야시조명계통 요구도 분석

Analysis of Requirements for Night Vision Imaging System

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ABSTRACT

This paper concerns about the requirement analysis for night vision imaging system(NVIS), whose purpose is to intensify the available nighttime near infrared(IR) radiation sufficiently to be caught by the human eyes on a miniature green phosphor screen. The requirements for NVIS are NVIS radiance(NR), chromaticity, daylight legibility/readability, etc. The NR is a quantitative measure of night vision goggle (NVG) compatibility of a light source as viewed through goggles. The chromaticity is the quality of a color as determined by its purity and dominant wavelength. The daylight legibility/readability is the degree at which words are readable based on appearance and a measure of an instrument's ability to display incremental changes in its output value. In this paper, the requirements of NR, chromaticity, and daylight legibility/readability for Type I and Class B/C NVIS are analyzed. Also the rationale is shown with respect to those requirements.

주요기술용어(주제어) : Night Vision Imaging System, Night Vision Goggles, NVG Compatibility, NVIS Radiance, Chromaticity, Daylight Legibility/Readability

1. Introduction

There are two main classes of night vision devices. The image intensification(I^2) systems enhance the lighting that is the available lighting of existing environment. The infrared(IR) devices, in contrast, will typically use heat emissions to identify the objects that cannot otherwise be detected using available light sources[1].

The concept of night vision imaging is to intensify available nighttime near IR radiation, (630nm to 930nm), sufficiently to be caught by the human eyes on a miniature green phosphor screen(NVG screen).

The nighttime IR radiation comes from such the sources of star light and moon light. The relative irradiation response of night sky has an excellent feature at the wavelength of between 630nm and 930nm. The intensification process of night vision goggle(NVG) at wavelengths of this

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region is used. The variations in the level of near infrared energy, due to variations in object reflectance, are translated into brightness variations across the face of the monochromatic green visible image, providing the necessary contrast for object recognition. The image is produced with sufficient quality and clarity to discern considerable details[2]. The night vision imaging system(NVIS) uses I^2 tubes to produce an enhanced image of a scene in light condition too low for normal navigation and pilotage.

The military specification that governs the aircraft NVG compatible lighting and light emitting displays is MIL-STD-3009[3]. The scope of this specification establishes performance, general configuration, test and acceptance requirements for NVIS-compatible aircraft interior lighting. This specification gives NVG interference(NI) levels (i.e., NVIS Radiance, NR), color and contrast requirements for the various lighted components to be used in "NVG-compatible" aircraft.

In this paper, the requirements of NR, chromaticity and daylight legibility/readability for Type I and Class C NVIS, which are used in Korea military, are analyzed. Also, the rationale is shown with respect to those requirements.

2. Night Vision Goggle Characteristics

The application of NVGs has become widespread in military aircraft. By allowing pilots to fly at nighttime missions, these NVGs provide the military with near 24-hour air operation. The NVGs amplify ambient scene illumination and produce a highly intensified monochromatic near day-like presentation of a nighttime scene. The NVGs are basically composed of an objective lens which focuses an image onto the photo-cathode of an image intensifier tube which in turn produces an amplified image that is viewed through an eyepiece lens. There are several versions of NVGs in use and in development, and several parameters that are used to characterize the image quality and capability of the NVGs[4].

I^2 tubes that are currently in use in NVIS optical devices use two different types of photosensitive materials. The generation II(GEN II) intensifier tubes use a tri-alkali photocathode microchannel. The generation III(GEN III) intensifier tubes use a gallium arsenide(GaAs) photocathode microchannel. The GEN II and GEN III I^2 tubes differ in their gain and response characteristics in both the visible and infrared regions. In figure 1, the normalized response characteristic of the GEN II AN/PVS-5 goggles and the GEN III AN/AVS-6 aviator's NVIS (ANVIS) goggles is shown in relationship to the Commission Internatiale de l'Eclairage(CIE) photopic curve and night sky radiation. The response of GEN III intensifiers is shown from 450nm to 930nm and is maximized in the near IR region between 700nm and 850nm. The optical filters, termed "minus blue filters", are used in conjunction with the objective lenses of GEN III goggles to restrict their response to visible light.

MIL-STD-3009 lighting requirements have been broken down into Types and Classes to give the user the convenience to specify the type and class of the lighting system, depending on the type of NVIS being used in the aircraft. Type I is direct view image of NVIS and Type II is projected image of NVIS. The class is classified A, B, and C according to the minus blue filter characteristics. The relative spectral response characteristics of Classes A, B, and C of NVIS is shown in figure 2.

3. NVG Compatibility

The NVGs are used to view what is outside the crewstation, not what is inside. The interference by light sources inside the crewstation is undesirable. All existing crewstation light sources emit some energy in the red and near-infrared wavelength region. To ensure maximum NVG performance, this energy from light sources must be suppressed to a certain level to avoid unnecessary interactions with the NVG.

The compatible lighting requirements of MIL-STD-3009 depend on the characteristics of the NVIS with which the lighting is intended to be compatible[3,5].

In order to quantify the interaction between the NVG and a particular light source, it is necessary to know the spectral characteristics of both. GEN Ill NVGs have a spectral response which is the greatest in the near IR, however, these systems also have considerable sensitivity in the visible region(see figure 1). Whatever NVG system is being used it is important that the precise spectral response should be known if NVG/source interaction is to be quantified accurately.

The NVG spectral response curve is analogous to the luminous efficacy function used in photometric calculations. The luminous efficacy describes the spectral sensitivity of the human eye and is used in the calculation of photometric quantities[6].

The other data necessary for quantifying NVG/source interaction is the source spectral radiance. The spectral radiance characterizes the electromagnetic energy emitted by the source as a function of wavelength. It is important to obtain spectral radiance data for the wavelength range 450~930nm as this is the region in which GEN Ill NVG sensitivity is typically defined.

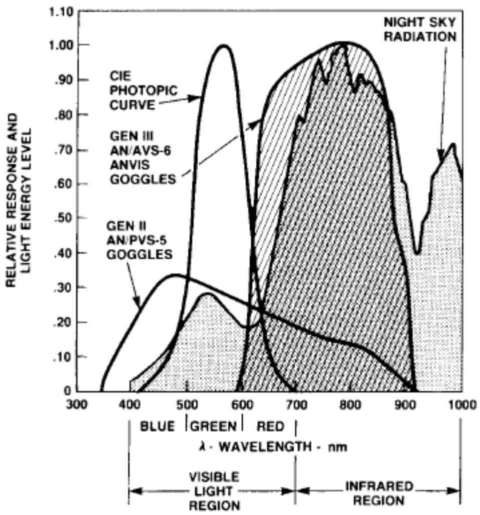
NI is a convenient way to indicate the amount of energy visible to the NVG. NI can be shown graphically as the area under a curve which is the product of the NVG spectral response and source spectral radiance. Worldwide there are many ways to quantify the effect of energy on the NVG but the concept of NI is common to most of these approaches.

A. Objectives for NVG Compatible Cockpit Lighting

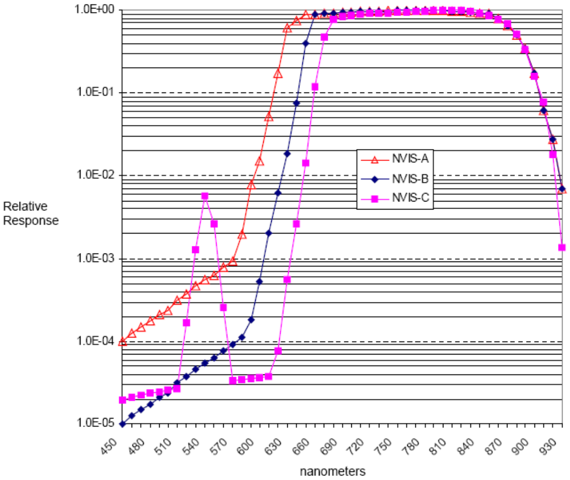
Some objectives for NVG compatible cockpit lighting can be defined:

1) Selection of the radiated spectra of NVG filtered general cockpit flood lighting to be outside the response characteristic of NVGs with minus blue filters.

2) Provision of the sufficient general illumination to locate switches and read cockpit instrumentation with unaided eyes. The illumination should be NVG filtered to achieve specified NVG compatibility, be perceptibly uniform and be green in color.



[Figure 1] Relative response of GEN II and GEN III Night Vision Goggles with respect to the CIE Photopic curve and Night Sky Infrared Radiation



[Figure 2] Relative spectral response characteristics of Classes A, B, and C NVIS

3) Retaining of the color differences within the NVG filtered light emitting displays to enhance information transfer to the pilot, specifically when pertaining to master caution and warning lights. The radiated spectra from master caution and warning displays should be NVG filtered to achieve a specified NVG compatibility.

4) The NVG filtered radiated spectra of master caution and warning lights and displays should contain wavelengths within NVGs short wavelength response to attract the pilot's attention when looking through the goggles. The luminance level should be low enough to prevent interference with goggle operation.

4. The History of NVIS Specification

Funding was provided in April 1983 to begin the development of a specification to define the requirements for ANVIS compatible lighting. This began a long process of determining exactly what compatible lighting was, how it could be quantified and what measurement equipment and techniques were necessary to confirm compliance. The specification was written by a Joint Aeronautical Commanders Tri-Service committee with the Naval Air Development Center serving as the lead technical laboratory. Industry representatives were included in the development of the requirements, and were kept updated in meetings of the Society of Automotive Engineers(SAE), Aerospace Lighting Institute(ALI) and the Aircrew Station Standardization Panel(ASSP). Many of the industry suggestions were incorporated in the specification. The resulting specification was MIL-L-85762 dated 24 January 1986 and was exclusively written for ANVIS compatible lighting and was strictly an ANVIS specification. MIL-L-85762 is used in place of two older aircraft lighting specifications; MIL-L-18276, used by the Army and Navy, and MIL-L-6503 used by the Air Force. Because other types of NVISs had been developed and approved for use, MIL-L-85762 had to be revised. The revised specification, MIL-L-85762A dated 26 August 1988, added the requirement for lighting that would be compatible with other types of NVISs. The revised specification covers all NVIS compatible lighting requirements including ANVIS which is referred to as one type of NVIS. Recently, the specification is revised MIL-STD-3009 dated 2 February 2001, added the requirement for Class C NVIS and exterior lighting compatibility definitions and criteria[7].

5. Analysis of Requirements

NVIS compatible lighting is very simply lighting which will not interfere with NVIS operation. Because NVIS are highly sensitive in the 600nm to 930nm portion of the electromagnetic spectrum, they respond to even tiny amounts of spectral radiance in this range. It is the amount of spectral radiance between 600nm and 930nm being emitted by a light source that determines how much interference there will be. This spectral radiance interferes with the outside scene being viewed through the NVIS by causing a veiling background brightness which can obscure the outside scene. If this interference is very low, then these effects will be negligible and the outside scene will remain clear. If this interference is high, the outside scene will be degraded, and if the interference is very high, the automatic gain control(AGC) will be activated causing the loss of NVIS sensitivity. The compatible lighting will not cause this interference so the pilot will have a clear image of the outside scene and will have the maximum NVIS sensitivity possible. The question is how much of this spectral radiance can be tolerated, how much spectral radiance causes interference, and how can this spectral radiance be quantified and measured.

A. NVIS Radiance

NR is defined as the NI produced by a light source over the wavelength interval from 450nm to 930nm. The maximum NR is specified according to lighting component type and NVG Class. The formula 1 shall be used to calculate the NVIS radiance at the specified luminance of Class B equipment.

The scaling factor in the equation (1) is a normalization constant used for numerically scaling the spectral radiance of the light source to the specified in table 1 luminance. The low NR values for crewstation illumination are desirable. Idealistically a lighted component would yield an NR value of zero. However the spectral analysis of NR will reveal that this is not a realistic goal. Since zero NR is not attainable, the importance of minimizing the NI produced by crewstation lighting cannot be overstated. The excessive NR causes a reduction in NVG gain which results in a loss of resolution of outside scene. The lighted components which operate with NR near specification limits may also causes windscreen reflections which are visible through the NVG, obstructing the pilot's view of outside scene. The NR limit of 1.7×10^{-10} is close to the that value of 1.63×10^{-10} measured for tree bark.

$$NVIS\ radiance(NR_B)\ at\ specified\ \ luminance = S\int_{450}^{930} G_B(\lambda)\ N(\lambda)\ d\lambda \quad (1)$$

Where :

$G_B(\lambda)$ = relative NVIS response of Class B equipment

$N(\lambda)$ = spectral radiance of lighting component (W/cm^2 sr nm)

S = scaling factor

$d\lambda$ = 5nm

1) Spectral Sensitivity of GEN III I^2 tube

The NVIS spectral response depends primarily on the spectral sensitivity of GEN III I^2 tubes. The Center for Night Vision and Electro-Optics (CNVEO) provided the data on the average tube sensitivity for each of the two tube manufacturers (ITT and Varian) and the sensitivity of an extremely sensitive tube(see figure 3a).

2) Minus-Blue Objective Lens Filter

In addition to being dependent on the intensifier tube sensitivity, the NVIS spectral response depends on the transmission characteristics of the objective lens. The spectral response of NVIS could be reduced in the visible portion of the spectrum so that cockpit lighting would have less interference with the NVIS. This can be done by placing a minus-blue filter onto the objective lens during manufacturing. The filter effectively blocks out the blue and green light while transmitting red and near infrared.

[Table 1] NR requirements(Type 1, Class B/C)

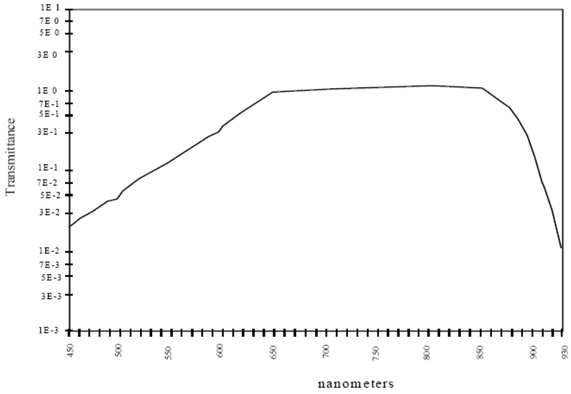
Lighting component		Not less Than(NR_B)	Not greater Than(NR_B)	luminance (fL)
Primary		-	1.7×10^{-10}	0.1
Secondary		-	1.7×10^{-10}	0.1
Illuminated controls		-	1.7×10^{-10}	0.1
Compartment lighting		-	1.7×10^{-10}	0.1
Utility, map, work, and inspection	Green	-	1.7×10^{-10}	0.1
	White	-	1.0×10^{-9}	0.1
Caution and advisory		-	1.7×10^{-10}	0.1
Jump lights		1.6×10^{-8}	4.7×10^{-8}	5.0
Warning signal		4.7×10^{-8}	1.4×10^{-7}	15.0
Master caution signal		4.7×10^{-8}	1.4×10^{-7}	15.0
Emergency exit lighting		4.7×10^{-8}	1.4×10^{-7}	15.0
Electronic and electro-optical displays (monochromatic)		-	1.6×10^{-10}	0.5
Electronic and electro-optical displays (multi-color)	White	-	2.2×10^{-9}	0.5
	MAX	-	1.1×10^{-8}	0.5
HUD systems		1.6×10^{-9}	4.7×10^{-9}	5.0

3) NVIS Relative Spectral Response

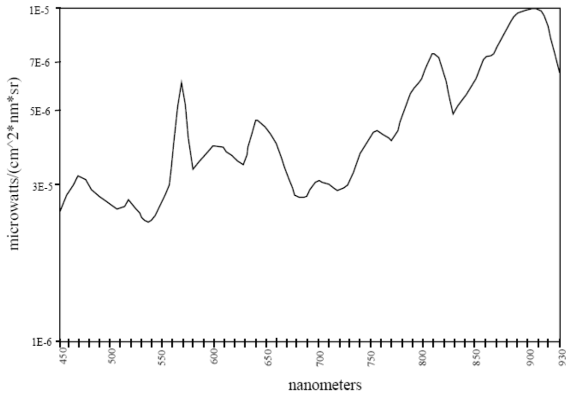
The NVIS relative spectral response is determined by selecting the minus-blue filter with the maximum allowable transmission and multiplying this by the composite I^2 tube sensitivity.

4) Maximum Allowable Quantity of NR

If the image of the cockpit lighting, when viewed through the NVIS, is not brighter than



(a)



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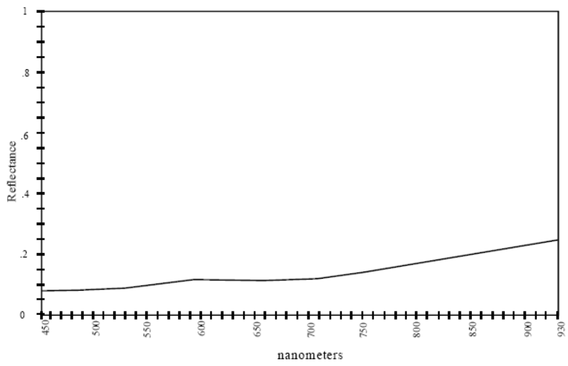


(c)

[Figure 3] (a) Normalized spectral sensitivity curve for a GEN III I^2 tube, (b) Spectral distribution of starlight, (c) Spectral reflectivity of tree bark.

the outside scene, then that lighting could be considered as being compatible. The most difficult terrain feature to see at night is a defoliated tree. The NR of a defoliated tree in starlight(see figure 3b) is calculated by multiplying the spectral radiance of starlight by the spectral reflectivity of tree bark(see figure 3c). In order to keep the cockpit lighting less than the outside scene, when viewed through NVIS, the NR of the cockpit lighting has to be less than that of tree bark in starlight. This rationale establish the value of 1.7×10^{-10} as the maximum allowable NR.

5) Luminance Level for NR

Since the total amount of NR emitted by a lighting component varies with how bright it is set, a luminance level have to be defined at which the NR is to be measured. When using NVIS a pilot views his cockpit lighting with his unaided eye. United States Air Force(USAF) tests showed that pilots set their cockpit lighting to less than 0.1 foot-Lamberts(fl)[7].

6) Monochromatic Displays

If the monochromatic display is required to display shades of gray imagery then it must meet the NR requirement of 1.7×10^{-10} maximum at 0.5 fl instead of 0.1fl.

7) Multicolor Displays

If a full color display is properly filtered and positioned outside the NVIS field-of-view(FOV) then it could be used with Class B NVIS. However, the NR of even a properly filtered multicolor display cannot meet the NR requirement for primary cockpit lighting. There are two levels of NR defined for multicolor displays. The first is the closest color to white that can be made and the second is the maximum allowable for the worst case color. The NR requirements for “white” multicolor displays is 2.2×10^{-9} maximum at 0.5fl for Types I Class B NVIS. The maximum NR for the worst case color is 1.1×10^{-8} maximum at 0.5fl for Types I Class B NVIS.

8) Head Up Display(HUD)

For Type I Class B the NR requirement is 1.6×10^{-9} minimum at 5fl and 4.7×10^{-9} maximum at 5fl. The lower limit was selected because a P43 phosphor with a Kaiser filter set to 5fl is just visible through the Type I Class B NVIS. The upper limit is three times the lower limit to maintain a three to one ratio.

B. Chromaticity

The NVIS Colors are designated as Green A, Green B, NVIS Yellow, NVIS Red, and NVIS White These color ranges are shown on the 1976 uniform chromaticity scale(UCS) diagram in figure 4. The NVIS GREEN B region is yellow-green in color, defined between the dominant wavelengths of 544nm and 562nm. The NVIS Yellow region includes the colors of greenish-yellow, yellow and yellowish-orange, defined between the dominant wavelengths of 572nm and 588nm. The NVIS RED region is not red, but contains the colors of orange and reddish-orange, defined between the dominant wavelengths of 598nm and 618nm. Chromaticity requirement is shown in table 2.

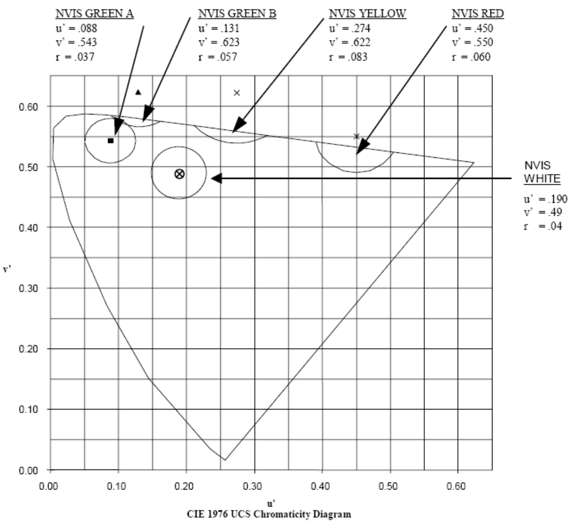
1) Factors Influencing on the Selection of Color

The NVIS relative response curve and the relative photopic response curve limit the color of NVIS compatible lighting to the blue-green, green and yellow-green region of the UCS diagram. Any of these colors could be made NVIS compatible but the color variations could be too large to produce a uniform cockpit color.

The maximum luminous efficiency of the eye is at 555nm so consideration was given to this dominant wavelength. Consideration was given to matching the color of the image produced in the NVIS on a P20 phosphor screen. In case of monochromatic CRTs, P43 is considered. The reason for these matches is to prevent unintentional distractions caused by differences in chromaticity. Also the color had to be as unsaturated as possible because the reading in highly saturated lighting is irritating and can cause eye fatigue. Using these factors the color was selected where the dominant wavelength was in the yellowish-green and less saturated area of the UCS diagram.

2) NVIS Green A

Since a degradation of pilot performance due to color uniformity differences could not be substantiated, a decision was made to select a color and tolerance. Applying this criteria to the other factors that were influencing the primary color selection for NVIS compatible lighting as the area within a circle whose radius is 0.037 and centered at u′ = 0.088, v′ = 0.543 on the 1976 UCS diagram. This color was labeled as NVIS Green A and was designated the primary color for crewstation lighting.



[Figure 4] NVIS lighting color limits

3) NVIS Green B

The annunciators which are intended to be daylight readable but have a NVIS Green A color, are not effective and are poor in their "attention getting" ability. This is because NVIS Green A is an unsaturated color and normally, colored daylight readable annunciators are extremely saturated. It is conducted on the color of annunciators which were both NVIS compatible and daylight readable and from these results NVIS Green B was formulated, NVIS Green B was defined as the

[Table 2] Chromaticity requirements(Type 1, Class B/C)

Lighting component	u'_1	v'_1	r	luminance (fL)	NVIS Color
Primary	.088	.543	.037	0.1	Green A
Secondary	.088	.543	.037	0.1	Green A
Illuminated controls	.088	.543	.037	0.1	Green A
Compartment lighting	.088	.543	.037	0.1	Green A
Utility, map, work, and inspection	.088	.543	.037	0.1	Green A
	.190	.490	.040	0.1	White
Caution and advisory	.088	.543	.037	0.1	Green A
Jump lights	.088	.543	.037	5.0	Green A
	.274	.622	.083	15.0	Yellow
Special lighting components	.131	.623	.057	0.1	Green B
Warning signal	.274	.622	.083	15.0	Yellow
	.450	.550	.060	15.0	Red
Master caution signal	.274	.622	.083	15.0	Yellow

area bounded by the spectral locus and a circle whose radius is 0.057 and centered at u′ = 0.131, v′ = 0.623 on the 1976 UCS diagram.

4) NVIS Yellow

The NVIS Yellow color was developed for warning indicators and master caution indicators because it was felt that color coding was necessary to get the pilot's attention. The color is very limited in red content because of the adverse effect of red on the Class A NVIS. A survey was taken of manufacturers to determine how yellow of a color could be made while having the least, impact on Class A NVIS. This led to the selection of the NVIS Yellow color which was defined as the area bounded by the spectral locus and a circle whose radius is 0.083 and centered at u′ = 0.274, v′ = 0.622 on the 1976 UCS diagram. The NVIS Yellow lighting components must meet the color requirement at a luminance of 15fl because MIL-STD-411[8] requires that master caution indicators and warning indicators have a luminance of 15fl at night.

5) NVIS Red

The Class B NVIS were designed to have a low sensitivity much farther into the red wavelength range than the Class A NVIS. This was done to allow some red lighting to be used in Class B NVIS compatible crewstations. However, if the lighting was too red it would adversely affect the Class B NVIS so the color had to be selected as close to orange as possible. Twenty test subjects were asked to identify a color that they would call red compared to NVIS Yellow. This test[7] was the basis for selecting the NVIS Red color and was defined as the area bounded by the spectral locus and a circle whose radius is 0.060 and centered at u′ = 0.450, v′ = 0.550 on the 1976 UCS diagram. The NVIS Red lighting components must meet the color requirements at a luminance of 15fl, which is same NVIS Yellow situation.

6) NVIS White

The NVIS white is to provide a broader-band light source that would allow color vision, since neither NVIS green A or B provide enough red or blue light for color vision. Moving to the less saturated NVIS white area allows one to see things like blue water and red roads on a map in their true color instead of a dark gray color, as you will under NVIS green illumination. The color was defined in the area toward green from a true white, and with a very large color tolerance. The NVIS White color which is defined as the area bounded by the spectral locus and a circle whose radius is 0.04 and centered at u′ = 0.19, v′ = 0.49 on the 1976 UCS diagram.

7) Luminance Settings for Color Measurement

The NVIS Green A and NVIS Green B lighting components have to meet the color requirements when they are set to a luminance of 0.1fl. This was done for consistency in measurements because some lighting technologies change color when the luminance is changed. The luminance of 0.1fl is selected based on USAF tests which showed that pilots using NVIS set their cockpit lighting at 0.1fl or lower. The adjustable lighting components which are designed to illuminate an area must produce the required color on a reflectance standard located 12inches away when adjusted to produce 0.1fl on the reflectance standard. The fixed lighting components which are designed to illuminate an area placed at the same distance from the reflectance standard as they are located from the area they are illuminating and adjusted to produce 0.1fl on the reflectance standard.

C. Daylight Legibility/Readability

1) Readability in Direct Reflected Specular Sunlight

The illuminated visual signals, requiring readability in direct reflected specular sunlight, must have a lighted contrast C_L(The On/Background contrast), not less than 0.4 and an unlighted contrast C_{UL}(The Off/Background contrast) equal to 0.0±0.1, under 10,000foot-candles (fc) of illumination as defined in MIL-S-22885[9]. The 10,000fc source is set to an angle of 15° off the normal of the display and is the angle of incidence. The photometer is set at the angle of reflectance of 15°. This is the most severe test for sunlight readability. It represents the worst case situation where the display is positioned such that the pilot sees a specular reflection of a white cloud in sunshine or the sun itself. This is primarily applied to illuminated switches and indicators mounted in a position where a specular reflection of the sky may be visible. The contrast value of 0.4 was reduced from 0.6 to allow for the additional filtering necessary to make the display NVIS compatible.

2) Daylight Readability Excluding Specular Sunlight

The illuminated visual signals, not requiring readability in direct reflected specular sunlight, must have a lighted contrast of not less than 1.0 as defined in MIL-S-38039[10]. This requirement is for signals located where there is no specular reflection of sunlight, but where the signals must be read in a 10,000fc diffuse environment.

3) Daylight Readability of Electronic and Electro-Optical Displays

The electronic and electro-optical displays intended to be daylight readable must meet the stated contrast values when subjected to a combined environment of a diffuse light source producing 10,000fc at the display, and a specular reflection of a glare source with a luminance of 2,000fl. These displays must also have a high luminance of 100fl, minimum, to meet the minimum luminance difference requirement. These requirements were developed by the USAF and are similar to those written into MIL-D-87213A[11] by the USAF. The rationale for a combined test is that in a fighter cockpit at high altitudes both conditions can exist simultaneously, so the test simulates a realistic environmental situation. The sunlight of 12,000fc to 15,000fc is reduced to 10,000fc after passing through the canopy striking off-axis(80～90% transmissivity). The 10,000fc source represents this condition. The sunlight can also illuminate the pilot's flight suit, helmet or other interior parts of the cockpit producing a 2,000fl source which can be specularly reflected off the display surface. The 2,000fl source represents this condition. Also the contrast values represent the minimum needed for legibility under various lighting conditions, and vibration and stress conditions. The lower contrast displays tend to “wash out” in bright conditions. The minimum contrast values are shown in table 3.

[Table 3] Minimum Contrast Values

Types	minimum contrast(C_L and C_I*)
Numeric only	1.5
Alphanumeric	2.0
Graphic Symbols	3.0
Video worst case	4.66

* C_I : On/Off contrast

6. Conclusion

The NVIS uses I^2 tubes to produce an enhanced image of a scene in light conditions too low for normal navigation and pilotage. For applying NVIS in aircraft, it should not be interfered with NVG, that is to say, it should be NVG compatible.

The factors for showing quantitative amount of interference between NVIS and NVG is NR and chromaticity.

This paper provides the analysis and rationale of NVIS requirements, especially NR, chromaticity, and daylight legibility/readability. This study has investigated that the colors of NVIS are Green A/B, NVIS Yellow, NVIS Red, and NVIS White. Also we present requirement analysis of illuminated visual signals, electronic and electro-optical displays intended to be daylight-readable, sunlight illuminance, and minimum contrast values.

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