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AD NO. _____

TECOM Project No. 7-CO-R87-AVO-003

TEST REPORT

OF

HUMAN FACTORS ENGINEERING TESTING OF
AIRCRAFT COCKPIT LIGHTING SYSTEMS

DINO PICCIONE
JAMES MORRISETTE
HUMAN FACTORS ENGINEERING

U.S. ARMY AVIATION DEVELOPMENT TEST ACTIVITY

FORT RUCKER, ALABAMA

DECEMBER 1987

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Prepared For:
U.S. Army Test & Evaluation Command
Aberdeen Proving Ground, MD 21005-5055

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REPLY TO
ATTENTION OF

DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MARYLAND 21005-5005



AMSTE-TC-M (70-10p)

MEMORANDUM FOR: Commander, U.S. Aviation Development Test
Activity, ATTN: STEBG-MP-P

SUBJECT: HFE Test Procedure for Army Aviation (Illumination),
TECOM Project No. 7-CO-R87-AVO-003

1. Subject report is approved.

2. Point of contact, this headquarters, is Mr. Roger
Williamson, AMSTE-TC-M, amstetcm@apg-4.arpa, AV 298-2170/3677.

FOR THE COMMANDER:

GROVER H. SHELTON
Chief, Meth Imprv
Directorate for Technology

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REPORT DOCUMENTATION PAGE

Form Approved
GMB No. 0704-0188

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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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FOREWORD

The U.S. Army Aviation Development Test Activity (USAAVNDTA) was responsible for the planning, execution, and reporting of this study. USAAVNDTA acknowledges Essex Corporation for its effort in all phases of this study.

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SECTION 1. SUMMARY

1.1 BACKGROUND. The Test and Evaluation of Cockpit Lighting Systems has evolved over the years from simple unstructured subjective evaluation to an evaluation process using sophisticated instrumentation and exacting criteria. Complicating the situation was the use of night vision goggles (NVG) in various configurations that imposed a whole new set of requirements on the lighting system. The red-colored lighting systems used since the dawn of Army aviation have been scrapped and replaced with blue-green systems. New specifications have been written to govern lighting system design and the nebulous concept of "NVG compatibility."

No test and evaluation guide for cockpit lighting existed and human factors practitioners had to determine how to conduct a lighting test on an impromptu basis. The definition of terms, specification of test equipment and environmental conditions was not standardized. This was especially true of NVG compatible lighting systems. Testing agencies and developers were not always in agreement on the procedures, instrumentation and analysis of test results.

It became clear that a uniform methodology for testing cockpit lighting systems needed to be developed for use by test personnel. This document attempts to correct this deficiency.

1.2 OBJECTIVE. This document seeks to provide a set of baseline procedures for testing aviation cockpit lighting systems. These procedures include a set of definitions, instrumentation and facility requirements, and references.

1.3 SUMMARY OF PROCEDURES.

1.3.1 A search was made for all documents containing criteria relating to aircraft cockpit lighting systems. Emphasis was placed on those documents applicable to Army aviation, but Navy and Air Force documents were not excluded. Next, a search was made for sources of lighting system test procedures that are accepted by the community of technical specialists involved in cockpit lighting. A final ingredient in this methodology investigation was the integration of procedures developed at the U.S. Army Aviation Development Test Activity (USAAVNDTA) in the course of past lighting system tests.

1.3.2 The document that was used most heavily was MIL-L-85762, Lighting, Aircraft, Interior, AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) Compatible. This specification was published in January, 1986. This is a comprehensive document covering most aspects of cockpit lighting, but especially NVG compatibility.

1.4 SUMMARY OF RESULTS. This methodology investigation resulted in a draft Test Operations Procedure (TOP) with sections of the TOP addressing specific cockpit lighting issues. The draft TOP may be seen in Appendix B. The main sections include:

- o Definitions
- o Display luminance
- o Illuminance
- o Contrast
- o Balance
- o Uniformity
- o Sunlight readability
- o Display color
- o Night vision goggle compatibility
- o Crewstation reflections
- o Lighting mockup evaluations
- o References

1.5 RECOMMENDATIONS. It is recommended that the craft TOP in Appendix B be staffed by this command through appropriate agencies, produced in final form, and submitted to HQ, TECOM for approval.

SECTION 2. DETAILS OF INVESTIGATION

2.0 The results of this investigation have been put in the format of a TECOM TOP. The draft TOP may be seen in Appendix B.

APPENDIX A
METHODOLOGY INVESTIGATION
PROPOSAL AND DIRECTIVE



DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MARYLAND 21005-6055

REPLY TO
ATTENTION OF

AMSTE-TC-M

1 1 SEP 1987

SUBJECT: FY87 PDTE Methodology Improvement Program Directive

Commander
U.S. Army Aviation Development Test
Activity
ATTN: STEBG-MP-P
Fort Rucker, AL 36362-5276

1. Reference TECOM Regulation 70-12, dated 29 May 1985, subject: TECOM Methodology Investigations.
2. This letter constitutes a directive for the investigations listed in enclosure 1 under the TECOM Methodology Improvement Program 1W665702D625.
3. The MIPs at enclosure 2 are the basis for headquarters approval of the investigations.
4. Special instructions:
 - a. All reporting will be in consonance with paragraph 9 of the reference. The final report will be submitted to this headquarters, ATTN: AMSTE-TC-M, in consonance with Test Event 570/580. Each project shall be completed in FY87 as reflected in the scheduling.
 - b. Recommendations for new TOP's or revisions to existing TOP's will be included as part of the recommendation section of the final report. Final decision on the scope of the TOP effort will be made by this headquarters as part of the report approval process.
 - c. The addressee will determine whether any classified information is involved, and will assure that proper security measures are taken when appropriate. All OPSEC guidance will be strictly followed during this investigation.
 - d. Prior to test execution, the test activity will verify that no safety or potential health hazards to humans participating in testing exist. If safety or health hazards do exist, the test activity will provide a safety/health hazards assessment statement to this headquarters prior to test initiation.

AMSTE-TC-M

1 1 SEP 1986

SUBJECT: FY87 RDTE Methodology Improvement Program Directive

e. Environmental documentation for support tests or special studies is the responsibility of the test activity and will be accomplished prior to initiation of the investigation/study.

f. Upon receipt of this directive, test milestone schedules as established in TRMS II data base will be reviewed in light of other known workload and projected available resources. If rescheduling is necessary and the sponsor nonconcurs, a letter citing particulars, together with recommendations, will be forwarded to Commander, U.S. Army Test and Evaluation Command, ATTN: AMSTE-TC-M, with an information copy to AMSTE-TE-O, no later than 15 calendar days from the date of this letter. Reschedules concurred in by the sponsor can be entered directly along with a properly coded narrative by your installation/test activity.

g. All work shall be performed such that energy consumption and conservation are considered throughout the effort.

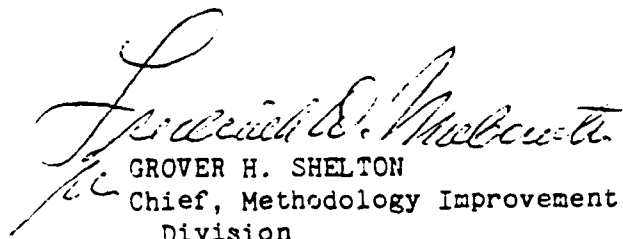
h. The HQ, TECOM POC's for individual investigations are listed in enclosure 1, AMSTE-TC-M, AUTOVON 298-2170/3677.

i. FY87 RDTE funds authorized for the investigations are listed on enclosure 1. DARCOM Form 1006 will be forwarded by the TECOM Resource Management Directorate. A cost estimate shall be submitted within 30 days following receipt of this directive.

5. TECOM - Providing Leaders the Decisive Edge.

FOR THE COMMANDER:

2 Encls


GROVER H. SHELTON
Chief, Methodology Improvement
Division
Directorate for Technology

RDTE METHODOLOGY INVESTIGATION PROPOSAL

December 1985

1. TITLE. Human Factors Engineering Test Procedure for Army Aviation (Illumination)
2. CATEGORY. Soldier/Machine Interface, Area A.
3. FIELD OPERATING ACTIVITY. US Army Aviation Development Test Activity (USAAVNDT Fort Rucker, Alabama 36362).
4. PRINCIPAL INVESTIGATOR. Mr. Roy L. Miller
Chief, Plans Branch
STEBG-MP-P AUTOVON 558-6167
5. STATEMENT OF PROBLEM. The test and evaluation of aircraft cockpit lighting is critical since all of the pilot's visual information during night operations is dependent on the adequacy of the lighting system. Aircraft lighting is governed by at least eight Military Specifications and Standards, and at least one new Military Standard (concerning night vision goggle compatibility) is being generated. Test procedures for measuring the adequacy of lighting systems are not documented, especially those that are night vision goggle compatible. Acceptable instrumentation and test facilities are currently not defined.
6. BACKGROUND. For the past several years, the Activity has relied on a contractor to conduct Human Factors Engineering (HFE) evaluations of aircraft lighting. As a result, the Activity has become dependent upon a contractor for a service that could be lost at any time due to a funding shortage, failure to award the contract to the same contractor, or contractor's loss of personnel experienced in aircraft lighting. The Activity's in-house expertise is very limited, but with properly documented procedures, our in-house personnel could accomplish the required tasks until more effective arrangements could be made. There is an urgent requirement to develop these detailed procedures.
7. GOAL. Produce a document that explains the objectives, criteria, data required, and data acquisition procedures for measuring lighting system adequacy including night vision goggle compatibility.
8. DESCRIPTION OF INVESTIGATION. The USAAVNDTA will:
 - a. Develop detailed testing procedures for conducting HFE evaluations of aircraft lighting. These procedures will take into consideration all applicable military standards and specifications and the application of their criteria into the procedures.
 - b. Procedure will consider application of qualitative and quantitative measurement techniques and the development of standardized questionnaire techniques.

TITLE: Human Factors Engineering Test Procedure for Army Aviation (illumination) (continued)

c. A detailed procedure will be published in test plan form which will be utilized by test project personnel in the preparation for and accomplishment of HFE evaluations.

9. JUSTIFICATION.

a. Association With Mission. The present TECOM TOP does not contain sufficient detail to provide adequate guidance to conduct HFE evaluations of aircraft lighting systems.

b. Present Capability, Limitations, Improvement, and Impact on Testing if not Approved. The present procedure is to utilize contractor personnel to conduct HFE evaluations of aircraft lighting systems. There are occasions when the contractor becomes overloaded due to remote site testing, and it becomes necessary for a project officer to collect HFE data. When this occurs, it is mandatory that he have available a "cookbook" that provides a detailed description of data required, data acquisition procedures, and analytical methods.

c. Dollar Savings. With these procedures, testing costs could be reduced due to reduced dependence on contractor testing. It is estimated that one in-house effort of 160 man-hours a year will be accomplished as a result of this investigation. Given an average labor rate of \$13.00 per hour for in-house labor and \$41.00 per hour for the contractor, it is estimated that the cost avoidance will be \$4,480 per year.

d. Workload. It is not anticipated that there will be any change in workload as a result of this investigation.

APPENDIX B
DRAFT TEST OPERATIONS PROCEDURE:
HUMAN FACTORS ENGINEERING
TESTING OF AIRCRAFT LIGHTING SYSTEMS

DRAFT

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

AMSTE-RP-702-10X

Test Operations Procedure (TOP) 7-2-512

AD No.

25 February 1988

HUMAN FACTORS ENGINEERING TESTING OF
AIRCRAFT COCKPIT LIGHTING SYSTEMS

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1. SCOPE. This TOP specifies procedures for testing the 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.

While it is considered essential that qualitative evaluations of cockpit lighting systems be conducted, the procedures for those evaluations are not covered here. Other documents, such as TECOM TOP 1-2-610^a, Human Factors Engineering, and TECOM PAM 602-1^b, Questionnaire and Interview Design (Subjective Testing Techniques), 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.

^aReference letters/numbers match those in Appendix D, References.
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2. FACILITIES AND INSTRUMENTATION.a. FACILITIES.

<u>ITEM</u>	<u>REQUIREMENTS</u>
(1) Darkened hangar or other enclosure	Facility must be a light controlled environment free from all extraneous light sources. The ambient illumination level must be strictly limited to 1×10^{-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-150 ¹
(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.

b. INSTRUMENTATION.DEVICES FOR MEASURINGPERMISSIBLE
ERROR OF MEASUREMENT

(1) Luminance/illuminance in the range of 1×10^{-3} to 1×10^4 and 1×10^{-5} to 1×10^4 respectively (e.g., photometer - see MIL-L-85752 ² , para B40 and B50)	1×10 fc. Spot size must be no greater than $\frac{1}{2}$ stroke width of display characters measured.
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25 February 1988

TOP 7-2-512

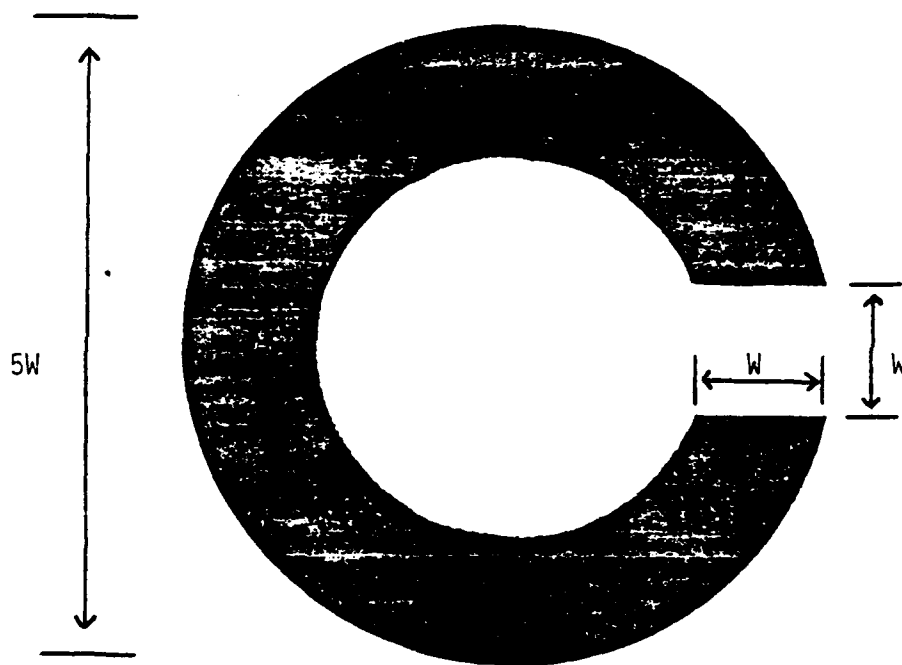


Figure 1. Landolt C-Ring

(2) Spectral radiance

See MIL-L-85762, para B30.

(3) Chromaticity

See MIL-C-25050³, 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 1×10^{-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.

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 (8) equally spaced measurements of the display markings for each instrument, control panel or other display. Also make at least eight (8) 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 0.1 footlambert (fL).

(3)⁴ For aircraft instruments with integral lighting conforming to MIL-L-27160⁴ and/or MIL-L-25467⁵, 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 0.1 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. This will allow for the accurate repetition of measurements, if required. An example of locations used for measurements may be found in MIL-S-22885D⁶, paragraph 4.8.3.5.

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

$$\frac{\sum x}{n} \text{ where: } \sum x = \text{the summation of all brightness measurements.}$$

$$n = \text{the number of measurements.}$$

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 the adequacy of illumination from system operators/users by appropriate means (e.g., questionnaires, interviews, etc.).

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 (8) equally spaced measurements of the display markings for each instrument. Also make at least eight (8) 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 0.1 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 the 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) A method of determining approximate contrast during day conditions may be accomplished 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-595, 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 a figure 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. One of the characteristics of a good cockpit lighting system is to provide 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 (8) equally spaced measurements of the display markings for each instrument. Also make at least eight (8) 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 0.1 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 the 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 the 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 all other displays (or areas) 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 be not 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 (8) equally spaced measurements of the display markings for each instrument. Also make at least eight (8) 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 0.1 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 the 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 the 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, that 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-22885, 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 $\theta_1 = 15 \pm 2$ 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 $\theta = 20$ degrees. Position a photometer at an angle of $\theta_2 = 15^\circ \pm 2^\circ$ 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 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.

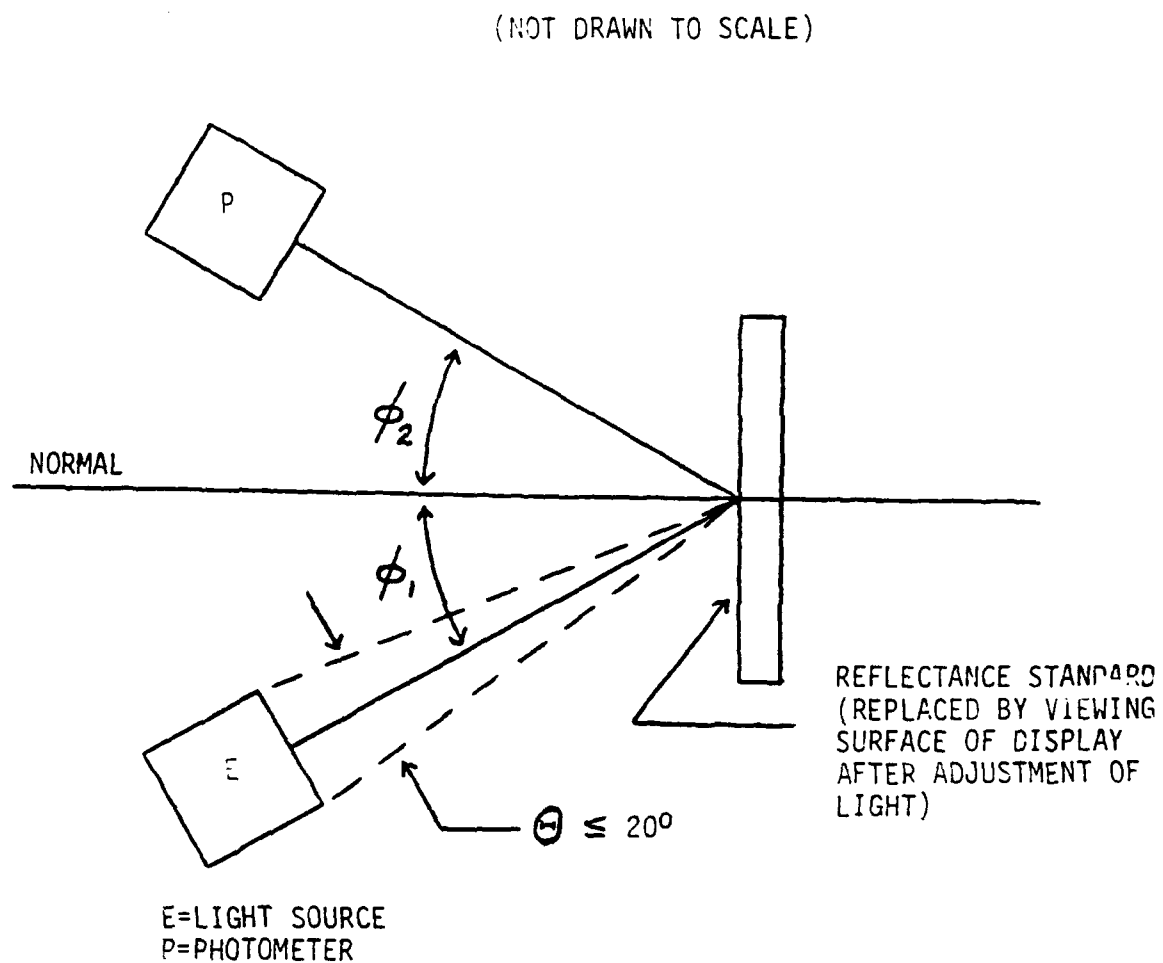


Figure 2. Specular reflectance test for readability
(Adapted from MIL-S-22885D, figure 8)

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-L-25050, 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 the conformance of instrument and panel lighting (IPL) red lighted displays to stated criteria is contained in MIL-L-25467 and MIL-P-7788^o called the color ratio method. This method is not endorsed and should only be used when the 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 the 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. Schedule the conduct of 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 experiences 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 0.1 fL as specified in MIL-L-85762, paragraph 3.10.9.1.1. Place the USAF 1951 medium-contrast resolution resolving power 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 1.7×10^{-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.

4.8.3 Data Required

(1) Landolt C-ring Targets. Analyze the target-to-observer distances using a treatments-by-subjects (repeated measures) analysis of variance (ANOVA). If the ANOVA indicates that at the 0.01 confidence level, there is no significant difference in the "lights-on" versus "lights-off" condition,

then the aircraft lighting system is not degrading NVG performance, and the criterion has been met.

(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, and the criterion has been met.

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. Controlling reflections can be accomplished 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-850⁹) 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, as appropriate.

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 in 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 5.8 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 not 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.

(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. Shortcomings 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 APP B). Present the data in tabular or narrative form as appropriate. Discuss nonconformity to the criteria and/or other specific problems noted in regards to the 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 it clear as to 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 - 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). Formerly, candle.

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 therefore visually contracted with 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)

$$C_{u1} = \frac{L_3 - L_1}{L_1} = \frac{L_{31}}{L_1}$$

for contrast of an unlighted (deactivated) display image element.

Footcandle (fc) - A footcandle is the unit of measure for surface illumination of light striking each and every point on a segment of the inside surface of an imaginary one-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 (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 ($\text{lm} \cdot \text{m}^{-2}$).

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.

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Photometer - An instrument for measuring photometric quantities.

Reflectance of a Surface or Medium - The ratio of the reflected light to the 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-L-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.

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1. 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

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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

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(3) Brightness range

(4) Speed of character changes

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APPENDIX D
REFERENCES

REQUIRED REFERENCES

1. MIL-STD-150A, Photographic Lenses, May, 1959.
2. MIL-L-85762, Lighting, Aircraft, Interior, AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) Compatible, January, 1986.
3. MIL-C-25050A, Colors, Aeronautical Lights and Lighting Equipment, General Requirements for, September, 1971.
4. MIL-L-27160C, Lighting, Instrument, Integral, White, General Specification for, March 1972.
5. MIL-L-25467D, Lighting, Integral, Red, Aircraft Instrument, General Specification for, July, 1977.
6. MIL-S-22885D, Switches, Push Button, Illuminated, General Specification for, January, 1983.
7. Federal Standard No. 595a, Colors, March, 1979.
8. MIL-P-7788E, Panels, Information, Integrally Illuminated, April, 1979.
9. MIL-STD-850B, Aircrew Station Vision Requirements for Military Aircraft, November, 1970.

RECOMMENDED REFERENCES

- a. Test Operations Procedure 1-2-610, Human Factors Engineering, Part 1 - Test Procedures, November, 1983.
- b. Man-Material Systems Questionnaire and Interview Design (Subjective Testing Techniques, July, 1975.

APPENDIX C. DISTRIBUTION

<u>Addresses</u>	<u>No. Copies</u>
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