse square rule). The units of NRI are Watts/steradian (W/sr).

NVIS FRIENDLY: NVIS Friendly exterior lights can be viewed by the unaided eye and also with night vision goggles, but without degradation to the operational use of the goggles common with Standard or Aviation lighting designs. An NVIS Friendly lighting system reduces (but does not eliminate) the amount of near infra-red energy contained by the light source. When viewed through night vision goggles, the NRI does not cause excessive “blooming” in the goggles. Excessive blooming can be defined as when the aircraft's exterior lights that are being viewed through the goggles merge together and obscure the outline of the aircraft (Figure 1).

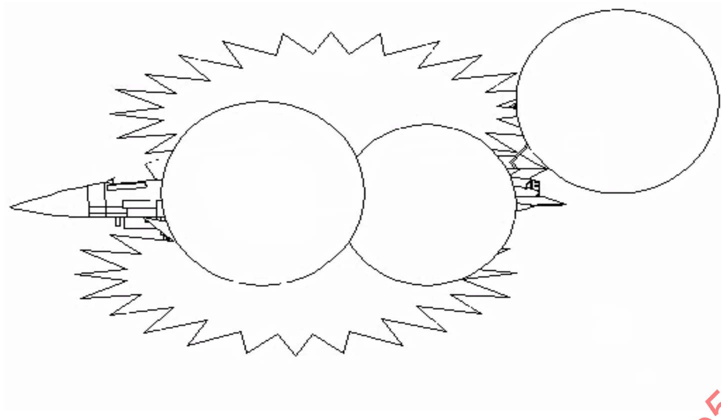

FIGURE 1 - Standard or Non-NVIS Friendly Exterior Lights

2.3 (Continued):

A NVIS Friendly exterior light will have some IR content compared to lights that are completely NVIS compatible which would not be seen with night vision goggles. The proper balance of restricting the amount of IR content for various exterior lights is the key to the definition of "NVIS Friendly". With a proper control of IR content, NVIS Friendly exterior lights will be detected when viewed through the night vision goggles, and not overwhelm the aircraft outline (Figure 2).

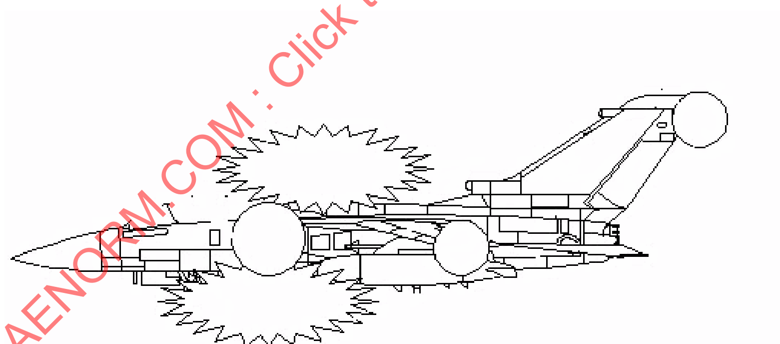

FIGURE 2 - NVIS Friendly Exterior Lights

3. TECHNICAL REQUIREMENTS:

3.1 Background Information:

As the use of night vision goggles becomes more and more part of the baseline configuration of interior cockpit design, technical requirements and specifications were developed to provide a common baseline design for aircraft cockpits and interior lighting systems. For exterior lighting, most of the NVIS requirements have been limited to defining covert Electroluminance (EL) strips for formation flying. However, the mission requirements for operational use of night vision goggles have driven the need to have the rest of the exterior lights to be made not only compatible with the goggles, but designed to be part of night time tactics. Existing standard exterior lights are designed primarily to prevent mid-air collisions. The specifications require most of the radiometric energy to be directed in all directions, and with additional energy via the position lights directed forward and aft along with color filters to provide orientation (aviation colors). However, with the use of night vision goggles, these standard visible lights overwhelm the goggles and require IR suppression. The IR suppression must not impact the lights to the extent that they fail the FAA and military specifications, nor the use of night vision goggles. This is the biggest challenge in designing NVIS Friendly exterior lights.

As the operational use of night vision goggles have evolved, so has the mission requirements such that, NVIS Friendly lights alone does not support all of the operational mission requirements. The opposing pilots and enemy ground forces also have the use of night vision goggle technology and projecting even NVIS Friendly light impacts the survivability of the mission and the pilot. However, turning off all the exterior lights (the first use of the covert mode) makes it very difficult for your fellow pilots to regroup (or rejoin) and increases the possibility of mid-air collisions. This fact created the requirement for what is commonly considered covert lighting. Covert exterior lighting has very different radiometric patterns than visible exterior lighting. This is due to the mission requirements that dictate no radiometric energy directed forward for the enemy pilot to detect, and no radiometric energy downward for enemy ground forces to detect. All of the covert lighting must be directed upward and aft to assist in rejoins. The major exceptions would be the Anti-Collision lights and any covert Landing/Taxi light systems.

Current civil and military specifications cover the photometric patterns for visible exterior lighting, but it does not detail the requirements for NVIS Friendly or covert designs.

3.2 Basic Visible Requirements for Exterior Lighting

All NVIS Friendly exterior lighting must still meet the standard (normal) visible requirements with the additional requirements of limited the amount of IR content the various exterior lights should contain. Exterior lights can be modified or replaced to make the lights NVIS-Friendly while retaining normal unaided eye viewing. The advantages of NVIS-Friendly lights are:

- Military aircraft can safely operate with goggles in civilian airspace and can be seen by other aircraft. This provides greater flexibility when conducting training operations. In a multi-man cockpit, one pilot can be on goggles and one off without affecting safety of flight.

- Can refuel aircraft while on goggles.

- Operate close to a combat area without being easily detected by goggles on the ground.

This ARP document will supplement the requirements that cover normal visible exterior lighting and include the additional requirements for Dual Mode (NVIS Friendly and Covert) exterior lighting.

3.2.1 Overview of Basic Design and Photometric Requirements for Single Mode (Non-NVIS) Exterior Lighting:

3.2.1.1 Requirements for Anti-Collision Lights: All aircraft are required to have an anti-collision light system in accordance to both the FAA and various military specifications. The lights shall be located as not to be detrimental to the crew's vision and will not detract from the conspicuity of the position lights. Lights that are located on top of the fuselage shall be located as far back from the pilot as practicable in order to reduce to a minimum the possibility of causing vertigo. The use of shielding is acceptable to prevent light beams from being directly or indirectly projected into the cockpit. For additional information on anti-collision light design requirements for multiple aircraft types, review AS8017A.

3.2.1.1.1 Field of Coverage for Anti-Collision Lights: The system shall consist of one or more light assemblies such that sufficient field of coverage shall extend in all directions within a plane not less than 30 degrees above and 30 degrees below the horizontal plane of flight. Allowed obstructed visibility totally not more than 0.03 steradian is allowable within a solid angle equal to 0.15 steradian centered about the longitudinal axis in the rearward direction.

3.2.1.1.2 Flashing Characteristics for Anti-Collision Lights: Flash characteristics for anti-collision lights are determined by the mission requirements for selected military aircraft. In accordance to MIL-L-6503 and MIL-L-6730, a minimum flash pattern frequency is required. This minimum effective flash frequency shall be not less than 40 nor more then 100 cycles per minute except when the anti-collision light system lights overlap due to more than one light source. In cases of overlap, effective flash frequencies shall not exceed 180 cycles per minute. The effective flash frequency is established as that frequency at which the aircraft's complete anti-collision light system is observed from a reasonable distance. Multiple flash patterns are allowed to meet mission requirements.

3.2.1.1.3 Chromaticity for Anti-Collision Lights: The chromaticity for anti-collision lights shall be aviation red, aviation white, or both. Chromaticity selection is determined by customer requirements.

3.2.1.1.4 Light Intensity Requirements for Anti-Collision Lights: The light intensity requirements for anti-collision lights are not dependent on the technology used for the light assembly. Existing technologies include rotating beacons, flashing incandescent, gas discharge tubes (strobes) and Light Emitting Diodes (LEDs). When a light signal consists of separate flashes, the maximum intensity during the flash must be greater than the intensity of a steady light to have the same apparent intensity. It is, therefore, convenient to evaluate flashing lights in terms of their effective intensity.

3.2.1.1.4.1 Measurement of Effective Intensity for Anti-Collision Lights: For measuring all Anti-Collision light systems, the minimum light intensity for each light assembly shall be expressed in terms of effective candlepower in accordance to the Blondel-Rey equation. This requirement is based on the assumption that the maximum intensity during the flash must be greater than the intensity of a steady light to have the same apparent intensity. For measuring multiple flash patterns, the Blondel-Rey formula is modified to take into consideration of changes to retina sensitivity with multiple flash stimulation. The modified Blondel-Rey formula is not currently applicable for application to FAA requirements however.

3.2.1.1.4.1 (Continued):

a. The Blondel-Rey equation is as follows is only valid for single flash characteristics:

$$I_E = \frac{\int_{t1}^{t2} I(t)dt}{0.2 + (t_2 - t_1)} \qquad \text{(Eq. 1)}$$

where:

I_E = effective intensity (effective candela)

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

t_2 -t_1 = flash time interval (seconds)

b. The modified Blondel-Rey formula is useable for flash trains.

In order to measure flash trains the expression of ($t_2 - t_1$) of the Blondel-Rey formula as stipulated above only shall be changed into

$$\Delta T = \frac{I(t)dt}{I_M} \qquad \text{(Eq. 2)}$$

The result you get the modified Blondel-Rey formula

$$I_E = \frac{1}{\dfrac{C}{\sum_{n=0}^{\infty} \int_{t_n}^{t_{n+1}} i_n dt} + \dfrac{1}{I_M}} \qquad \text{(Eq. 3)}$$

where:

$\int_{t_n}^{t_{n+1}} i_n dt$ = Area pulse train in [cd s]

C = Blondel-Rey constant 0.2 in [s]

I_M = Absolute peak value in [cd]

3.2.1.1.4.2 Minimum Effective Intensity for Anti-Collision Lights: Both the FAA (Part 23, 25, 27 and 29) and MIL-L-6503 have minimum values for anti-collision light effective intensity requirements along the horizontal plane. These minimum values are detailed in Table 1. The military specification limits their photometric requirements from 0 degrees to 30 degrees above and below the horizontal plane.

TABLE 1 - Minimum Effective Light Intensities

Angle Above or Below the Horizontal Plane	Effective Intensity (cd) for FAR 23 & 25	Effective Intensity (cd) for FAR 27 & 29
0° to 5°	400	150
5° to 10°	240	90
10° to 20°	80	30
20° to 30°	40	15
30° to 75°	20	N/A

3.2.1.2 Requirements for Position Lights: The design requirements for position lights are defined into two categories: FAA regulated civilian aircraft and military aircraft. For civilian aircraft, FAA requirements will define the photometric requirements. For most military aircraft, MIL-L-6503H or MIL-L-006730 will define the photometric requirements. Neither of these documents contains any information or requirements for NVIS Friendly and Covert lighting.

3.2.1.2.1 FAA Position Light Requirements: The major design issue with NVIS-Friendly lights is maintaining the minimum Federal Aviation Administration (FAA) intensity, distribution patterns and color for the Position (Navigation) lights as defined in Tables 2 and 3. Anti-collision lights must also meet their respective FAA or military specification requirements.

TABLE 2 - FAA Navigation Light Requirements (must equal or exceed values)

FAR Part 23, 25, 27 and 29

Intensities in the horizontal plane — Intensities in any vertical plane perpendicular to the horizontal plane

	Angle from right or			Angle above or below the horizontal plane : Intensity, I	
Dihedral angle	Left of longitudinal	Intensity		0°	1.00
(light included)	Axis, measured	(I)		0° to 5°	0.90
	From dead ahead	(candelas)		5° to 10°	0.80
				10° to 15°	0.70
L and R (fwd	0° to 10°	40		15° to 20°	0.50
red and green)	10° to 20°	30		20° to 30°	0.30
	20° to 110°	5		30° to 40°	0.10
A (rear white)	110° to 180°	20		40° to 90°	0.05

TABLE 3 - FAA FAR Overlapping Requirements

Maximum Intensities in Overlapping Beams of Forward and Rear Position Lights

Overlaps	Maximum Intensity	
	Area A (cd)	Area B (cd)
Green in Dihedral Angle L	10	1.00
Red in Dihedral Angle R	10	1.00
Green in Dihedral Angle A	5	1.00
Red in Dihedral Angle A	5	1.00
Rear White in Dihedral Angle L	5	1.00
Rear White in Dihedral Angle R	5	1.00

3.2.1.2.1 (Continued):

Whereas area A includes all directions in the adjacent dihedral angle that passes through the light source and intersects the common boundary plane at more than 10 degrees but less than 20 degrees.

Whereas area B includes all directions in the adjacent dihedral angle that passes through the light source and intersects the common boundary plane at more than 20 degrees.

3.2.1.2.2 Military Position Specifications: The photometric requirements for position lights on military aircraft are more demanding than with FAA FAR requirements. The light distribution is defined in Table 4.

TABLE 4 - Military Navigation Light Requirements

Intensities in the horizontal plane

Dihedral angle (light included)	Angle from right or Left of Longitudinal	Intensity (I) (candelas)
L and R (Fwd Red and Greed)	Axis, measured From dead ahead	
	0° to 10°	40
	10° to 20°	40
	20° to 30°	30
	30° to 40°	20
	40° to 50°	15
	50° to 70°	10
	70° to 110°	6
	110° to 120°	
	120° to 130°	5 cd Max
A (rear white)	90° to 100°	5 cd Max
A (rear white)	100° to 110°	
A (rear white)	110° to 180°	20

Intensities in any vertical plane perpendicular to the horizontal plane

Angle above or below the horizontal plane	: Intensity, I
0°	1.00
0° to 5°	0.90
5° to 10°	0.80
10° to 15°	0.70
15° to 20°	0.50
20° to 30°	0.30
30° to 40°	0.10
30° to 90°	4 cd min

3.2.1.3 Requirements for Formation Lights: Since the FAA does not specify formation lights, the best specification document is MIL-L-6503 (Air Force) or MIL-L-006730 (Navy). In MIL-L-006730, formation lights are divided into two types. Type I formation lights are point light sources that can use but are not limited to either incandescent lamps or LEDs. Type II formation lights are area light sources that use but are not limited to either electroluminescent (EL) strips or LEDs combined with a fiber optic weave or other diffusing media.

3.2.1.4 Requirements for Landing/Taxi Lights: All aircraft are required to have both landing and taxi lights for night flying operations. Consideration must include sufficient backup systems as to prevent single bulb (or light source) failure to render one of these lighting functions inoperable. Design location of these lights shall preclude direct or indirect projection of light into the cockpit. The use of covers to prevent stray light into the cockpit is allowed, but it must not reduce or distort the pattern requirements of the lighting assembly. The key requirement is to provide proper illumination in front and beneath the aircraft to allow ground reference for the pilot in all phases of landing and taxi operations. Fixed-wing aircraft shall separate light sources for the landing and taxi light functions due to the difference beam pattern requirements. If halogen lamps are used, the filaments for the taxi light must be horizontal to the wide beam pattern. The filament orientation should be considered to maximize light output. Placement of the light assemblies must be so there is no blockage of the required beam pattern due to aircraft structure.

3.2.1.4.1 Landing Light Photometric Requirements: The landing light photometric requirement shall provide no less than 2 footcandles on the ground line 400 feet ahead of the pilot. The centerline of the beam pattern must match the centerline of the line of flight. For aircraft that have landing light assemblies built into the wing structure, the minimum 2 footcandle requirement must be met 400 feet ahead of the centerline of the light assembly as measured from the horizontal from the centerline of the aircraft structure to the location of the light assembly on the wing. The landing light assemblies shall be mounted so the centerline beam pattern matches the angle of landing approach of the aircraft.

3.2.1.4.2 Taxi Light Photometric Requirements: The Taxi light photometric requirement shall provide no less than 0.5 footcandles as measured in the vertical plane on the ground line 300 feet ahead of the pilot. This minimum illumination must be maintained to 10 feet outboard of the most extreme wingtip structure of the aircraft.

3.2.1.5 Requirements for Refueling Lights: Any aircraft that intends to have inflight refueling capabilities, there should be sufficient light illumination for the receiver aircraft to visually locate the tanker and sufficient light illumination of the probe location or the drogue (depending of the type of refueling technique) to allow safe transfer of fuel while in this close proximity flying pattern. The light output must have variable dimming control that can be adjusted uniformly over the range of the control from full on to full off and be design so not to create direct light energy from entering either the receiver cockpit area or the tanker crew area. Detailed design criteria for standard aerial refueling can be found in ARP694A. The requirements called out in this document are for fixed wing aircraft only.

3.2.1.5.1 Requirements for Boom/Receptacle Style Refueling Lights: For Boom/Receptacle refueling with the brightness control set to the full, the minimum intensity within the fuel receptacle or slipway area shall be 15 candela and 2.5 candela in the area surrounding the receptacle location. Multiple light assemblies are allowed to meet this requirement.

3.2.1.5.2 Requirements for Probe/Drouge Style Refueling Lights: For inflight refueling using drogue system, there must be a minimum of 500 candelas within a ±10 degree horizontal distribution and ±5 degree vertical distribution.

3.3 Overview of Photometric Requirements for NVIS Friendly Portion of Dual Mode Exterior Lighting:

NVIS Friendly exterior lights must not only meet the existing FAA and/or military specifications for visible (normal) lighting, but now must limit the IR content to allow their use in operations that were explained in 3.2.1.

3.3.1 Definition of NVIS Friendly Exterior Lights: NVIS Friendly Exterior lights are lights that have a portion of their infra-red radiometric energy filtered out. The amount of filtering is determined by the mission requirements of the individual aircraft. These lights are visible to the unaided eye, but do not overwhelm the pilot that is using night vision goggles.

3.3.1.1 NVIS Friendly Exterior Lighting Verses NVIS Compatible Interior Lighting: NVIS Friendly lighting is different from NVIS compatible lighting within the cockpit because there are no fixed brightness levels that can be used for scaling purposes. For NVIS compatible cockpit lighting, there is an assumption that the lights will be set to certain brightness levels. For example, the assumption was that panel light brightness level would be around 0.1 footlamberts, and for warning lights it would be 15 footlamberts. Since the brightness levels can be controlled by the pilot, the military specifications for defining NVIS compatible light was to use a ratio based on scaling factors set to known brightness levels within the cockpit. Case in point, NVIS panels are measured at brightness levels that are greater than 0.1 footlamberts since this low energy level may cause problems with some of the spectroradiometer obtaining a good measurement due to dark current designs. Therefore, when a NVIS panel is measured at brightness values of 1.0 footlamberts, the NVIS radiance value obtained would then be linked to the photopic value and scaled back down to the brightness level the pilot would normally have it set to. For example, an NVIS panel that has a luminance of 1.336 footlamberts and a NVIS Radiance of 1.871E-9, this radiance value would be scaled to an assumed brightness of 0.1 footlamberts. This then converts the NVIS radiance value to 1.401E-10 (when scaled to 0.1 footlamberts). This scaling factor works well for controlled cockpit environments. However, exterior lights can not be set to a predetermined brightness level (and, therefore, a known scaling factor assigned) since the pilot can not control the environment that they will view the exterior lights. A method must be determined that will remove the scaling factors used in MIL-L-85762A (MIL-STD-3009).

3.3.1.1.1 Defining the Method for Establishing NVIS Friendly Design Requirements: Interior lighting components can use MIL-L-85762A to provide measurement guidance. However, as previously noted, for exterior lights, the pilot cannot control the brightness levels of another aircraft or the natural ambient light (stars, moon, cloud cover, etc.). When the pilot views the exterior lights from another aircraft, factors like distance, viewing angles, and changes in the pattern of the various lights renders scaling an impossible task to establish. To resolve this, two approaches can be used. The first is to apply a standard scaling factor for all exterior lights. This assumes that the level of NVIS radiance will remain the same for all viewing angles and that there is a photopic value that can be used to scale the NVIS radiance values. This could be used in limited cases for NVIS Friendly exterior lights since there is a luminance value to scale to and in most cases, the photometric patterns of the lights are well known. A possible scaling factor for NVIS Friendly exterior lights could be 15 footlamberts. This falls between the 40 candela values for position lights and the typical 6 candela values for Type I (point source) formation lights. However, covert lighting does not have a photopic value that will allow a scaling factor to be used (see 3.4 for more information on covert lighting). Existing NVIS Friendly position lights also have been found to have different radiometric and photometric patterns depending on the angle of which they are seen (only Type II formation lights have uniform patterns). Using a single scaling factor will, therefore, not correctly determine what the pilot will see when using night vision goggles. Therefore, a method not using scaling factors must be employed. This method must consider the fact that exterior lights have changing radiometric and photometric values at different part of their spread pattern. The most direct method is to use a radiometer version of the photometric candela formula used for exterior lights. This radiometric formula will use the radiometric intensity of the exterior light source and integrate that energy with the night vision goggles. This integration of radiometric energy with night vision goggles shall be called NVIS Radiant Intensity (NRI).

3.3.1.2 NVIS Radiant Intensity (NRI): NVIS Radiant Intensity is a method of linking radiant intensity (watts per steradian) and integrating that with the response curve of the night vision goggles. It is the NVIS radiometric version of candela for photometric data. To obtain NRI, the test conditions and measurement devices must be considered. NRI should be used for exterior light sources that have varying radiometric patterns. For formation lights that are Type II (that can use but are not limited to either EL or LED/Fiber Optic weave), NRI should not be used. The radiometric energy of Type II lights can not be expressed as a measurement of radiometric flux per unit area (Watts per square meter) since it is not a point source. The use of scaled NVIS radiance is still applicable (for NVIS Friendly lights) and unscaled NVIS Radiance for the covert portion.

3.3.1.3 Units and Formulas That Should be Used to Define NRI: For point light sources, the radiometric energy source follows the inverse square law ($E = I/d^2$). The radiant intensity of Dual Mode exterior lights and its application to NRI not only needs to include the inverse square law, but also how the radiant intensity of the exterior light source is measured. If the energy source is measured directly, the detector will incorporate a cosine correction factor. However, if measured off a lambertian surface (as called out in MIL-L-85762A, paragraph 4.8.13.2), additional factors must be included. They include the cosine law for Radiant Incidance (E), and relationship to radiant sterance (L) and Radiant Exitance (M). The formula for a Lambertian surface is:

$L = M/\pi$
L = Radiant Sterance (Watts per steradian per square meter)
M = Radiant Exitance (Watts per square meter)

The Lambert's Cosine Law formula is:

$E_\alpha = E \bullet \cos(\alpha)$ (Watts per square meter)
E_α = Radiant Incidance at the angle α
α = Off axis angle from the normal to the lambertian surface

In creating the formula for defining covert light, start with the basic NRa formula as defined in MIL-L-85762A (or MIL-STD-3009);

$$\text{NVIS Radiance} = G(\lambda)_{max} \int_{450nm}^{930nm} G(\lambda) \cdot SN(\lambda) \cdot d\lambda \qquad \text{(Eq. 4)}$$

where:

$G(\lambda)_{max}$ = 1 mA/W

$G(\lambda)$ = relative NVIS response (Class A)

S = scaling factor

$N(\lambda)$ = spectral radiance of the energy source (W/cm^2 sr nm)

$d\lambda$ = 5 nm

3.3.1.3 (Continued):

In addition to the NVIS radiance formula, the inverse square law applies to the radiometric energy of the light source. If you are measuring the radiometric energy off a calibrated reflectance standard, the reflection grade of the surface must be included along with the angle of the target to the spectroradiometer. The reflection standard will radiate in a pattern of π•sr. Including all of these key factors, the formula will then become:

$$NRI_{A/B} = \frac{\int_{450nm}^{930nm} G(\lambda) \cdot S(\lambda) \cdot d\lambda \cdot \pi \cdot x^2}{\cos\alpha \cdot \rho} \quad \text{(Eq. 5)}$$

where:

x = Distance of Radiance Source to Reflection standard (meter)

ρ = Reflection Grade to Reflection standard

α = Off axis angle from the normal to the lambertian surface

See Figure 3 for test setup.

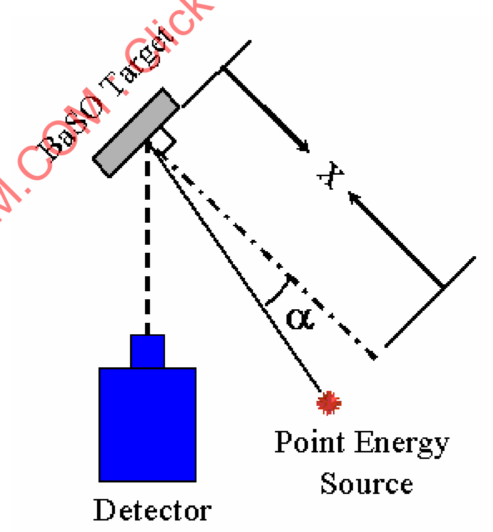

FIGURE 3 - Test Set-Up for NRI

3.3.1.3 (Continued):

This will define the NVIS Radiant Intensity (NRI) in units of W/sr. A note to remember is to check the units your spectroradiometer uses for defining Radiant Sterance (L). Depending on the level of energy, the units for Radiant Sterance can be in (mW/sr•cm^2). Remember to link the distance units to the Radiant Sterance units. In paragraph 4.8.14.2, NVIS radiance measurements are orientated so the IR energy source is perpendicular to the reflectance standard. The spectroradiometer is set up at a 45º angle with the reflectance standard. Having the detector at a different angle than 45º should not impact the results, but for consistency, follow the set up of MIL-L-85762A. Having the energy source at a different angle other than perpendicular to the target **WILL** have an impact. It will follow the Lambert's cosine Law (the irradiance or illuminance falling on any surface varies as the cosine of the incident angle. Therefore, always the energy source perpendicular to the target (if not, include the cosine factor). In most cases, the reflection grade of the Reflection standard is nominally 1.0.

This set up would remove the cosine law component and the reflection grade coefficient. The remaining part of the NRI formula would be unscaled NVIS radiance (in NRa) multiplied by the distance squared. Please remember to match to the Radiant Sterance units for consistency. This simplified formula for NRI is:

NRI = [(Unscaled NVIS Radiance) •(Distance)^2•(π)]

The units are in Watts/sr.

If you are **NOT** measuring off a Lambertian surface and are measuring the energy directly with accurate cosine correction optics, the factor of π is removed from the formula resulting in the following definition for NRI:

NRI = [(Unscaled NVIS Radiance Class A) •(Distance)^2]

The units are in Watts/sr.

3.3.2 NVIS Friendly Requirements for Anti-Collision Lights: A strobe flash that use condenser discharge lamps, such as xenon lamps, are inherently compatible with night vision goggles due to their extremely short pulse duration time (around 1 ms). The uses of IR suppression filters are not normally required for this light system. However, for anti-collision light systems with longer pulse duration times (rotating beacons, LEDs), an IR suppression filter may need to be incorporated to allow night vision goggle use. Even with the added filter, all visible photometric FAA and military specifications must still be met.

3.3.2.1 NRI Limits for Anti-Collision Light Systems: Since Anti-Collision lights are meant to be the first light that you can detect, the NRI limits will be the highest for all NVIS Friendly lights. Table 5 defines the NRI limits in accordance to their angle above and below the horizontal plane. The test procedures to obtain the NRI values are detailed in 4.3.1.3.

TABLE 5 - NRI Limits for Anti-Collision Lights

	Class A NRI (W/sr) White		Class A NRI (W/sr) Red	
Angle	min	max	min	max
0° to 5°	5.00E-01	1.00E+00	1.50E+00	5.00E+00
5° to 10°	1.00E-01	4.00E-01	1.00E-01	3.00E+00
10° to 20°	1.00E-02	5.00E-02	5.00E-02	9.00E-01
20° to 30°	1.00E-03	1.00E-02	1.00E-02	4.00E-01

3.3.2.2 Chromaticity Requirements for NVIS Friendly Anti-Collision Lights: The chromaticity requirements for NVIS Friendly Anti-Collision lights will be the same requirements detailed in the FAR 23, 25, 27 and 29 specifications. The Anti-Collision lights shall remain Aviation White or Aviation Red.

3.3.3 NVIS Friendly Requirements for Position Lights: The position lights are divided into three color groups:

- Red for position lights on the left side of the aircraft.
- Green for position lights on the right side of the aircraft.
- White for position lights pointing aft.

The pilots without night vision goggles can determine basic orientation and position of the aircraft using the three colors. However, when viewed through night vision goggles, all of the position lights will appear green. The only source of determining which color the positions lights are through the goggles is by the amount of "blooming" or IR content the various color light will have. If all of the position lights have the same amount of IR content, the lights will appear to be interchangeable when viewed through the night vision goggles. Having all of the position lights appearing the same eliminates the navigation advantages the three different colors provided. Therefore, to assist in providing aircraft orientation and position, the NVIS Friendly exterior lights should have different IR contents unless mission requirements dictate otherwise. From previous flight test evaluations, it was determined that the red colored position lights should have the highest IR content so it will appear to be the brightest when viewed through the goggles. The green position lights are naturally NVIS Friendly and, therefore, will have the lowest IR content and appear the dimmest when viewed through the night vision goggles. The white color position lights will have an IR content that is between the two other colors. The differing levels of IR contents then allows the pilot to distinguish the different color position lights when viewed through night vision goggles.

3.3.3 (Continued):

A key consideration in defining the NVIS Friendly requirements is to link them to mission requirements. Different military aircraft have different mission requirements. This will have an impact on the NVIS Friendly radiance limits for the various exterior lights. In previous flight tests, some pilots want to have different levels of NVIS Friendly radiance for the three position light colors. Flight tests for other aircraft that incorporates different rejoin and formation flying tactics have shown that the pilots want all of the position lights regardless of there visible color to have the same NVIS Friendly limits. In developing the design requirements for your particular aircraft, keep mission requirements in mind when deciding whether to use different NVIS Friendly radiance limits or a common limit. The following limits are based off values obtained from various retrofit programs and should be used only as a starting point in determining the NRI limits.

3.3.3.1 NRI Limits for Position Lights Having Different Levels for Different Colors: If you are using different NRI limits for the three different colors, have the green color have the lowest limit, the red color the highest limit, and the white color between the two. Please remember that the NVIS Friendly position lights must still have the photometric patterns that standard aviation color requirements set years ago. The forward red and green position lights have most of their photopic energy directed forward. Since NVIS radiance scaling is not used to define NVIS Friendly requirements, this means that the NRI levels must be linked to dihedral angles used in defining the photometric requirements in 3.2.1. The level of detail coverage requirements in terms of dihedral angle (both vertical and horizontal) need not be a strict as the photometric requirements since the NRI levels naturally correspond to the photometric levels. This will not be the case for the covert requirements. The table below (Table 6) shows the linkage of NRI values to dihedral angle of the aircraft. All values are while the position lights are in the "Bright" mode and in the 0° horizontal plane. A multiplication factor that links the NRI value to angles above and below the horizontal plane are not normally required since the photometric pattern of the position lights naturally limits the values below the maximum values found in the 0° horizontal plane. However, if you using filtered incandescent lamps, the IR suppression filters could have different values at off axis angles. Additional testing in the horizontal plane may be required for such designs.

TABLE 6 - NRI Limits for Color Linked Position Light

Dihedral Angle and Light Color	Angle from Right or Left of Longitudinal Axis (But-line)	Maximum Intensity (NRI) (units in Watts/sr)
Left (Red)	0° to 20°	2.0E-01
	20° to 40°	1.0E-01
	40° to 60°	1.0E-02
	60° to 110°	1.0E-03
	110° to 130°	1.0E-04
Right (Green)	0° to 20°	2.0E-03
	20° to 40°	1.0E-03
	40° to 60°	1.0E-04
	60° to 110°	1.0E-05
	110° to 130°	1.0E-06
Aft (White)	90° to 110°	2.0E-02
	110° to 180°	2.0E-03

3.3.3.1 (Continued):

NOTE: Unless otherwise defined, minimum NRI values should be 10% of rated maximum values.

3.3.3.2 NRI Limits for Position Lights Having Common Levels: If the mission requirements call out a common NRI level regardless of color, the NRI levels will only be dependent on pattern requirements. Remember, the forward red and green position lights have most of their photopic energy directed forward. Since NVIS radiance scaling is not used to define NVIS Friendly requirements, this means that the NRI levels in the forward direction will be higher than the NRI limits for the aft position light and the side angles of the forward position lights. Therefore, NRI limits for position lights should be linked to dihedral angles used in defining the photometric requirements in 3.2.1. The mission requirements should be the main determinant in deciding the NRI limits. Table 7 includes values that are based on previous flight test from a fixed wing fighter aircraft.

TABLE 7 - NRI Limits for Non-Color Linked Position Light

Dihedral Angle and Light Color	Angle from Right or Left of Longitudinal Axis (But-line)	Maximum Intensity (NRI) (units in Watts/sr)
Left or Right	0° to 20°	2.0E-01
	20° to 40°	1.0E-01
	40° to 60°	1.0E-02
	60° to 110°	1.0E-03
	110° to 130°	1.0E-04
Aft	90° to 110°	2.0E-02
	110° to 180°	2.0E-03

3.3.3.3 Chromaticity Requirements for NVIS Friendly Position Lights: The chromaticity requirements for NVIS Friendly position lights will be the same requirements detailed in the FAR 23, 25, 27 and 29 specifications. The left side position lights shall remain Aviation Red, the right side Aviation Green, and the aft position light Aviation White.

3.3.4 NVIS Friendly Requirements for Formation Lights: Formation lights operational use is at a closer range than position lights. Therefore, the NRI limits should be lower than most of the position lights. However, the type of formation lights used also impacts the NRI limits. As defined in MIL-L-006730, formation lights are either point light sources (Type I) or area light sources (Type II). Each type of formation lights has different luminance requirements that will have an impact on the NVIS Friendly limits. Formation light sources have a variable dimming range as opposed to have either a "Bright" or "Dim" setting.

3.3.4.1 NVIS Friendly Requirements for Formation Lights (Type II): Formation lights that are area light sources (Type II) have a variable dimming range. In addition, the light output of Type II formation lights are greater than the light output for point light sources. For Type II formation lights, the minimal visible light output is 15 footlamberts at the maximum power setting. Since Type II formation lights are area light sources, the formulas use for NRI can not be used. To define the requirements, unscaled NVIS radiance should be used. Since these lights are variable, the only requirement will be for the lower limit when the Type II is at the maximum power condition.

3.3.4.1.1 NVIS Friendly Radiance Limits for Type II Formation Lights: Since Type II formation lights do not have a beam pattern with variable photometric values per dihedral angles, a simple unscaled NVIS radiance range will only be required. Multiple measurements of the Type II light source should be conducted to ensure uniformity along the area light source. All measurements must be done when the light source is at maximum power setting. Measurements will be taken on the surface of the EL strip. The unscaled NVIS radiance values shall be greater then 1.0E-7 NRa, but less than 8.0E-7 NRa.

3.3.4.1.2 Chromaticity Requirements for NVIS Friendly Type II Formation Lights: The chromaticity requirements for NVIS Friendly Type II formation lights shall be contained within the Aviation Green requirements as detailed in the FAR 25 specifications.

3.3.4.2 NVIS Friendly Requirements for Formation Lights (Type I): Formation lights that are point light sources (Type I) that have a variable dimming range. In addition, the light output of Type I formation lights is less than the light output for area light sources (Type II). For Type I Formation lights, the typical visible light output is 6 candelas at the maximum setting. Since the pilot with night vision goggles views the exterior lights unscaled, the lowered light output of Type I formation lights will have a high NVIS radiance limit than Type II Formation lights. Type I formation lights also do not have dihedral angle photometric requirements. Type I formation lights should have a wide beam pattern with as level photometric value as possible. However, since these lights are point light sources, the use of NRI requirements should be used. Since mission requirements mandate the location of Type I formation lights, linking NRI limits to dihedral angles would be impractical. Therefore, one NRI limit will apply for all angles when measured at the maximum power setting.

3.3.4.2.1 NRI Limits for Type I Formation Lights: For Type I formation lights, the NRI limits shall be greater than 2.0E-4 W/sr and less than 2.0E-3 W/sr.

3.3.4.2.2 Chromaticity Requirements for NVIS Friendly Type I Formation Lights: The chromaticity requirements for NVIS Friendly Type I formation lights shall be contained within the Aviation White requirements as detailed in the FAR 23, 25, 27 and 29 specifications.

3.3.5 NVIS Friendly Requirements for Landing/Taxi Lights: Landing and taxi lights normally have a fixed brightness setting. The requirements for having NVIS Friendly landing and/or taxi lights would be situations where some personnel in the general area are operating with NVIS goggles and other are not. The photometric beam spread pattern of a NVIS friendly landing/taxi light must meet the minimum requirements of non-NVIS friendly version. The NRI limits will be higher than most of the other exterior lights due to the critical nature of landing and/or taxiing with goggles.

3.3.5.1 NRI Limits for Landing/Taxi Lights: For either function (landing or taxi), the limits shall be greater than 5.0E-2 W/sr and less than 2.0E-1 W/sr.

3.3.5.2 Chromaticity Requirements for NVIS Friendly Landing/Taxi Lights: The chromaticity requirements for NVIS Friendly landing/taxi lights shall be same as the standard landing/taxi lights.

3.3.6 NVIS Friendly Requirements for Refueling Lights: Refueling lights normally have a variable dimming range as opposed to having either a "Bright" or "Dim" setting. This is true for all types of lighting technologies used (incandescent, EL strips or LEDs).

3.3.6.1 NRI Limits for Refueling Lights: With variable refueling lights, the NRI limits should be taken when the lights are at the maximum power setting. For NVIS Friendly refueling lights, the NRI limits shall be greater than 2.0E-2 W/sr and less than 2.0E-1 W/sr.

3.3.6.2 Chromaticity Requirements for NVIS Friendly Refueling Lights: The chromaticity requirements for NVIS Friendly refueling lights are dependent on the light technology used. For incandescent and LEDs, the chromaticity shall be contained within the Aviation White requirements as detailed in the FAR 25 specifications. For EL strips, the chromaticity shall be contained within the Aviation Green requirements as detailed in the FAR 25 specifications.

3.4 Covert Requirements:

Covert lighting by its very name requires that it cannot be viewed by the naked eye. Since covert lighting has only recently been developed, there are no military specifications to guide in the design and application. This document will attempt to fill this void.

3.4.1 Definition of Covert Exterior Lights: Covert exterior lights were developed to meet a mission requirement to give pilots the ability to conduct basic rejoins in combat situations. The covert exterior light differs from visible (both normal aviation and NVIS Friendly) exterior lights in having completely different coverage and different design goals. Visible exterior lights are met to prevent mid-air collisions. The radiometric energy is directed on all directions with extra photopic energy directed forward. Covert exterior lights should have as little radiometric energy forward or downward.

3.4.2 Design Requirement for Covert Lighting: The use of covert exterior lighting has different requirements than visible or NVIS Friendly exterior lighting. Covert lighting is meant to operate in hostile airspace and should have its radiometric energy directed upward and aft. The exact energy patterns will be determined by the mission requirements of the aircraft. However, this section will provide general guidelines for the various types of exterior lights (i.e., position, formation, etc).

3.4.2.1 Photometric Requirements for Covert Lighting: The vast majority of the radiometric output of covert lighting is in the near infrared wavelengths. However, there is normally a small amount of photopic or visible energy. The maximum amount of photopic energy allowed for covert lighting shall be less than 0.02 candela when operated at maximum power setting for point light sources (the only exception would be high energy covert applications where the allowance of visible light may be required to achieve the NRI values). For area light sources, the maximum amount of photometric energy allowed for the covert portion shall be less than 0.02 footlamberts when operated at maximum power setting.

3.4.2.2 Chromaticity Requirements for Covert Lighting: Covert energy sources should have as little photopic energy has possible. However, the peak emission of the energy sources should be contained within the wavelengths where the night vision goggles have the highest response. Therefore, the covert portion of the IR energy sources shall peak between 750 to 850 nm. This will ensure that the radiometric energy is in the maximum response zone for the night vision goggles.

3.4.3 Covert Radiance Limits for Anti-Collision Lights: For covert anti-collision lights, the radiant intensity pattern of the IR energy sources must be the greatest of all the exterior lights. Pilots using night vision goggles must detect the energy from this light assembly at least 8 miles away. The beam spread pattern for a covert anti-collision light is similar to visible anti-collision lights. The angle distribution shall be given with the assumption that the 0° will be the forward position of the aircraft or parallel to the centerline of the aircraft, 90° the outboard position, and 180° the aft position. The energy sources shall be mounted so that the center of the beam spread pattern is parallel to the waterline of the aircraft.

3.4.3.1 NRI Limits for the Anti-Collision Covert Light: The covert energy sources shall have a NRI value of not less than 1.00E-0 W/sr with a horizontal field of coverage of 360 degrees. Values shall be taken every 10 degrees to maintain coverage uniformity.

The covert energy sources shall have the following minimum NVIS Radiance values when measured above the horizontal plane (waterline):

TABLE 8 - NRI Limits for the Anti-Collision Covert Light

Angles above the horizontal plane	Percentage of Radiance at each given horizontal value
0º	1.00
10º	0.90
15º	0.80
20º	0.60
30º	0.40

The covert energy sources shall have a NRI value of not greater than 2.00E-4 when measured 10 degrees below the horizontal plane (waterline).

3.4.4 Covert Radiance Limits for Position Lights: For covert position lights, the radiant intensity pattern of the IR energy sources must meet the mission requirements for night vision goggle tactics. For covert position lights, that function is to serve as radiometric signals for rejoins between either two fighters or a combination therein. The typical separation distance between two aircraft requiring rejoins is about 3 to 4 miles. This exceeds the night vision goggle detection range for dual mode EL strips (which can only be typically seen within two miles). Therefore, the need for high intensity IR energy sources located on position lights was made part of the mission requirements for covert position lights.

Just like visible position lights that have a large amount of the luminous intensity directed in one primary axis, (for example, visible position lights require 40 candelas in the forward direction, but less than 5 candelas off axis), covert position lights will require a high radiant intensity narrow beam pattern along with a moderate radiant intensity wide beam spread pattern. The narrow IR beam portion of the covert position light will assist in the rejoins from the 3 to 4 mile range, and the moderate wide beam intensity portion will supplement the other covert formation lights. For the covert lights to be seen at the ranges of 3 to 4 miles, a range of radiometric energy from the energy sources must be established to provide a guideline for engineering designs. The exact dihedral angle of the narrow beam and wide beam with respects to the aircraft are based on mission requirements and flight test. The NRI limits given below will be defined along the energy axis of the IR source (for point light sources).

3.4.4.1 NRI Values for the Left and Right Covert Position Lights: The beam spread pattern for the covert positions lights should have the following values:

For the "Bright" signal, the NRI limits should fall within the following:

3.00E-3 < NRI (W/sr) < 3.00E-2 (within the 14° ± 7° cone).
3.00E-4 < NRI (W/sr) < 2.00E-3 (outside the 14° ± 7° cone, but within the 70° ± 10° cone).

For the "Dim" signal, the NRI values should fall within the following:

3.00E-4 < NRI (W/sr) < 2.00E-3 (within the 14° ± 7° cone).
3.00E-5 < NRI (W/sr) < 2.00E-4 (outside the 14° ± 4° cone, but within the 70° ± 10° cone).

A suggested center point of the cone should be situated on the waterline of the aircraft and approximately 115° aft of the forward axis of the aircraft. This will focus the radiant intensity of the energy sources slightly aft. This pattern has been flight-tested and meets the mission requirements for covert rejoins.

3.4.4.2 NRI Values for the Aft Covert Position Lights: The beam spread pattern for the covert positions lights should have the following values:

For the "Bright" signal, the NRI limits should fall within the following for measurement:

3.00E-4 < NRI (W/sr) < 3.00E-3 (within the 70° ± 10° cone).

For the "Dim" signal, the NRI limits should fall within the following:

3.00E-6 < NRI (W/sr) < 3.00E-5 (within the 70° ± 10° cone).

The center point of the cone should be situated on the waterline of the aircraft and 180° aft of the forward axis of the aircraft. This pattern has been flight-tested and meets the mission requirements for covert rejoins.

3.4.4.3 NRI Limits for Right Wingtip Covert Lights that are Supplemental to Position lights that are not Installed on the Wingtip: The covert energy sources shall have the following NRI limits in the horizontal plane (waterline):

TABLE 9 – Horizontal NRI Limits for Right Wingtip Covert

Angles	Bright/Dim	Limits for NRI (W/sr) Minimum/Maximum
0° to 20°	Bright	0.0 to 2.00E-3
20° to 250°	Bright	2.00E-4 to 2.00E-3
250° to 300°	Bright	0.0 to 2.00E-3
300° to 360°	Bright	0.0 to 2.00E-4

The Dim values shall be 70% ± 10% the above values of the BRT values at the same angle requirements.

The covert energy sources shall have the following minimum NRI values when measured above the horizontal plane (waterline):

TABLE 10 - Vertical NRI Limits for Right Wingtip Covert

Angle Above the Horizontal Plane	Percentage of NRI at Each Given Horizontal Value
0°	1.00
40°	0.80
40° and above	0.0 to 0.80

There should be as little radiance possible below the horizontal.

3.4.4.4 NRI Limits for Left Wingtip Covert Lights that are Supplemental to Position lights that are not Installed on the Wingtip: The covert energy sources shall have the following NRI Limits in the horizontal plane (waterline):

TABLE 11 – Horizontal NRI Limits for Left Wingtip Covert

Angles	Bright/Dim	Limits for NRI (W/sr) Minimum/Maximum
0° to 60°	Bright	0.0 to 2.00E-3
60° to 110°	Bright	2.00E-4 to 2.00E-3
110° to 340°	Bright	0.0 to 2.00E-3
340° to 360°	Bright	0.0 to 2.00E-4

The Dim values shall be 70% ± 10% the above values of the BRT values at the same angle requirements.

The covert energy sources shall have the following minimum NRI values when measured above the horizontal plane (waterline):

TABLE 12 - Vertical NRI Limits for Left Wingtip Covert

Angles Above the Horizontal Plane	Percentage of NRI at Each Given Horizontal Value
0°	1.00
40°	0.80
40° and above	0.0 to 0.80

There should be as little radiance possible below the horizontal.

3.4.5 Covert Radiance Limits for Formation Lights: For covert formation lights, the radiant intensity pattern of the IR energy sources must meet the mission requirements for night vision goggle tactics. For covert formation lights, that function is to serve as radiometric signals for nighttime assisted formation flying. The beam spread pattern for covert formation light is similar to visible formation lights with one key difference. There must be no IR energy directed downward. Most of the energy should be directed upward and to left and right of the aircraft. Make sure that no IR energy is directed toward the pilot. Furthermore, the IR energy should be less than the high-energy IR energy sources used in the left and right position lights. These covert formation lights need to be detected for night vision goggle operation in the range from a few hundred feet to less than 2 miles.