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| 14. ABSTRACT<br>This TOP outlines the procedures for testing human factors engineering aspects of cockpit lighting and the methodology involved in quantifying, qualifying, and presenting data for cockpit lighting. Cockpit lighting characteristics testing outlined in this TOP include display luminance, illuminance, contrast, balance, uniformity, sunlight readability, display color, night vision imaging system compatibility, and crewstation reflections.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                             |                              |                                          |                                                                  |                                              |  |
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US ARMY TEST AND EVALUATION COMMAND  
TEST OPERATIONS PROCEDURE

\*Test Operations Procedure 07-2-513A  
DTIC AD No.

15 July 2011

HUMAN FACTORS ENGINEERING TESTING OF  
AIRCRAFT COCKPIT LIGHTING SYSTEMS

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\*This TOP supersedes TOP 07-2-513, Human Factors Engineering Testing of Aircraft Cockpit Lighting Systems, 2 August 1989

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1. SCOPE.

This Test Operations Procedure (TOP) specifies procedures for testing human factors engineering (HFE) aspects of cockpit lighting systems. In this TOP, there is a heavy reliance on testing against quantitative criteria as opposed to qualitative (subjective) evaluations. The criteria listed in Appendix C serve as appropriate guidelines against which lighting tests are conducted. Specific test requirement documentation should also be consulted. While it is considered essential that qualitative evaluations of cockpit lighting systems be conducted, procedures for those evaluations are not covered here. Other documents, such as TOP 01-2-610<sup>1</sup>, and Test and Evaluation Command Pamphlet (TECOM PAM) 602-1<sup>2</sup>, contain guidance on how to collect this type of data. The test procedures in this TOP have been verified and conform to accepted industry practices. The parameters being measured and analyzed have been shown to have a direct bearing on crew system effectiveness and flight safety.

2. FACILITIES, EQUIPMENT, AND INSTRUMENTATION.

2.1 Facilities.

| <u>Item</u>                        | <u>Requirement</u>                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Darkened hangar or other enclosure | Facility must be a light controlled environment free from extraneous light sources. The ambient illumination level must be strictly limited to a maximum of $1 \times 10^{-4}$ footcandles (fc) or 1% of the light source being measured, whichever is less, and $1 \times 10^{-6}$ fc for night vision imaging system (NVIS) testing. Power must be available to operate all aircraft lighting systems and displays under test as well as test equipment. |

2.2 Equipment.

| <u>Item</u>                                              | <u>Requirement</u>                                                                                                                                                                                                                                     |
|----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| US Air Force 1951 visual acuity targets, medium-contrast | Described in Military Standard (MIL-STD) 150A <sup>3</sup> and Naval Ordnance Laboratory (NOLTR) 72-18 <sup>4</sup> (Figure 1).                                                                                                                        |
| Landolt C-ring                                           | Square white target board with a circular "C" centered on the board. The gap in the "C" must be equal to the thickness of the ring and 1/5 the ring diameter. Overall ring dimensions should be appropriate for the testing distances used (Figure 2). |

\*Superscript numbers correspond to Appendix F, References.

| <u>Item</u>                              | <u>Requirement</u>                                                                                                                                                                                                          |
|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Landolt C acuity charts, medium-contrast | White charts (six variations) containing three groups (numbered -5 to -3) of six rows (numbered 1-6) each with six Landolt “C” figures each randomly oriented in one of four directions (up, down, left, right) (Figure 3). |
| Artificial sun                           | Lamp capable of illuminating displays at 10,000 fc operating at a color temperature of 4,500 to 5,500 K (preferably 5,000 K or above).                                                                                      |
| Artificial starlight                     | Lamp capable of illuminating resolution charts with levels between $1 \times 10^{-5}$ and $1 \times 10^{-3}$ fc with a color temperature of 2,856 K.                                                                        |
| Calibrated reflectance standard          | Prepared white surface having a diffuse reflectance of 80% or higher.                                                                                                                                                       |

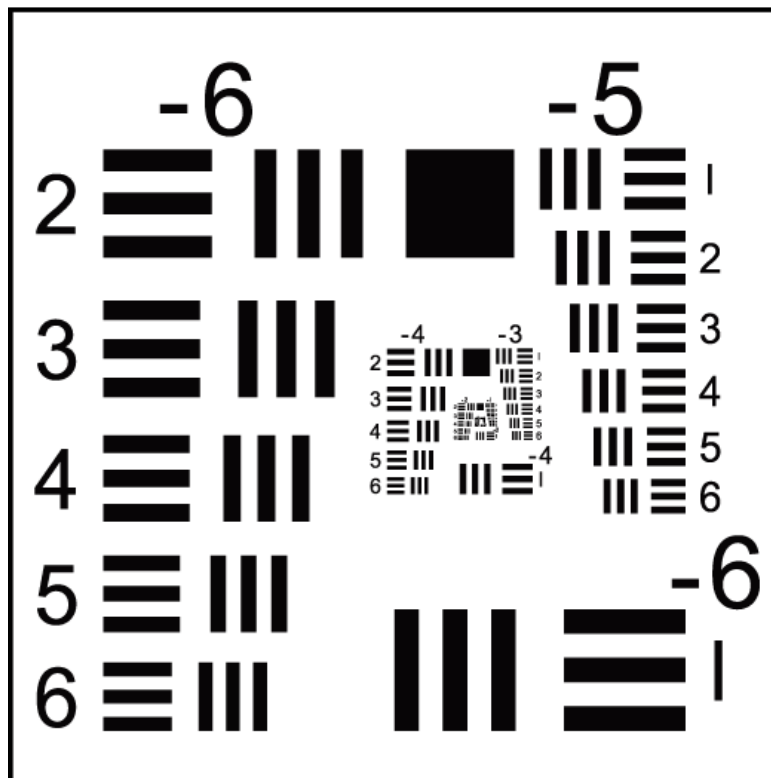


Figure 1. United States Air Force (USAF) 1951 resolving power target.

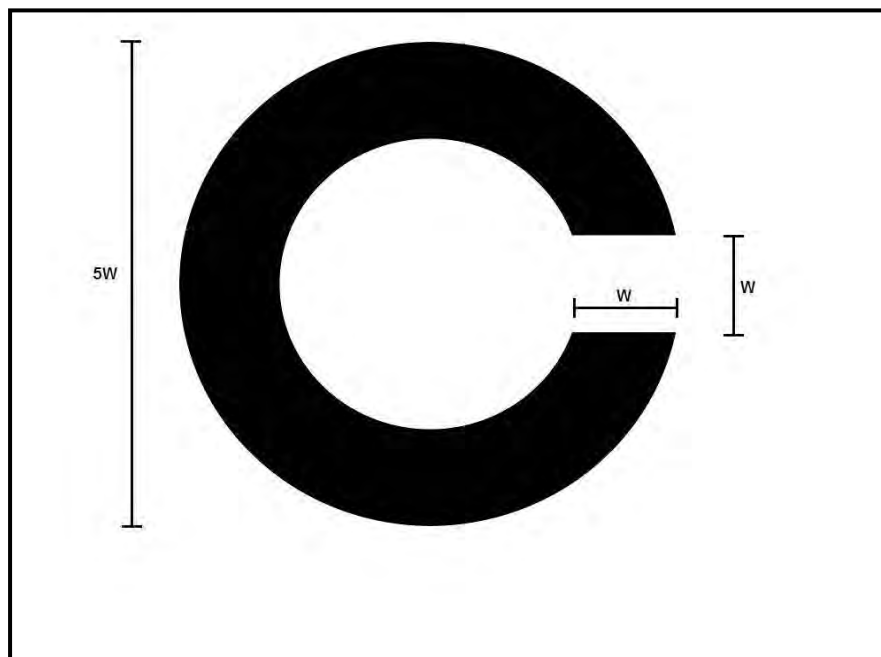


Figure 2. Landolt C-Ring.

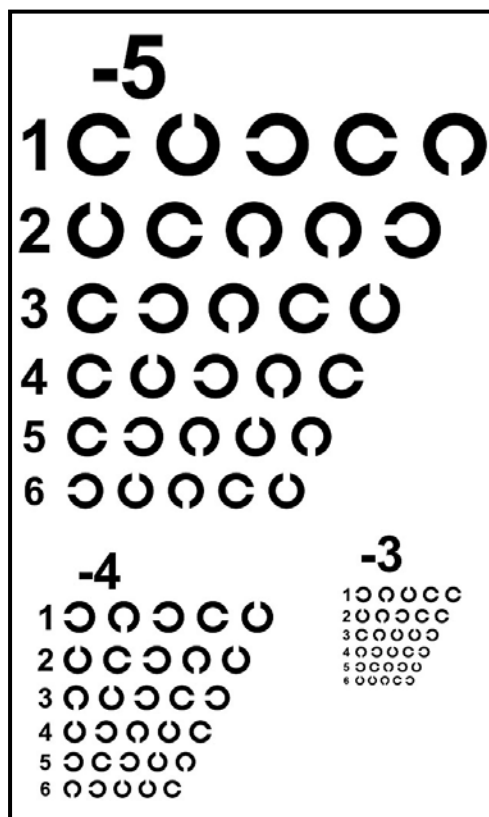


Figure 3. Landolt C acuity chart.

## 2.3 Instrumentation.

| <u>Devices for Measuring</u>                                                                                                                                                          | <u>Notes and Device Special Features</u>                                                                                                              |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Photometer to measure luminance in the range of $1 \times 10^{-3}$ to $1 \times 10^4$ footLamberts (fL) (Military Specification [MIL-L] 85762 <sup>5</sup> , paragraphs B40 and B50). | Absolute accuracy $\pm 4$ % of reading or $\pm 2$ % of full-scale. Spot size must be no greater than 1/2 stroke width of display characters measured. |
| Photometer to measure illuminance in the range of $1 \times 10^{-5}$ to $1 \times 10^2$ fc (MIL-L-85762, paragraphs B40 and B50).                                                     | Wide-band, low-light level photo sensor fitted with a cosine integrator and a photopic filter.                                                        |
| Photometer to measure NVIS radiance ( $NR_A$ ) at $1 \times 10^{-11}$ to $1 \times 10^{-6}$ Watts/cm <sup>2</sup> .                                                                   | Wide-band, low-light level photo sensor fitted with a cosine integrator and a long-pass filter with a cutoff between 625 and 655 nanometers (nm)      |
| Photometer to measure illuminance in the range of $1 \times 10^1$ to $2 \times 10^5$ fc.                                                                                              | Small handheld meter fitted with a cosine integrator for measuring daylight illumination.                                                             |
| Scanning spectral radiometer to measure spectral radiance.                                                                                                                            | See MIL-L-85762, paragraph B30.                                                                                                                       |
| Scanning spectral radiometer to measure chromaticity.                                                                                                                                 | See MIL-L-85762, paragraph B30.                                                                                                                       |
| Chromaticity meter (photometer) to measure chromaticity coordinates.                                                                                                                  | Small handheld photometer designed for direct measurement of chromaticity coordinates for test items in stalled in aircraft.                          |

## 3. REQUIRED TEST CONDITIONS.

- a. The cockpit lighting issues addressed in this TOP pertain to both day and night conditions. The worst-case condition for daytime use of displays is under direct shafting sunlight, which is defined as 10,000 fc at a color temperature of approximately 5,000 K. At night, displays must be lighted for use during visually unaided flight as well as when using visual aids such as NVIS.
- b. Test conditions for night lighting will require an extremely dark environment so that photometric measurements will be valid. The testing environment rarely allows the measurement of individual displays or groups of displays in a lighting laboratory as is the case during manufacturing or engineering development. Measurements during testing are normally

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made in the cockpit of the aircraft, which requires a large darkened enclosure with a controlled-light environment.

c. The facility for making light measurements should be free of any artificial light source and darkened to at least  $1 \times 10^{-4}$  fc. A strict requirement is that environmental light must not contribute more than 1% of the value being measured. Lighting measurements should not be made if this requirement cannot be met.

d. The facility for testing NVIS compatibility should be free of any artificial light source and darkened to at least  $5 \times 10^{-6}$  fc.

e. The order in which tests are performed is not important; however, the availability of test items and facilities must be considered when constructing the schedule.

f. Care should be taken to block light sources from the photometric measuring device displays. Persons making the light measurements should wear dark-colored clothing to avoid reflecting light back to the source display and influencing the accuracy of the photometer measurements.

#### 4. TEST PROCEDURES.

##### 4.1 Display Luminance.

The luminance of a display is the amount of light emitted or reflected by the display surface. This characteristic is measured in fL or lumens per meter squared. Luminance is the primary determinant of the subjective brightness of a display. The luminance of the markings on a display (together with contrast, marking size, etc.) is a determinant of display readability. Display luminance is used to calculate marking/background contrast, display uniformity, and instrument panel lighting balance. The purpose of any display is to transfer information to the user. Display luminance is an important indicator of the efficiency of the information transfer process.

##### 4.1.1 Method.

a. Ensure that displays are powered by the same voltage that is applied in the operational environment. Failure to apply the correct voltage will result in light measurements that are not representative of the display in use.

b. Make at least eight equally spaced measurements of the display markings for each instrument, control panel, or other display. Also, make at least eight measurements of the display background adjacent to the markings. Make separate sets of measurements of pointers and lubber lines. All measurements shall be accurate to within 0.01 fL.

c. For aircraft instruments with integral lighting conforming to MIL-L-27160C<sup>6</sup> and/or MIL-L-25467D<sup>7</sup>, measure stray light using a neutral diffusing sheet of white paper which

conforms with, and is perpendicular, to the cover glass of the instrument. Reflectance of the paper shall be  $85 \pm 5\%$ . Take measurements at a 90 degree angle to the white paper, 1.25 cm (0.5 in.) in front of the cover glass. Measurements shall be accurate to within 0.01 fL.

d. When multiple luminance levels are possible, make repeated measurements across the luminance range from full OFF to full ON.

e. Mark an illustration of each display with the location of the measurements taken. The separation distance and relative angles between the sensor and the measured surface should be documented. This will allow for accurate repetition of measurements, if required. An example of locations used for measurements may be found in MIL-S-22885D<sup>8</sup>, paragraph 4.8.3.5.

f. Collect subjective comments regarding adequacy of display luminance from system operators/users by appropriate means (e.g., questionnaires, interviews, etc.) derived and administered in accordance with TOP 01-2-610 and TECOM PAM 602-1.

#### 4.1.2 Data Required.

Separate measurements shall be made for display markings, pointers, lubber lines, background, and ambient illumination. Calculate the average using the formula:

$$x/n$$

where:  $x$  = the summation of all brightness measurements  
 $n$  = the number of measurements

#### 4.2 Illuminance.

Illuminance refers to the amount of light falling onto a surface (incident light). An example would be the amount of sunlight striking an instrument panel. As the ambient illumination level approaches the luminance level of the lighted display, contrast and readability degrade. Therefore, it is important to specify under what illumination conditions luminance measurements are made. At night, the level of illumination plays an important role when performing aircrew tasks such as reading instruments when using the secondary lighting system, map reading using utility or dome lights, or general tasks using cabin lights. The common unit of measure used for illuminance is the fc. Environmental illumination (i.e., sunlight, moonlight, starlight) shall be measured whenever other lighting measurements are taken to document the operational and/or test conditions.

##### 4.2.1 Method.

a. Place the sensor or reflectance standard as close as possible to the surface being illuminated, and orient it in the same plane. If environmental illumination is being measured, make the measurement in the horizontal plane.

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b. Collect subjective comments regarding adequacy of illumination from systems operators/users by appropriate means (e.g., questionnaires, interviews, etc.) derived and administered in accordance with TOP 1-2-610 and TECOM PAM 602-1.

#### 4.2.2 Data Required.

Calculate the illumination level by dividing the luminance of the reflectance standard by the reflectance factor of the standard:

$$\text{Illumination (fc)} = \frac{\text{luminance (fL)}}{\text{reflectance}}$$

#### 4.3 Contrast.

Contrast refers to the relationships between the luminance of an object, display, or portion of a display, and the luminance of its immediate background. Poor display contrast degrades the readability of markings and negatively impacts operator effectiveness.

##### 4.3.1 Method.

a. Ensure that displays are powered by the same voltage that is applied in the operational environment. Failure to apply the correct voltage will result in light measurements which are not representative of the display in use.

b. Make at least eight equally spaced measurements of the display markings for each instrument. Also make at least eight measurements of the display background adjacent to the markings. Make separate sets of measurements of pointers and lubber lines. All measurements shall be accurate to within 0.01 fL.

c. When multiple luminance levels are possible, make repeated measurements across the luminance range from full OFF to full ON.

d. Mark an illustration of each display with the location of the measurements taken. This will allow for accurate repetition of measurements, if required. An example of locations used for measurements may be found in MIL-S-22885D, paragraph 4.8.3.5.

e. Approximate contrast during day conditions may be determined by obtaining the percent reflectivity of the instrument face, markings, and pointers, using the last three digits of the display color numbers as defined in FED-STD-595a<sup>9</sup>, paragraph 5.3.2. This yields only an approximation and should not be used in lieu of the above procedure.

##### 4.3.2 Data Required.

a. Calculate the luminance contrast (C) between the background and an image element using the formula in Appendix A.

b. In terms of reflectivity, luminance contrast equals the absolute difference between the higher reflectivity ( $R_1$ ) and the lower reflectivity ( $R_2$ ) divided by the higher reflectivity:

$$C = \frac{R_1 - R_2}{R_1}$$

#### 4.4 Balance.

A good cockpit lighting system provides lighted displays that appear to have the same brightness across the whole cockpit. If an aircraft has unevenly balanced display brightness, the pilot is presented with some displays that are so bright that they are a source of glare and others so dim that they are unreadable. Bright displays interfere with the ability to see outside the cockpit. Dim displays take longer to read and require the pilot to fixate and stay “inside” the cockpit for a longer time than may be acceptable. Balance measurements are used to compare the average luminance of displays in the cockpit.

##### 4.4.1 Method.

a. Ensure that displays are powered by the same voltage that is applied in the operational environment. Failure to apply the correct voltage will result in light measurements which are not representative of the display in use.

b. Make at least eight equally spaced measurements of the display markings for each instrument. Also, make at least eight measurements of the display background adjacent to the markings. Make separate sets of measurements of pointers and lubber lines. All measurements shall be accurate to within 0.01 fL.

c. When multiple luminance levels are possible, make repeated measurements across the luminance range from full OFF to full ON.

d. Mark an illustration of each display with the location of the measurements taken. This will allow for accurate repetition of measurements, if required. An example of locations used for measurements may be found in MIL-S-22885D, paragraph 4.8.3.5.

e. Collect subjective comments regarding adequacy of lighting balance from system operators/users by appropriate means (e.g., questionnaires, interviews, etc.).

##### 4.4.2 Data Required.

To analyze the lighting balance between lighted displays, compare the mean of each display or area within a display (e.g., indicator, pointers, lubber lines, etc.) to the mean of each other display (or area) to form a series of pairwise comparisons. If the ratio of two displays (or areas) is greater than 3:1, the lighting will probably appear out of balance to the user. MIL-L-85762 requires that the average luminance ratio between lighted instruments and panels shall not be greater than 2:1.

#### 4.5 Uniformity.

Uniformity refers to the evenness of lighting within a single display. The physical properties of light and the subjective reactions of system operators/users should be considered. Instruments which are grossly non-uniform may take longer to read. Portions of an indicator may be so dim that they are unreadable while other portions are too bright.

##### 4.5.1 Method.

a. Ensure that displays are powered by the same voltage that is applied in the operational environment. Failure to apply the correct voltage will result in light measurements which are not representative of the display in use.

b. Make at least eight equally spaced measurements of the display markings for each instrument. Also make at least eight measurements of the display background adjacent to the markings. Make separate sets of measurements of pointers and lubber lines. All measurements shall be accurate to within 0.01 fL.

c. When multiple luminance levels are possible, make repeated measurements across the luminance range from full OFF to full ON.

d. Mark an illustration of each display with the location of the measurements taken. This will allow for accurate repetition of measurements, if required. An example of locations used for measurements may be found in MIL-S-22885D, paragraph 4.8.3.5.

e. Collect subjective comments regarding adequacy of lighting balance from system operators/users by appropriate means (e.g., questionnaires, interviews, etc.).

##### 4.5.2 Data Required.

Calculate uniformity of luminance within a display by dividing the standard deviation of the luminance measurements within a display by the mean of all luminance measurements taken for that display. If the result is greater than 0.25, the display will probably appear non-uniform to the user.

#### 4.6 Sunlight Readability.

Sunlight readability is a performance characteristic of a display which enables that display, when energized, to be readable in the worst-case direct sunlight conditions. The display must be readable regardless of the display orientation or the location of the sun, including the glare angle wherein the sun is shining directly onto the display. It is also required that under these same severe sunlight conditions, displays which are not energized shall not appear energized or produce a ghost image.

#### 4.6.1 Method.

a. Daylight readability of all indicators and displays will be assessed while installed in the aircraft. Displays should be set to display a set of alphanumeric figures to be read during test (e.g., a test screen). The test items/displays will be adjusted to maximum brightness and illuminated with an artificial light source having a color temperature of 4,500 K to 5,500 K.

b. The lamp will be moved toward the display until the illumination at the face of the test item is 10,000 fc, as measured by a photometer placed as close as possible to the face of the test item. A qualitative judgment regarding the readability of the display under this lighting condition, including alphanumeric figures on the screen, will be made and recorded. Any false indications or ghost images should also be recorded.

c. If the display is not readable, the artificial illumination level will be decreased until readability is acceptable. The acceptable artificial illumination level will be recorded.

#### 4.6.2 Data Required.

Maximum level of illumination at which test item is readable.

#### 4.7 Display Color (Chromaticity and Spectral Radiance).

Color is defined as that characteristic of light by which a human observer may distinguish between two structure free patches of light of the same size and shape. Color can be quantified by determining the tristimulus values of the light (the amounts of each of the primary colors of light required to match the color of the light in question). Chromaticity and spectral radiance are of extreme importance for NVIS-compatible cockpit lighting systems.

#### 4.7.1 Method.

a. Procedures for determining “X” and “Y” values for chromaticity should conform to the requirements of MIL-L-87562, paragraph 4.8.13, or MIL-C-25050A<sup>10</sup>, paragraph 4.4 and 4.5, as appropriate. Spectral radiance requirements for NVIS compatibility shall conform to MIL-L-87562, paragraph 4.8.14.

b. An alternate method for determining conformance of instrument and panel lighting (IPL) lighted displays to stated criteria is to use a chromaticity meter which provides a direct determination of the “X” and “Y” chromaticity values.

#### 4.7.2 Data Required.

Data required are as stated in the appropriate specifications cited above.

#### 4.8 Night Vision Imaging System Compatibility.

The purpose of using NVIS in an aircrew station is to enable the aircrew to operate in the terrain flight environment (nap-of-the-earth, contour, low level) at night without the use of artificial illumination. NVIS compatibility is functionally defined as the characteristic of a lighting system that allows the crew to acquire information (e.g., read instruments) inside the cockpit without degraded performance of the NVIS when looking outside the cockpit.

##### 4.8.1 Method.

a. NVIS compatibility tests may be conducted in a controlled indoor environment (hangar or other facility capable of isolating the cockpit and the resolution chart locations) using artificial illumination with a color temperature at 2,856 K or at a field site that has no artificial illumination or artificial lights within view. The method using the indoor environment is preferred since it provides better control of test lighting conditions and provides some independence from weather and moon phase. Conduct the test on open, level terrain with at least 50 feet of space available in front of the aircraft (this increases to 500 feet when using the moving Landolt C-ring target method). The aircraft must have a full operational lighting system. The outdoor test should be scheduled to start at a time after astronomical twilight, when weather conditions are clear, and when the moon remains below the horizon throughout the test period. Testing when the moon is above the horizon should be limited to periods when the illumination of the moon disk is 5% or less. Radio communication between the observer and data collectors is highly desirable. Aviator night vision imaging system (ANVIS) hardware versions used should be as specified by procuring activity for the item(s) under test.

##### b. Using Landolt C-ring Target.

This method is useful for testing NVIS compatibility, although it is not the preferred method, as it is the most time-consuming method and requires more equipment and resources. This method contains sufficient controls to prevent “cheating” on the part of observers and easily deals with differences between observers.

(1) Test participants should be dark-adapted and experienced in the use and operation of ANVIS hardware. Set the cockpit lighting system so that all displays are at a level in accordance with MIL-STD-3009<sup>11</sup>. Energize master caution/warning lights with at least two caution or warning annunciations energized. Energize multipurpose displays and display the “page” that emits the greatest amount of light. Include video displays used for target acquisition, if applicable. Have the test participant/observer don the ANVIS and adjust the device for outside viewing focused at infinity.

(2) Mount the Landolt C-ring on a device that will present the observer with a stable image as it is moved toward him. Place the Landolt C-ring far enough away so that the gap in the “C” is not resolvable. Orient the gap at the top, bottom, left, or right of the target (12-, 9-, 6-, or 3-o’clock position), ensure that the “C” is centered on the target, and the target is square so that no extraneous cues are available. Slowly move the target closer to the observer until the gap is resolved and measure the target-to-observer distance. Disregard incorrect responses and

repeat the trial with a reoriented gap. Repeat this procedure for at least 10 trials, reorienting the “C” gap in a random fashion for each trial.

(3) Extinguish all cockpit lighting and repeat the above procedure for the “lights-off” condition using the same observer.

(4) Use at least 6 observers; 10 or more are preferred. The order of presentation should be counterbalanced such that half the observers experience the “lights-on” condition first, and the other half experiences the “lights-off” condition first.

c. Using USAF 1951 Resolving Power Target.

This technique is faster and more economical than the procedure above but there is a lack of control over observer response. If more than one observer is used, there is no specified method for interpreting non-identical results.

(1) Set the cockpit lighting system at 0.1 fL for all lighting except electro-optical displays, which are set to 0.5 fL, as specified in MIL-STD-3009. Place the USAF 1951 medium-contrast resolution target as specified in MIL-STD-3009, where an observer wearing ANVIS hardware within the aircraft is capable of resolving an element in a target group midway between the largest and smallest target groups on the resolution chart (approximately 25 to 40 feet from the observer).

(2) For indoor testing, illuminate the resolution target so that the photopic illumination of the target is between  $3 \times 10^{-5}$  fc and  $6 \times 10^{-5}$  fc using a 2,856 K color temperature light source and measure the  $NR_A$ . All illumination measurements should be made with the face of the sensor in a plane parallel with and as close to the face of the chart as possible. For outdoor testing, measure the illumination at the face of the chart using a photometer in fc and  $NR_A$ .

(3) Observers (pilots) will view the resolution chart in a minimum of three lighting conditions: cockpit lighting OFF, lighting at standard level in accordance with MIL-STD-3009 without the item under test lit, and lighting at standard level with the item under test at full brightness. Possible fourth and fifth conditions may be used. In the possible fourth condition, the item under test is dimmed to a standard level in accordance with MIL-STD-3009. In the possible fifth condition, cockpit lighting and item under test are dimmed to a subjectively comfortable level as flown. In each condition, observers will note the group and element value for the smallest element they can resolve all three lines in both the vertical and horizontal axes. Upon viewing the chart in each condition, pilots will record their results and readjust the cockpit lighting to the next lighting condition without readjusting the ANVIS. The aircraft lighting will be considered NVIS acceptable if there is no change in the resolution values between the aircraft lights-on and aircraft lights-off conditions.

d. Using Landolt C Resolution Chart.

This technique is an alternative to the traditional USAF 1951 resolution chart method and limits the effect of observers’ biases by requiring an objective test of readability of the “C” orientation

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direction. It also makes improvements on the traditional Landolt C target test by allowing for a stationary target and a less time/resource-consuming method. Follow procedures outlined in Appendix B.

e. Cross-Cockpit/Off-Axis Viewing.

The utilization of multifunction panel-mounted displays in cockpits creates the possibility of degraded NVIS performance during cross-cockpit viewing even when the lighting system proves non-detrimental to visual acuity based on classic testing when pilots are looking forward. To account for this possibility, testing should be conducted using cross-cockpit/off-axis viewing of resolution charts positioned to the sides of the aircraft. These tests would serve as additional test conditions in each of the lighting conditions being tested following the methods outlined above.

4.8.2 Data Required.

a. Landolt C-ring Targets. Analyze the target to observer distances using a treatments-by-subjects (repeated measures with replication) analysis of variance (ANOVA). If the ANOVA indicates that at the 0.05 significance level there is no significant difference in the “lights-on” versus “lights-off” conditions, the aircraft lighting system is not degrading NVIS performance.

b. For USAF 1951 resolving power target, observers should report group and element values in all lighting conditions. If observers wearing ANVIS can resolve the same group and element in the “lights under test on” as in the “lights under test off” conditions, the aircraft lighting system under test is not degrading NVIS performance.

c. For Landolt C resolution charts, observers wearing ANVIS should report group and row numbers of smallest row readable in all lighting conditions. If observers can resolve the same group and row in the “lights under test off” and “lights under test on” lighting conditions, the lighting system under test is not degrading NVIS performance.

d. For cross-cockpit/off-axis viewing, observers wearing ANVIS should report a chart reading applicable to the chart being used in all lighting conditions. If observers can resolve the same value in the “lights under test off” and “lights under test on” lighting conditions, the lighting system under test is not degrading NVIS performance.

4.9 Crewstation Reflections.

An optimal crewstation lighting system will provide sufficient light to support information transfer without causing objectionable glare from light sources, or reflections on the cockpit canopy, windshields, or side windows. Reflections can be controlled by limiting light levels, shielding, optimizing windshield angles, or other means.

4.9.1 Method.

a. An observer sits at each crewstation and notes the presence of reflections on each crewstation transparency. Make observations with all lighted components operating at full-rated

voltage. Make a second set of observations with dimming controls set to the minimum level required for quick and easy readability.

b. Record each set of observations on an external vision plot (see MIL-STD-850B<sup>12</sup>) of the cockpit transparencies. “Map” the location of each reflection on the vision plot as accurately as possible, and record the source of each reflection. Pay particular attention to the reflections caused by video displays, multipurpose displays, keyboards, liquid crystal displays, heads-up displays, or other electro-optical devices used in the crewstation.

c. Energize light sources that are energized only on a provisional basis (e.g., caution, warning or advisory lights, IFF lights, threat warning displays) to determine the presence of reflections. If the displays cannot be energized, display luminous intensity may be simulated by placing a white diffuse reflecting material (e.g., white paper) on the display surface and illuminating the surface at the appropriate light level. Note the presence of reflections.

d. When possible, make all observations from the aircraft design eye point. If the design eye point is not obtainable from a normal flying position, make observations using participants as close as possible to the 5th, 50th, and 95th percentile male and female sitting eye height (NATIC/TR-91/040<sup>13</sup>) as measured from the seat reference point defined in MIL-STD-1333B<sup>14</sup>.

#### 4.9.2 Data Required.

Present reflections on the external vision plot to show the extent and location of external scene obscuration.

#### 4.10 Lighting Mock-up Evaluation.

The purpose of a lighting mock-up evaluation is to check for gross problems with cockpit lighting, its integration with cockpit geometry and layout, and to assure that lighting will support the intended missions of the aircraft system.

##### 4.10.1 Method.

a. Prior to entering the mock-up, the evaluator must be thoroughly familiar with the aircraft system’s mission, crew requirements, operating environment, control/display technology being used, and details of the cockpit layout so that time spent in the mock-up is productive (see Appendix C).

b. Make evaluations from each crewstation and, if applicable, from passenger stations.

c. Make day/sunlight readability evaluations first using an artificial sun as described in paragraph 4.6. Evaluate the readability of all primary displays, target acquisition systems, mission equipment, warning/caution systems, and other displays needed during day flight.

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d. Conduct night evaluations only after at least 20 minutes of dark adaptation. NVIS compatibility evaluations may be made using the USAF 1951 resolution targets as specified in paragraph 4.8. Evaluate the placement of displays using the ANVIS look-under capability.

e. Check for unlighted displays, insufficiently lighted displays, non-dimmable displays, glare sources, or unnecessarily lighted displays. Exercise all dimming controls and check each display for lighting uniformity. Exercise all dimming controls and check for lighting balance across the cockpit.

f. Evaluate windshield/canopy reflections as specified in paragraph 4.9.

g. Check that display marking schemes are compatible with lighting (e.g., color or shape-coded marking that is obvious during the day may not be discernable when lighted at night).

h. Exercise all systems that are potential glare sources at night. For example, an electronic display used by an observer for target detection may be a glare source for the pilot if proper shielding is not available. Note the presence of glare that may cause discomfort or interfere with the pilots' ability to see outside the cockpit.

i. From outside the cockpit, view lighted displays and the crewstation to detect any light sources that may degrade the visual signature of the aircraft.

#### 4.10.2 Data Required.

Discuss evaluations in narrative form with specific findings and recommendations. Findings should be related to mission effectiveness if possible.

### 5. PRESENTATION OF DATA.

For each subtest completed, compile data and compare the results against the stated criteria (Appendix C). Present data in tabular or narrative form as appropriate. Discuss nonconformity to the criteria and/or other specific problems noted in regards to impact on system effectiveness. Give particular attention to safety implications, if any.

## APPENDIX A. DEFINITIONS.

| Term                          | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Balance                       | Refers to the evenness of lighting across multiple displays governed by the same brightness control. The physical properties of light and the subjective reactions of system operators/users should be considered. If lighting is not balanced, sections of a display/control panel may be too bright or too dim when another section, using the same brightness control, is adjusted for operator use. This can impact operational factors such as windshield reflections, system operability, night vision goggle compatibility, etc. In addition, imbalanced control/instrument panels may take longer to read and/or scan. The terminology for this characteristic has not been standardized. In MIL-L-85762, the comparison of lighting between different displays is referred to as uniformity. |
| Brightness                    | <p>Refers to the intensity of visual sensation that results from viewing surfaces or spaces from which light comes to the eye. The sensation is determined in part by the measurable luminance, illuminance, and or reflectance properties of the surface viewed and, in part, the conditions of observation such as the adaptation state of the eye.</p> <p>NOTE: In many documents the term brightness is often used when referring to the measurable luminance. While the context usually makes clear which meaning is intended, the preferable term for a measurable quantity of light is luminance (or luminous intensity), thus reserving brightness for the subjective sensation.</p>                                                                                                          |
| Candela (formerly candle)     | The international scientific unit of luminous intensity in a specified direction. One candela is one lumen per steradian or 1/60 the intensity of a square centimeter of a black body radiator operated at the freezing point of platinum (2,047 K).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Chromaticity of a color       | The dominant or complementary wavelength and purity aspects of the color taken together, or of the aspects specified by the chromaticity coordinates of the color taken together.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Contrast (luminance contrast) | <p>The relationship between the luminances of an object and its immediate background.</p> <p>When: <math>L_1</math> = the average background luminance of the display surface in areas adjacent to activated display image elements</p> <p><math>L_2</math> = the average luminance of activated display image elements</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

## APPENDIX A. DEFINITIONS.

| Term             | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                  | $L_3$ = the average luminance of deactivated display image elements<br><br>Then:<br>$C_L = \frac{L_2 - L_1}{L_1} = \frac{\Delta L_{21}}{L_1}$ for contrast of a lighted (activated) display.<br><br>$\varsigma C_I = \frac{L_2 - L_3}{L_3} = \frac{\Delta L_{23}}{L_3}$ for contrast between a lighted (activated) display image element and the same element unlighted (deactivated).<br><br>$C_{ul} = \frac{L_3 - L_1}{L_1} = \frac{\Delta L_{31}}{L_1}$ for contrast of an unlighted (deactivated) display image element. |
| Footcandle (fc)  | The unit of measure for surface illumination of light striking each and every point on a segment of the inside surface of an imaginary 1-foot radius sphere with a 1-candela source at the center. One footcandle is the illumination on one square foot of surface over which is evenly distributed one lumen. One footcandle equals one lumen per square foot.                                                                                                                                                             |
| Footlambert (fL) | A unit of luminance equal to that of a perfectly diffusing and reflecting surface illuminated by one footcandle.                                                                                                                                                                                                                                                                                                                                                                                                             |
| Illuminance      | The density of light flow incident on a surface; it is the quotient of the amount of total light divided by the area of the surface when the surface is uniformly illuminated. The common English measurement for illuminance is the footcandle (fc). The metric measurement is lumens per meter squared ( $\text{lm} \cdot \text{m}^{-2}$ ).                                                                                                                                                                                |
| Illumination     | The act of illuminating or being illuminated.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Lumen            | Unit of luminous flux. Radiometrically, it is determined from the radiant power. Photometrically, it is the luminous flux emitted within a unit solid angle (of steradian) by a point source having a uniform luminous intensity of one candela.                                                                                                                                                                                                                                                                             |

## APPENDIX A. DEFINITIONS.

| Term                               | Definition                                                                                                                                                                                                                                                                                      |
|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Luminance                          | The amount of light per unit area reflected from or emitted by a surface. The light may be measured when leaving, passing through, and/or arriving at a surface. The common English unit of measure for luminance is the footlambert (fL). The metric measurement is candelas per square meter. |
| Luminous Intensity                 | The density of light flow per unit solid angle in the direction in question. Luminous intensity may be expressed in candelas or in lumens per steradian.                                                                                                                                        |
| Photometer                         | An instrument for measuring photometric quantities.                                                                                                                                                                                                                                             |
| Reflectance of a Surface or Medium | The ratio of reflected light to incident light.                                                                                                                                                                                                                                                 |
| Spectral Radiance                  | Radiant energy per unit wavelength interval at a given wavelength.                                                                                                                                                                                                                              |
| Uniformity                         | The evenness of lighting distribution within a single display.                                                                                                                                                                                                                                  |

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## APPENDIX B. PROCEDURE FOR USING LANDOLT “C” RESOLUTION CHART.

This technique is an alternate to the traditional USAF 1951 resolution chart and limits the effect of observers’ social bias by requiring an objective test of readability of the “C” orientation direction.

1. Landolt C resolution Chart.

a. The resolution chart (Figure 3) is a white board and has 18 rows of black or grey letter “C”. These are organized into 3 groups of 6 rows. The groups are identified by a negative number (-5, -4, -3). Within each group, the rows are numbered 1 through 6. In each row, the location of the opening in the C is randomly rotated to one of the 4 locations: top, bottom, left or right.

b. Each “C” has a height equal to all others on its row. The gap in the “C” must be equal to the thickness of the ring and 1/5 the ring diameter (Figure 2)

2. Method.

a. Instruct the pilots/observers using the following, or similar, set of instructions:

You are to attempt to identify the location of the gap in the C for each item in a row. You should be able to identify the orientation of all five items in the largest row at the top of the chart (-5/1). Scan down the chart to find the smallest row where you can identify the orientation of all five items. Report the group and row number for this row. Call out the sequence of orientations for the five items on that row. Then you may be asked to call out the sequence of items on the row above (next larger) or the row below (next smaller) your initial reading. If you are unsure of the orientation of any item in a row, give your best guess.

b. Place chart 1 at 25 to 40 feet from the pilot’s eye position. Record the distance used.

c. If artificial starlight is used, position the light source near the nose of the aircraft with the opening toward the chart. Set the light level measured at the chart between  $3.0 \times 10^{-5}$  and  $6.0 \times 10^{-5}$  fc using the low-light level photometer with the photopic filter on the sensor. The sensor should have the sensing face parallel to the chart surface. Check the NVIS-A radiance level using the low-level fitted with the long-pass filter on the sensor. It should be between  $5.0 \times 10^{-10}$  to  $9.0 \times 10^{-10}$  W/cm<sup>2</sup>.

## APPENDIX B. PROCEDURE FOR USING LANDOLT “C” RESOLUTION CHART.

d. If natural lighting is being used (outdoor testing), measure the photopic level (fc) and NVIS radiance ( $\text{W}/\text{cm}^2$ ) using the appropriate filters on the low-light level photometer. The levels should be below  $9.0 \times 10^{-4}$  fc and  $9.0 \times 10^{-9}$   $\text{W}/\text{cm}^2$  for valid testing. All measurements with the low-light level photometer should be made with the sensing face parallel to the chart surface. If the testing takes a significant length of time, measurements should be made several times during the testing period and at the end.

e. Have the pilots don and adjust the ANVIS with all aircraft lighting turned off. This will be the only adjustment of ANVIS through the course of the test, as settings should remain the same throughout all lighting conditions.

f. Have the pilots scan the chart and determine the smallest element row that they can discern the orientation of all 5 Landolt Cs. Check their response against the answer sheet. If four or five items were correctly identified, ask them to read the next smaller element row, guessing if necessary. Repeat this procedure until three or fewer Landolt Cs are correctly identified. If the initial row reading results in three or fewer correct items, ask the pilots to read the next larger row. Repeat this until four or five items are correctly identified. The smallest row where four or five items are correctly identified is the group and element value for that test condition.

g. Change the chart to the next chart and setup the next crewstation lighting condition. Repeat the chart reading procedure as above.

h. Continue changing charts and lighting conditions until all conditions have been tested. If the supply of charts is exhausted, start over with one of the charts other than the last one used. (Note: The order of the charts must be predetermined and appropriately ordered scoring sheets must be available to score the readings “on-the-fly”.)

## APPENDIX C. CRITERIA.

The criteria listed in this appendix serve as appropriate guidelines against which lighting tests are conducted. Specific test requirements documentation should also be consulted.

### 1. Display Luminance.

- a. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays - MIL-STD-3009, paragraph 4.3.3.
- b. Cathode Ray Tube Displays - Military-Handbook (MIL-HDBK)-759C<sup>15</sup>, paragraph 5.2.4.2.
- c. Caution, Warning and Advisory Lights - MIL-STD-411F<sup>16</sup>, paragraph 5.1.
- d. Control Panel Assemblies - MIL-P-7788E<sup>17</sup>, paragraphs 3.5.3 and 3.5.4.
- e. Dot Matrix Segmented Displays - MIL-STD-1472F<sup>18</sup>, paragraph 5.2.6.7.
- f. Heads-up Displays - MIL-STD-1472F, paragraph 5.2.6.12.
- g. Indicator Lights - MIL-HDBK-759C, paragraph 5.2.2.3.
- h. Legend Lights - MIL-STD-1472F, paragraph 5.2.2.2.
- i. Red Lighted Aircraft Instruments - MIL-L-25467D, paragraphs 3.3.8 and 3.3.9.
- j. Stray Light - MIL-L-25467D, paragraph 3.3.9.  
MIL-L-27160C, paragraph 4.5.5.5.
- k. Transilluminated Displays - MIL-STD-1472F, paragraphs 5.2.2.  
MIL-HDBK-759C, paragraphs 5.2.2.1.3.
- l. White Aircraft Lighting - MIL-L-27160C, paragraph 3.3.5.

## APPENDIX C. CRITERIA.

### 2. Illuminance.

- a. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays - MIL-STD-3009, paragraph 4.3.3.
- b. Secondary Instrument and Display Lighting - MIL-L-6503H<sup>19</sup>, paragraph 3.3.2.2.  
MIL-L-85762, paragraph 3.9.10.2.

### 3. Contrast.

- a. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays - MIL-STD-3009, paragraph C.5.11.
- b. Panel Assemblies - MIL-P-7788E, paragraph 3.4.3.4.
- c. General - MIL-STD-1472F, paragraph 5.2.1.2.3.
- d. Legend Lights - MIL-HDBK-759C, paragraph 5.2.2.2.3.
- e. Scale Indicators - MIL-STD-1472F, paragraph 5.2.3.1.8.
- f. Transilluminated Displays - MIL-STD-1472F, paragraph 5.2.2.1.11.  
MIL-HDBK-759C, paragraphs 5.2.2.1.3.1 a. and 5.2.2.1.3.1 b.
- g. White Aircraft Lighting - MIL-L-27160C, paragraph 3.5.

### 4. Balance.

- a. AN/AVS-6 (ANVIS) Night Vision Google Compatible Displays - MIL-STD-3009, paragraph 5.7.3.

APPENDIX C. CRITERIA.

- b. General -  
MIL-STD-1472F, paragraph 5.2.1.2.2.  
MIL-HDBK-759A, paragraph 1.2.1.2.

5. Uniformity.

MIL-STD-1472D<sup>20</sup>, paragraph 5.2.1.2.2.  
MIL-HDBK-759A<sup>21</sup>, paragraph 1.2.1.2.

6. Sunlight Readability.

- a. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays -  
MIL-STD-3009, paragraphs C.5.8, C.5.9, and C.5.10.
- b. Caution, Warning and Advisory Lights -  
MIL-STD-411F, paragraph 5.1.
- c. Lighted Pushbutton Switches -  
MIL-S-22885D, paragraph 3.40.

7. Display Color.

- a. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays -  
MIL-STD-3009, paragraph C.6.
- b. Cathode Ray Tube Displays -  
MIL-HDBK-759C, paragraph 5.2.4.5.  
MIL-L-85762, paragraphs 3.10.8 and 3.10.9.
- c. Control Panel Assemblies -  
MIL-P-7788E, paragraph 3.5.2.
- d. Dot Matrix Segmented Displays -  
MIL-STD-1472F, paragraph 5.2.6.7.7.  
MIL-HDBK-759A, paragraph 1.2.6.2.3.3.6.
- e. General Requirements -  
MIL-C-25050A, Warning, Caution, and Advisory Light.  
MIL-STD-411F, paragraphs 5.1.1.1, 5.1.2.1, and 5.1.3.1.

APPENDIX C. CRITERIA.

- f. Indicator Lights -  
MIL-STD-1472F, paragraph 5.2.2.3.3.
  - g. Legend Lights -  
MIL-STD-1472F, paragraph 5.2.2.2.2.  
MIL-HDBK-759A, paragraph 1.2.2.2.4.
  - h. Light Emitting Diodes -  
MIL-STD-1472F, paragraph 5.2.6.6.4.  
MIL-HDBK-759C, paragraph 5.2.6.7.1.
  - i. Low Light and Dark Adaptation -  
MIL-STD-1472F, paragraph 5.2.1.2.1.1
  - j. Transilluminated Displays -  
MIL-STD-1472C, paragraph 5.2.2.1.13.
  - k. White Aircraft Lighting -  
MIL-L-27160C, paragraphs 3.3.4 and 3.4.
8. Night Vision Goggle Compatibility.  
  
MIL-STD-3009.
9. Crewstation Reflections.  
  
a. General -  
MIL-L-85762, paragraph 3.10.12.  
MIL-L-6503H, paragraph 3.3.
- b. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays -  
MIL-STD-3009, paragraph 4.3.8.
10. Lighting Mock-up Evaluations.  
  
MIL-L-85762, paragraph 3.4.

## APPENDIX D. LIGHTING MOCK-UP EVALUATION.

### 1. Overall Cockpit Review.

Complete a generalized cockpit inspection for adequacy of the following:

- a. Non-dimmable displays.
- b. Sources of glare.
- c. Unlighted controls/displays.
- d. Windshield reflections.
- e. Color coding scheme.
- f. Map lights.
- g. Dome/compartment lights.
- h. Lamp replacement.
- i. Lamp redundancy.
- j. Amount of stray light.

### 2. Control/Instrument Panel Review.

Complete an inspection of each separate control/instrument panel or logical grouping of controls and displays for adequacy of the following:

- a. Apparent balance of lighting between displays in the panel or grouping.
- b. Lighting balance throughout range of brightness control.
- c. Range of brightness control.
- d. Smoothness of brightness controls.
- e. Number of brightness controls.
- f. Brightness control scheme (association of brightness controls and items lighted).
- g. Unlighted controls and/or displays.
- h. Non-dimmable light sources.

#### APPENDIX D. LIGHTING MOCK-UP EVALUATION.

- i. Lighting color uniformity throughout grouping.

### 3. Individual Display Review.

Complete an inspection of each individual display for adequacy of the following:

- a. Readability.
  - (1) Bright shafting sunlight.
  - (2) Diffuse daylight.
  - (3) Night.
- b. Display brightness.
- c. Brightness control and range.
- d. Apparent uniformity of brightness in all parts of the display.
- e. Ability to discriminate shape- and/or color-coded markings.
- f. Control of stray light.
- g. Apparent contrast of markings to backgrounds.

### 4. Special Displays.

Complete an inspection of each of the following special displays for adequacy of those attributes listed.

- a. Warning/Caution/Advisory System.
  - (1) Adequacy of master warning and/or master caution audio cues in association with lighting cues.
  - (2) Display brightness.
  - (3) Placement of warning/caution lights within central cone of vision.
  - (4) Acknowledge system.

#### APPENDIX D. LIGHTING MOCK-UP EVALUATION.

(5) Readability of warning, caution, and advisory messages in all lighting conditions including bright shafting sunlight.

(6) Overlay of messages on cathode ray tube (CRT), heads up display (HUD), or other displays.

(7) Glare caused by warning, caution, or advisory lights.

(8) Display contrasts.

b. CRTs/Multipurpose Displays.

(1) Flicker.

(2) Jitter.

(3) Glare.

(4) Brightness range.

(5) Reflections on display surface.

(6) Readability.

(7) Viewing distance.

(8) Symbol line height/width ratio.

c. Heads-up Displays.

(1) Readability.

(2) Field-of-view.

(3) Symbol height/width ratio.

(4) Viewing distance.

(5) Symbol brightness.

(6) Lighting uniformity.

(7) Reflections on display surfaces.

APPENDIX D. LIGHTING MOCK-UP EVALUATION.

- d. Vertical Tape Displays.
  - (1) Display brightness.
  - (2) Glare.
  - (3) Brightness range.
- e. Digital Displays.
  - (1) Readability.
  - (2) Character size.
  - (3) Brightness range.
  - (4) Speed of character changes.

APPENDIX E. ABBREVIATIONS.

|                 |                                                     |
|-----------------|-----------------------------------------------------|
| AD No.          | accession number                                    |
| ANOVA           | analysis of variance                                |
| ANVIS           | aviator night vision imaging system                 |
| ATF             | United States Army Aviation Flight Test Directorate |
| CRT             | cathode ray tube                                    |
| fc              | footcandle                                          |
| fL              | footLamberts                                        |
| HUD             | heads up display                                    |
| HFE             | human factors engineering                           |
| MIL-C           | military specification                              |
| MIL-HDBK        | military handbook                                   |
| MIL-L           | military specification                              |
| MIL-P           | military specification                              |
| MIL-S           | military specification                              |
| MIL-STD         | military standard                                   |
| NOLTR           | Naval Ordnance Laboratory                           |
| NR <sub>A</sub> | NVIS radiance                                       |
| NVIS            | night vision imaging system                         |
| TECOM PAM       | Test and Evaluation Command Pamphlet                |
| TOP             | Test Operations Procedure                           |
| USAF            | United States Air Force                             |

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APPENDIX F. REQUIRED REFERENCES.

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7. MIL-L-25467D, Lighting Integral, Red, Aircraft Instrument, General Specification for, 12 July 1977.
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9. Federal Standard Number 595a, Colors, March 1979.
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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), US Army Test and Evaluation Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: US Army Redstone Test Center, Aviation Flight Test Directorate (TEDT-RT-ATC), Redstone Arsenal, AL 35898. Additional copies can be requested through the following website: <http://itops.dtc.army.mil/RequestForDocuments.aspx>, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.