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

This is a document that specifies the procedures, test equipment and facilities to perform tests and evaluations of aircraft cockpit lighting systems. The topics include display luminance, illuminance, contrast, balance, uniformity, sunlight readability, display color, night vision goggle compatibility, crewstation reflections and mockup evaluations. These procedures are closely tied to U.S. Army lighting requirements.



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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

AMSTE-RP-702-10X
Test Operations Procedure (TOP) 7-2-518 — 2 August 1989
AD No.

# HUMAN FACTORS ENGINEERING TESTING OF AIRCRAFT COCKPIT LIGHTING SYSTEMS





## 1. SCOPE.

a. This TOP specifies procedures for testing human factors engineering aspects of cockpit lighting systems. There is a heavy reliance on testing against quantitative criteria, as opposed to qualitative (subjective) evaluations. The criteria listed in Appendix B serve as appropriate guidelines against which lighting tests are conducted. Specific test requirements documentation should also be consulted.

b. 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 TECOM TOP 1-2-610[1], Human Factors Engineering, and TECOM PAM 602-1[2], Questionnaire and Interview Design (Subjective Testing Techniques), contain guidance on how to collect this type of data.

[1]Reference letters/numbers match those in appendix D, References.
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c. 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 AND INSTRUMENTATION.

### 2.1 FACILITIES.

| ITEM | REQUIREMENTS |
| --- | --- |
| (1) 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 $1 \times 10^{-4}$ fc or 1% of the light source being measured, whichever is less. Power must be available to operate all aircraft lighting systems and displays including CRTs used for target acquisition and multipurpose displays. |
| (2) USAF 1951 medium-contrast targets | Described in MIL-STD-150A[3] |
| (3) 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. (See fig. 1.) |
| (4) Artificial sun | Lamp capable of illuminating displays at 10,000 fc operating at 3,000 to 5,500 degrees Kelvin (preferably 5,000°K or above). |
| (5) Calibrated reflectance standard | Prepared white surface having a diffuse reflectance of 80% or higher. |

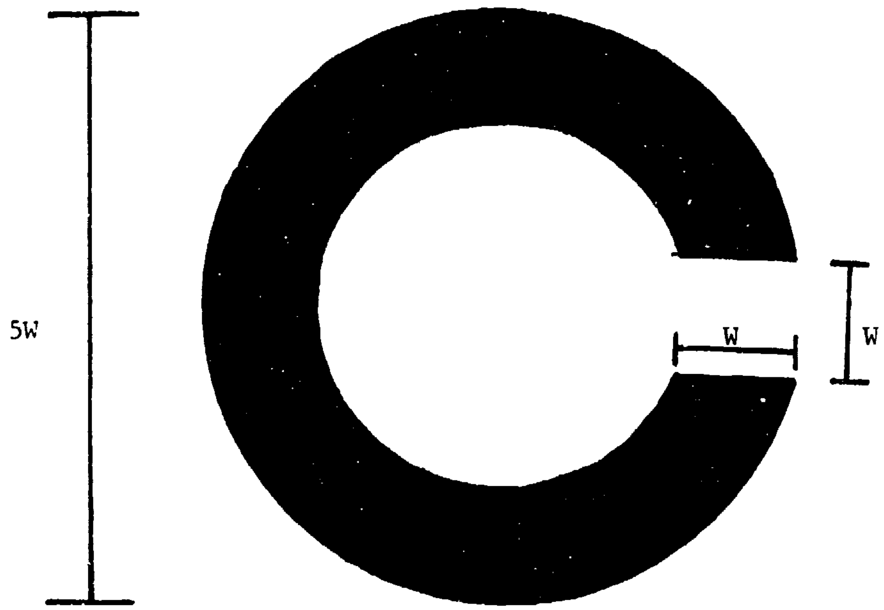


Figure 1. Landolt C-Ring

## 2.2 INSTRUMENTATION.

| DEVICES FOR MEASURING | PERMISSIBLE ERROR OF MEASUREMENT |
| --- | --- |
| (1) Photometer to measure luminance/illuminance in the range of 1x10E-3 to 1x10E4 fL and 1x10E-5 to 1x20E4 fc respectively, (see MIL-L-85762[4], para B40 and B50). | Absolute accuracy ±4% of reading or ±2% of full-scale. Spot size must be no greater than ½ stroke width of display characters measured. |
| (2) Scanning spectral radiometer to measure spectral radiance | See MIL-L-85762, para B30. |
| (3) Scanning spectral radiometer to measure chromaticity | See MIL-C-25050A[5], para 4.3. |

## 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 footcandles (fc) at 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 night vision goggles (NVG).

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 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, and the preference is to have a light level so low that it is not measurable. A strict requirement is that environmental light must not contribute more than 1 percent of the value being measured. Lighting measurements should not be made if this requirement cannot be met.

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

e. 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 photometer accuracy of the 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 footlamberts 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 efficacy of the information transfer process.

a. Method.

(1) 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.

(2) 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 footlambert (fL).

(3) For aircraft instruments with integral lighting conforming to MIL-L-27160C[6] and/or MIL-L-25467D[7], measure stray light using a neutral diffusing sheet of white paper which conforms with and is perpendicular to the coverglass of the instrument. Reflectance of the paper shall be 85 ± 5 percent. Take measurements at a 90° angle to the white paper, 1.25 cm (0.5 in.) in front of the coverglass. Measurements shall be accurate to within 0.01 fL.

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

(5) 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[8], paragraph 4.8.3.5.

(6) 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 TECOM TOP 1-2-610 and TECOM Pam 602-1.

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

$\frac{x}{n}$ 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 footcandle. Environmental illumination (i.e., sunlight, moonlight, or starlight) shall be measured whenever other lighting measurements are taken to document the operational and/or test conditions.

a. Method.

(1) 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.

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

b. 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 relationship 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.

a. Method.

(1) 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.

(2) 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.

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

(4) 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.

(5) 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[9], paragraph 5.3.2. This yields only an approximation and should not be used in lieu of the above procedure.

b. Data Required.

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

(2) If 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 brightnesses, 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. This procedure measures the average luminance of displays in the cockpit.

a. Method.

(1) 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.

(2) 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.

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

(4) 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, para 4.8.3.5.

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

b. 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 nonuniform may take longer to read, and portions of an indicator may be so dim that they are unreadable while other portions are too bright.

a. Method.

(1) 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.

(2) 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.

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

(4) 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.

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

b. 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.

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.

a. Method.

(1) Arrange luminance measuring equipment and displays under evaluation as specified in MIL-S-22885D, paragraph 4.8.3.5.

(2) Direct a light source having a color temperature of 3,000°K to 5,000°K at an angle of $0_1 = 15 \pm 2$ degrees to the normal of a diffuse reflectance standard of at least 80% reflectivity. Limit the size of the light source so that it projects light in an area less than or equal to $0 = 20$ degrees. Position a photometer at an angle of $0_2 = 15° \pm 2°$ to the normal of the reflectance standard. (See fig. 2.)

(3) Adjust the light source to produce 10,000 fc illumination on the reflectance standard as measured by the photometer. Remove the reflectance standard and replace with the viewing surfaces of the display to be tested. Using this test configuration, measure the luminance of the legend, both illuminated and nonilluminated, plus that of the adjacent background areas. Take three luminance readings per legend character.

(4) Observe the display to be tested in the operational environment (daylight) to determine under which conditions the display is subjected to direct sunlight or other light sources. Note the impact of direct sunlight on readability. Measure illuminance of the display for each observation.

b. Data Required. Calculate the contrast (C) of the display using the formula in Appendix A.

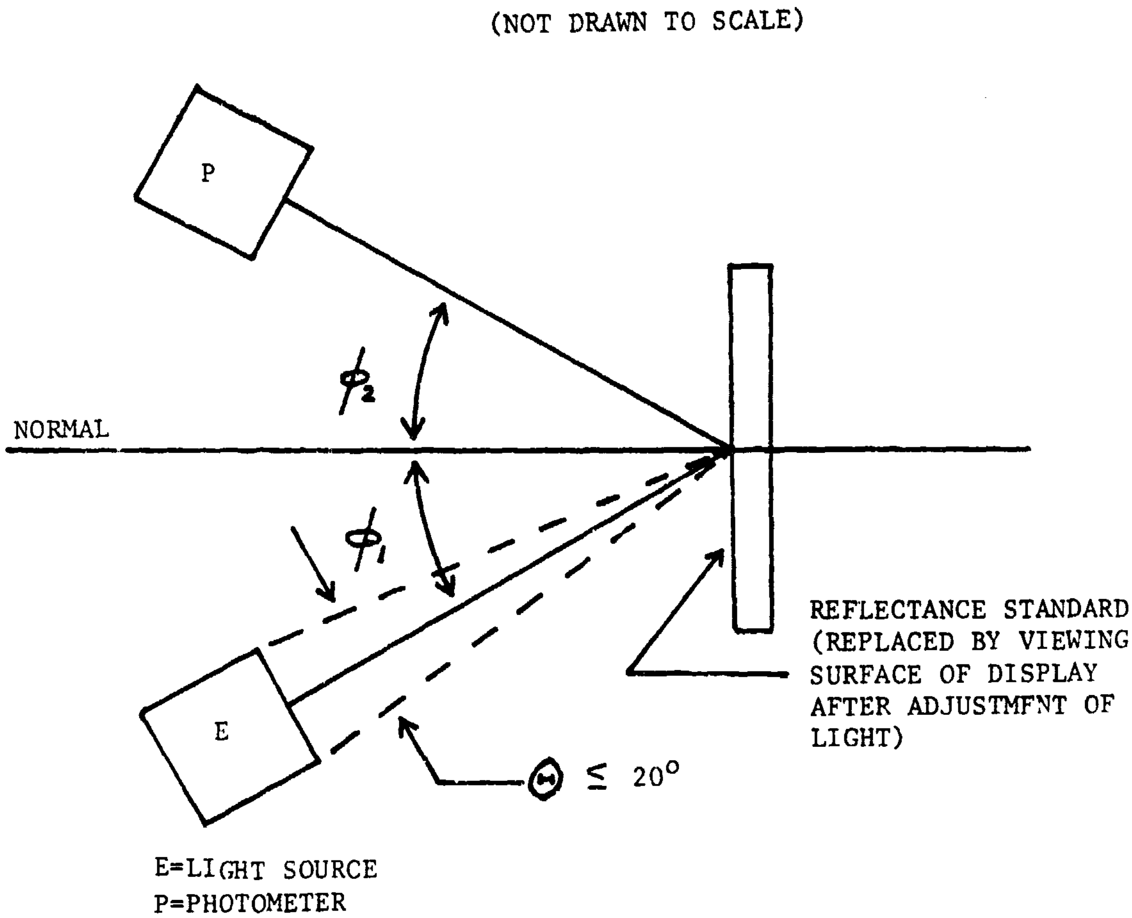


Figure 2. Specular reflectance test for readability (Adapted from MIL-S-22885D, figure 8)

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 NVG compatible cockpit lighting systems.

a. Method.

(1) Procedures for determining X and Y values for chromaticity should conform to the requirements of MIL-L-85762, para 4.8.13, or MIL-C-25050A, para 4.4 and 4.5, as appropriate. Spectral radiance requirements for NVG compatibility shall conform to MIL-L-85762, para 4.8.14.

(2) An alternate (less precise) method for determining conformance of instrument and panel lighting (IPL) red lighted displays to stated criteria is the color ratio method described in MIL-L-25467D and MIL-P-7788E[10]. This method is not endorsed and should only be used when facilities for measuring the "X" and "Y" values are not available, and approximate data are sufficient.

b. Data Required. Data required is as stated in the appropriate specifications cited above.

4.8 Night Vision Goggle Compatibility. The purpose of using night vision goggles (NVG) 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. NVG 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 degrading performance of the NVG when looking outside the cockpit.

a. Method.

(1) NVG compatibility tests may be conducted in a controlled laboratory environment using artificial illumination, or at a field site that has no artificial illumination or artificial lights within view. The method using the field site is preferred since it is a representative operating environment, but environmental conditions may vary during the test. Conduct the test on open, level terrain with at least 500 feet of space available in front of the aircraft. The aircraft must have a fully operational lighting system. The test should be scheduled so that weather conditions are clear and moonlight illumination is appropriate as defined in criteria documents. Radio communication between the observer and data collectors may be needed.

(2) Using Landolt C-ring targets. This is the preferred method for testing NVG compatibility, although 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.

(a) Test participants should be dark-adapted and experienced in the use and operation of NVG. Set the cockpit lighting system so that all displays are quickly and easily legible. 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. Have the test participant/observer don the NVG and adjust the device for outside viewing focused at infinity.

(b) 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-, 6-, 9-, 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.

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

(d) Use at least six observers while 10 or more are preferable. The order of presentation should be counterbalanced such that half the observers experience the "lights-on" condition first, and the other half experience the "lights-off" condition first.

(3) 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 and if more than one observer is used, there is no specified method for interpreting nonidentical results.

(a) Set the cockpit lighting system at 0.01 fL as specified in MIL-L-85762, paragraph 3.10.9.1.1. Place the USAF 1951 medium-contrast resolution target as specified in MIL-L-85762, paragraph 4.8.2, such that an observer wearing an Aviator Night Vision Imaging System (ANVIS) within the aircraft is just capable of resolving an element in a target group midway between the largest and smallest target groups on the resolution chart.

(b) Illuminate the resolution target so that the ANVIS radiance from the white portions of the target equals $1.7 \times 10^{-10}$ ANVIS radiance (AR).

(c) View the resolution chart again with all aircraft lighting extinguished. If the observer wearing NVG can resolve a smaller element on the chart with the lights extinguished, record this difference.

b. Data Required

(1) 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" condition, then the aircraft lighting system is not degrading NVG performance.

(2) For USAF 1951 resolving power target, if all observers wearing NVG can resolve the same element in the "lights-on" as in the "lights-off" condition, the aircraft lighting system is not degrading NVG 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.

a. Method.

(1) 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.

(2) Record each set of observations on an external vision plot (see MIL-STD-850B[11]) of the cockpit transparencies. "Map" the location of each reflection on the vision plot as accurately as possible. Also record the source of each reflection. Pay particular attention to reflections caused by video displays, multipurpose displays, keyboards, liquid crystal displays, heads-up displays, or other electro-optical devices used in the crewstation.

(3) 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 display 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.

(4) When possible, make all observations from the aircraft design eye position. 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) as measured from the seat reference point defined in MIL-STD-1333B[12].

b. 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.

a. Method.

(1) 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.)

(2) Make evaluations from each crewstation and, if applicable, from passenger station.

(3) Make day/sunlight readability evaluations first using the artificial sun. Evaluate the readability of all primary displays, target acquisition systems, mission equipment, warning/caution systems, and other displays needed during day flight.

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

(5) Check for unlighted displays, insufficiently lighted displays, nondimmable displays, glare sources, or unnecessarily lighted displays. Exercise all dimming controls and check each individual display for lighting uniformity. Exercise all dimming controls and check for lighting balance across the cockpit.

(6) Evaluate windshield/canopy reflections as specified in paragraph 4.9 above.

(7) Check that display marking schemes are compatible with lighting (e.g., a color or shape coded marking that is obvious during the day may no be discernable when lighted at night).

(8) Exercise all systems that are potential glare sources at night. For example, a CRT 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 ability to see outside the cockpit.

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

b. 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 the results and compare to the stated criteria. (See Appendix B.) 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

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 - refers to the intensity of visual sensation which 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 by the conditions of observation such as the adaptation state of the eye.

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.

Candela (formerly candle) - the international 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 (2047°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) - the relationship between the luminances of an object and its immediate background.

When: $L_1$ = the average background luminance of the display surface in areas adjacent to activated display image elements

$L_2$ = the average luminance of activated display image elements

$L_3$ = the average luminance of deactivated display image elements then:

$$C_L = \frac{L_2 - L_1}{L_1} = \frac{L_{21}}{L_1}$$

for contrast of a lighted (activated) display.

$$C_1 = \frac{L_2 - L_3}{L_3} = \frac{L_{23}}{L_3}$$

for contrast between a lighted (activated) display image element and the same element unlighted (deactivated).

$$C_{ul} = \frac{L_3 - L_1}{L_1} = \frac{L_{31}}{L_1}$$

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 ($lm \cdot m^{-2}$).

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 (one steradian) by a point source having a uniform luminous intensity of one candela.

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 lumens per meter squared ($lm \cdot m^{-2}$).

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 display.

# APPENDIX B
# 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-L-85762, para 3.9.10.1.

b. Cathode Ray Tube Displays -
MIL-HDBK-759A, para 1.2.4.2.1.

c. Caution, Warning and Advisory Lights -
MIL-STD-411D, para 5.1.

d. Control Panel Assemblies -
MIL-P-7788E, para 3.5.3 and 3.5.4.

e. Dot Matrix Segmented Displays -
MIL-STD-1472C, para 5.2.6.8.8.

f. Head-up Displays -
MIL-STD-1472C, para 5.14.1.1.5.2.

g. Indicator Lights -
MIL-HDBK-759A, para 1.2.2.3.3b.

h. Legend Lights -
MIL-STD-1472C, para 5.2.2.2.3.

i. Light Emitting Diodes -
MIL-STD-1472C, para 5.2.6.7.3.

j. Red Lighted Aircraft Instruments -
MIL-L-25467D, para 3.3.8 and 3.3.9.

k. Stray Light -
MIL-L-25467D, para 3.3.9
MIL-L-27160C, para 4.5.5.5.

l. Transilluminated Displays -
MIL-STD-1472C, para 5.2.2.1.9 and 5.2.2.4.4,
MIL-HDBK-759A, para 1.2.2.1.7 and 1.2.2.4.4.

m. White Aircraft Lighting -
MIL-L-27160C, para 3.3.5.

2. Illuminance

Secondary Instrument and Display Lighting -
MIL-L-6503, para 3.3.2.2
MIL-L-85762, para 3.9.10.2.

3. Contrast

a. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays -
MIL-L-85762, para 3.10.2.1.

b. Panel Assemblies -
MIL-P-7788E, para 3.4.3.4.

c. General -
MIL-STD-1472C, para 3.17.

d. Legend Lights -
MIL-HDBK-795a, para 1.2.2.2.8.

e. Red Lighted Aircraft Instruments -
MIL-L-25467D, para 3.3.13.

f. Scale Indicators -
MIL-STD-1472C, para 5.2.3.1.8
MIL-HDBK-759A, para 1.2.3.1.5.6.

g. Transilluminated Displays -
MIL-STD-1472C, para 5.2.2.1.12
MIL-HDBK-759A, para 1.2.2.1.7b.

h. White Aircraft Lighting
MIL-L-27160C, para 3.5.

4. Balance

a. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays -
MIL-L-85762, para 3.10.11.

b. General -
MIL-STD-1472C, para 5.2.1.2.2
MIL-HDBK-759A, para 1.2.1.2.

c. Red Lighted Aircraft Instruments -
MIL-L-25467D, para 6.4.

5. Uniformity

MIL-STD-1472C, para 5.2.1.2.2
MIL-HDBK-759A, para 1.2.1.2.

6. Sunlight Readability

a. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays -
MIL-L-85762, para 3.10.2.

b. Caution, Warning and Advisory Lights -
MIL-STD-411D, para 5.1.

c. Lighted Pushbutton Switches -
MIL-S-22885D, para 3.40.

7. Display Color

a. AN/AVS-6 (ANVIS) Night Vision Goggle Compatible Displays -
MIL-L-85762, para 3.10.8 and 3.10.9.

b. Cathode Ray Tube Displays -
MIL-HDBK-759A, para 1.2.4.2.6
MIL-L-85762, para 3.10.8 and 3.10.9.

c. Control Panel Assemblies -
MIL-P-7788E, para 3.5.2.

d. Dot Matrix Segmented Displays -
MIL-STD-1472C, para 5.2.6.8.7
MIL-HDBK-759A, para 1.2.6.2.3.3.6.

e. General Requirements -
MIL-C-25050A, Warning, Caution, and Advisory Light
MIL-STD-411D, para 5.1.1.1, 5.1.2.1, and 5.1.3.1.

f. Indicator Lights -
MIL-STD-1472C, para 5.2.2.3.3.

g. Legend Lights -
MIL-STD-1472C, para 5.2.2.2.2 and MIL-HDBK-795A, para 1.2.2.2.4.

h. Light Emitting Diodes -
MIL-STD-1472C, para 5.2.6.7.4.

i. Low Light and Dark Adaptation
MIL-STD-1472C, para 5.2.1.2.1.1
MIL-HDBK-759A, para 1.2.1j and 1.2.1.1.

j. Red Lighted Aircraft Instruments - MIL-L-25467D.

k. Transilluminated Displays - MIL-STD-1472, para 5.2.2.1.18 MIL-HDBK-759A, para 1.2.2.1.

l. White Aircraft Lighting - MIL-L-27160C, para 3.3.4 and 3.4.

8. Night Vision Goggle Compatibility

MIL-L-85762, para 3.4, 3.10.3.

9. Crewstation Reflections

a. MIL-L-85762, para 3.10.12.

b. MIL-L-6503H, para 3.3.

10. Lighting Mock-up Evaluations

MIL-L-85762, para 3.4.

APPENDIX C
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 control

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

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. Discriminability of shape and/or color coded markings

f. Control of stray light

g. Apparent contrast of markings to background

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

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

(6) Overlay of messages on CRT, HUD, or other displays

(7) Glare caused by warning, caution, and advisory lights

(8) Display contrast

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. Head-up Displays

(1) Readability

(2) Field-of-view

(3) Symbol height/width ratio

(4) Viewing distance

(5) Symbol brightness

(6) Brightness range

(7) Lighting uniformity

(8) Reflections on display surface

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 D
# REFERENCES

## REQUIRED REFERENCES


1. Test Operations Procedure (TOP) 1-2-610, Human Factors Engineering, November 1983.

2. TECOM Pam 602-1, Man-Material Systems, Questionnaire and Interview Design (Subjective Testing Techniques), July 1975.

3. MIL-STD-150A, Photographic Lenses, May 1959.

4. MIL-L-85762, Lighting, Aircraft, Interior, AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) Compatible, January 1986.

5. MIL-C-25050A, Colors, Aeronautical Lights and Lighting Equipment, General Requirements for, September 1971.

6. MIL-L-27160C, Lighting, Instrument, Integral, White, General Specification for, March 1972.

7. MIL-L-25467D, Lighting, Integral, Red, Aircraft Instrument, General Specification for, July 1977.

8. MIL-S-22885D, Switches, Push Button, Illuminated, General Specification for, January 1983.

9. Federal Standard No. 595a, Colors, March 1979.

10. MIL-P-7788E, Panels, Information, Integrally Illuminated, April 1979.

11. MIL-STD-850B, Aircrew Station Vision Requirements for Military Aircraft, November 1970.

12. MIL-STD-1333B, Aircrew Station Geometry for Military Aircraft, 9 January 1987.