AFGS-87213A
30 November 1987
SUPERSEDING
MIL-D-87213 (USAF)
18 September 1984

U.S. AIR FORCE GUIDE SPECIFICATION

DISPLAYS, AIRBORNE, ELECTRONICALLY/OPTICALLY GENERATED

AMSC: NA

FSC 6610

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AIR FORCE GUIDE SPECIFICATION

DISPLAYS, AIRBORNE, ELECTRONICALLY/OPTICALLY GENERATED

This specification is approved for use by the Department of the Air Force and is available for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 **Scope.** This specification establishes the development requirements for electronically generated displays for airborne use, including head up displays (HUD's) and multi-function displays (MFDs), including displays for TV, FLIR, and radar video, and the associated electronic display generation equipment. It is an Air Force Guide Specification (AFGS), also called a Mil-Prime Specification.

1.2 **Use.** This specification cannot be used for contractual purposes without supplemental information (identified by blanks within the specification) relating to the performance requirements of the equipment. Section 3 and section 4 paragraphs from this general specification should be completed using the information in the associated handbook guidance and lessons learned paragraphs, and used in a contract-peculiar item development specification, subsystem specification, or system specification.

1.2.1 **Structure.** This specification uses the subject arrangement and numbering conventions of MIL-STD-490.

1.2.2 **Instructional handbook.** The instructional handbook, which is the appendix to this specification, provides the rationale for requirements, guidance for inclusion of supplemental information and a lessons learned repository for this technical area.

1.3 **Deviation.** Any projected design for a given application which will result in improvement of system performance, reduced life cycle cost, or reduced development cost through deviation from this specification or where the requirements of this specification result in compromise in operational capability shall be brought to the attention of the contracting activity for consideration of change.

2. APPLICABLE DOCUMENTS

2.1 There are no applicable documents in the untailored specification.

3. REQUIREMENTS

3.1 **Item definition.** The display system shall provide all necessary information to the operator clearly, requiring a minimum of operator effort, while operating in the environment specified herein, including laboratory, ground, and airborne operation. The system shall perform the following major functions: ____________.

3.1.1 **Item diagrams.** (reserved)

3.1.2 **Interface definition.** The equipment shall be compatible with the electrical, mechanical, and cooling interface requirements of the __________ aircraft and the associated equipment. The equipment shall not be damaged by operation of the associated equipment when in any mode of operation (including off mode); nor shall the equipment, in any mode of operation, be damaged when any or all of the associated equipment or any unit of the __________ is disconnected. The performance of the associated equipment shall not be degraded or interfered with by operation of the equipment covered herein.

3.1.2.1 Electrical interface. The equipment shall be compatible with the input signals, and provide output signals as described in __________. Interface signals include __________.

3.1.2.1.1 Power input. The equipment shall perform as specified herein when supplied with electrical power in accordance with the requirements of __________ except __________. The equipment shall remain safe, shall automatically recover to full performance, and shall remain unaffected in reliability, when exposed to transient power conditions as described in __________. Power consumption shall not exceed __________.

3.1.2.1.2 Video. The equipment shall be compatible with __________ -line, __________ -frame-per-second, __________ -field-per-second, __________ -aspect-ratio video as defined by __________. Video output for a __________ video recorder shall be provided.

3.1.2.1.3 Data bus. The equipment shall interface with the __________ data bus.

3.1.2.2 Mechanical interface. The equipment shall be designed to be __________ mounted. Mounting interface details and tolerances shall be in accordance with __________.

3.1.2.3 Cooling. The equipment shall be cooled by __________.

3.1.2.4 Display recording interface. The equipment shall provide the following interface for cockpit TV video recording __________.

3.2.1 Performance. The following performance requirements shall be met under the full range of environmental conditions specified herein except __________.

3.2.1.1 Redundancy. The display system shall provide redundant features or redundant units such that __________ in the event of any single-point failure.

3.2.1.2 Lighting color. Displays and control panel lighting shall __________. Emitted light shall be compatible with __________.

3.2.1.3 Symbology. The equipment shall be capable of displaying each of the symbols shown and described in __________. All symbols shall be limited to the viewable display area. Symbols at the edge of the display area shall not be distorted and shall not "wraparound" to the opposite side. The equipment shall simultaneously display symbols in each of its modes as follows: __________.

3.2.1.3.1 Symbol size and movement. Alphanumeric symbols shall be at least _____ cm high by _____ cm wide. The symbology shall be capable of a minimum displacement of __________.

3.2.1.3.2 Symbology freeze. The symbology shall not lock up or freeze when sensor parameters are changing except in special cases where a symbol is intentionally frozen. If a lockup or freeze occurs, that symbol shall be __________.

3.2.1.3.3 Symbol line width. The symbol line width shall be __________ when measured at the 50 percent intensity points with symbol luminance set at _______ cd/m^2.

3.2.1.3.4 Primary symbology checking. Primary symbology consists of altitude, airspeed, pitch, roll, heading, vertical velocity, velocity vector (flight path marker), horizon line, and ________. When incoming data or processing that affects the primary symbology is identified as invalid (for example, a fail indication from a self-test), the affected primary symbology shall be removed from the display. The processor shall check the information (incoming data) needed to generate the primary symbology to determine if it is reasonable with respect to the physical aircraft parameters (rate of change, maximum value, minimum value, period between change, etc.). The equipment shall also cross-check related data for predetermined difference if more than one source is available. If the incoming data isn't reasonable or doesn't fall within the predetermined differences, then the symbology associated with the data shall ________.

3.2.1.4 Display modes. The equipment shall provide the following modes of operation: ________.

3.2.1.5 Video resolution. The vertical resolution shall be sufficient to produce ten percent minimum modulation when one half of the scan lines are "on" while operating in ________ raster format. The horizontal resolution shall be ________ TV lines per picture height (see section 6) minimum with a 10-percent line modulation. These requirements are to be met while simultaneously meeting the contrast, luminance, and ambient requirements of 3.2.1.6.

3.2.1.6 Display luminance and contrast. The following luminance and contrast ($[L_t - L_b]/L_b$) requirements shall be met when measured from the design eye position. Luminance shall not degrade more than ________ percent when measured from anywhere within ________ cm of the design eye position. The display luminance and contrast shall not change more than ± ________ percent when changing modes. No random bright flashes shall occur during mode switching.

3.2.1.6.1 HUD stroke-written line luminance. The luminance of all stroke-written symbols shall be such that projected images are clearly defined when superimposed on a background luminance of 34,000 cd/m² *(10,000 footlamberts) and color temperature of 3000 to 5000 Kelvin.* The average line luminance over the total symbol area shall be a minimum of ___ cd/m² with a design goal of ________ cd/m² when viewed through the HUD combiner glass. The contrast ($[L_t - L_b]/L_b$) of the symbology with a 35,000 cd/m² ambient background shall be a minimum of ________ with a design goal of 0.5.

3.2.1.6.2 HUD raster luminance. The raster video luminance shall be such that ________ shades of gray (____ steps, ____ levels) are visible against a ________ cd/m² background luminance with an *equivalent color temperature* of 3000 to 5000 Kelvin. The contrast ($[L_t - L_b]/L_b$) of the peak raster video with a ________ cd/m² ambient background shall be a minimum of ________. The ratio between adjacent gray shades shall be a minimum of 1.4:1 (contrast of 0.4).

3.2.1.6.3 MFD luminance and contrast. The luminance and contrast of all displayed data shall be adequate for easy visibility in illumination environments from ______ to ______. The following contrast requirements shall be met in a combined environment consisting of _____ lux (_____ fc) diffuse illumination and the specularly reflected image of a ____ cd/m² (____ fL) glare source. The contrast ($[L_t - L_b]/L_b$) of stroke-written symbols shall be _____ minimum. The display shall be capable of presenting a minimum of _____ shades of gray (____-1 steps) and the overall contrast of raster video shall be _____ minimum. The ratio between adjacent gray shades shall be a minimum of 1.4:1 (contrast of 0.4). The difference luminance (ΔL) between the brightest image and the dimmest in this environment shall be at least ____ cd/m² (____ fL.). The minimum contrast and shades of gray requirements above shall also be met in any less bright environment. The contrast between an "off" element and its background shall be less than ______.

3.2.1.6.4 Night brightness mode. The equipment shall provide a night brightness mode as follows: ____________ .

3.2.1.6.5 Color difference. The color difference (CD) between ________ and _________ shall be adequate for easy discrimination of __________ and be a minimum of __________ units on the 1976 CIE diagram defined in CIE Publication 15 Supplement 2 (1978), under lighting conditions of __________.

3.2.1.6.6 Luminance uniformity.

a. Symbol luminance uniformity. The difference in luminance between any two symbols or symbol segments within any circle whose diameter is one-fourth the display's minimum dimension shall not exceed _____ percent of the average value. Total variation across the display shall not exceed _____.

b. Raster luminance uniformity. The difference in luminance between any two points within any circle whose diameter is one-fourth the display's minimum dimension shall not exceed _____ percent of the average value when a flat field signal is applied. Total variation across the display shall not exceed _____ percent.

3.2.1.7 Display size. The active display area shall be at least _____ cm by _____ cm. Rounding of display corners shall not exceed _____.

3.2.1.8 Display color. The display color shall be __________ when measured in __________ ambient lighting.

3.2.1.9 Phosphor characteristics. Phosphor type and persistence shall be __________.

3.2.1.10 Video/symbology overlay. The equipment shall be capable of displaying __________ symbols while displaying video.

3.2.1.11 Video size. The equipment shall display video from the __________. The __________ aspect ratio raster shall be centered horizontally and subtend at least __________. The center of the raster shall be __________.

3.2.1.12 Viewability during gunfire. During periods of gunfire, any apparent displayed image size change or symbology movement (or combination of both) shall not degrade the pilot's capability to use critical symbology and shall not exceed ____ percent of the jitter values specified herein. The equipment shall return to full performance immediately upon cessation of gunfire.

3.2.1.13 Flicker, jitter, and noise. The display shall not exhibit flicker which is discernable to the eye. Jitter shall be less than __________(3 sigma). The effects of electrical noise shall not cause any visible distortion, positional or dimensional instability, or luminance variation in any symbology, reticle, or raster and shall not interfere with proper presentation or usability of the display. Motions at frequencies above 0.25 Hz are considered jitter, while lower frequency movements shall meet the requirements of the stability paragraphs herein.

3.2.1.14 Dimensional stability.

a. Symbology dimensional stability. The dimensional stability of the symbology shall be ± _____ for symbols less than _____ in height or width and for larger symbols, ±_____ per _____ of height or width.

b. Raster dimensional stability. The raster shall be dimensionally stable so that in the course of normal operation, during mode switching, or aircraft power variation, the total display image size shall not change more than _____ percent in height or _____ percent in width.

3.2.1.15 Positional stability.

a. Symbology positional stability. The positional stability of the symbology shall be ± _____.

b. Raster positional stability. Displayed video data variation shall not exceed plus or minus ____ percent azimuth or elevation under any combination of environments.

3.2.1.16 Raster distortion and linearity. No picture element shall be displaced by more than _____ percent of the picture height from its true position referenced from the center of the picture.

3.2.1.17 Reflections.

a. The relative intensity of second surface reflections visible in the HUD field-of-view shall not exceed _____ percent of the primary symbol or video luminance.

b. Reflectivity of the display face shall not exceed _____ percent.

3.2.1.18 Solar effects. The optical design shall limit images and background illuminations arising from solar illumination to less than _____ percent of the luminance of the illuminating source when viewed from anywhere within the eye motion box. Continuous direct sun illumination on the equipment within the cone of acceptance shall not result in damage to any subcomponent whether operating or not.

3.2.1.19 Automatic brightness control and sensor. An automatic brightness control (ABC) shall be provided to maintain visual contrast on the display as the ambient changes. The range of the ABC shall be suitable for ambient light levels in the range of _____. As a further design goal, the ABC shall automatically increase brightness during night mode operation when bright lights are in the operator's forward field-of-view.

3.2.1.20 Warm-up time. The equipment shall be functionally operational and conform to all accuracy and performance requirements within ____ minutes of being switched on when operated in the environment specified herein, including temperature extremes. Transient power loss for up to _____ seconds shall not require re-warm-up longer than the period of power loss.

3.2.1.21 Controls. Brightness, Contrast, and ______________ shall be provided. Brightness and contrast shall change logarithmically with linear control movement, to give the subjective impression of linear control.

3.2.1.22 Nuclear survivability. Nuclear survivability shall be in accordance with __________.

3.2.1.23 Processor standards. General purpose processors shall use the instruction set and be programmed in ______________ language. Processor configuration and programming techniques shall comply with ______________. Software which controls symbol format shall be contained in ______________ memory devices, to allow flexibility of symbol format with minimal impact on the display hardware. Specialized processors and languages may be used for specific display generation tasks which cannot be done with standard general purpose processors.

3.2.1.24 **Damage protection**

3.2.1.24.1 **Overload protection.** In addition to the electrical overload protection requirements of __________, the equipment shall be protected from chain reaction failures including those from external overloads (shorts) caused by grounding of external wiring during installation, test, or other causes. Insofar as practical, no damage to an LRU shall result from open circuits or grounding of wiring external to the LRU.

3.2.1.24.2 **CRT protection.** The shall be designed such that the CRT is undamaged in the event of failure or switch-off of the aircraft electrical power supplies or sweep circuitry. The protection shall be effective over the total brightness range.

3.2.1.24.3 **High voltage protection.** The equipment shall be designed to preclude damage to components from high voltage power supply and CRT high voltage arcs by use of arc suppressors or ______________.

3.2.1.25 **HUD-Specific requirements.**

3.2.1.25.1 **HUD field of view (FOV).** The HUD shall have a total field of view of at least ______________ vertical (V) by ______________ horizontal (H). The instantaneous FOV (IFOV) (total seen by both eyes) shall be at least ______________ V x ______________ H. The overlapping binocular IFOV (the overlapping area seen by both eyes at the same time) shall be at least V x ______________H. The FOV and its relationship to the horizontal datum shall be as described in ______________. The above requirements are to be met with the eye at the design eye. The total FOV shall be viewable from within the eye motion limits (box) shown in __________ and the overlapping binocular IFOV shall not decrease to less than 75 percent of the above requirement with up to ___ cm of eye displacement around the central line of sight within the eye motion box.

3.2.1.25.2 **Parallax.** For a single display element in elevation and azimuth for two eyes 6.35 cm (2.5 inches) apart laterally, 90 percent of the measured values shall not exceed the following: ___ mr vertically , ___ mr horizontally converging, and ___ mr horizontally diverging. No values shall exceed 1.1 times these values. All eye position and field angle data used to satisfy the HUD field-of-view requirement shall be the basis for compliance with this requirement.

3.2.1.25.3 **HUD standby reticle.** A standby reticle shall be provided which meets the size and shape requirements of __________. It shall be independent of ______________. It shall be manually depressible and shall meet the following detail requirements.

a. Luminance: The reticle line luminance shall be such that the projected images shall be visible and achieve a contrast of at least ______________ against a background luminance of 34,000 cd/m^2 (10,000 fL) and equivalent color temperature of 3000 to 5000 Kelvins. The average luminance of the projected image shall be a minimum of cd/m^2 when viewed through the combining glass.

b. Line widths. Standby reticle line width shall be ______________ mr when measured at the 50 percent intensity points with the reticle luminance set at ______________ cd/m^2 at the combining glass.

c. Color. The color of the standby reticle shall lie at UCS 1976 coordinates and _______.

3.2.1.25.4 **HUD accuracy.** The accuracy of the placement of fire control and navigation cueing symbology on the HUD combiner glass shall be adequate for maximum effective use of the and the following:

a. Calculated errors shall be based on 3 sigma values where normal distribution is assumed.

b. The errors shall include input signal conversion and computational errors in the HUD.

c. The errors shall be measured relative to the HUD mounting surface.

d. Static errors shall be computed as the root-mean-square of azimuth and elevation component errors.

e. Input signals are assumed to be perfect.

f. Accuracies are with no canopy in place, except for the symbols listed under "canopy distortion compensation."

Accuracy of placement of primary HUD symbols on the combiner shall not exceed ± ___ mr within a diameter circle and ± ___ mr everywhere in the TFOV.

3.2.1.25.4.1 Flight symbol accuracies. The equipment shall reproduce flight symbol input signals on the display to the following accuracies: ________________.

3.2.1.25.4.2 Algorithm accuracies. The algorithms used to compute fire control symbology locations shall have the following accuracies: ___________.

3.2.1.25.4.3 Symbol/video registration error. When symbols are overlaid on the video images, they shall be registered to within ±___ percent of the distance from FOV center vertically and horizontally with respect to the commanded true position within the video scene.

3.2.1.25.4.4 Standby reticle positional accuracy. The same accuracy requirements stated for the primary reticle shall apply for the standby reticle except ________________.

3.2.1.25.4.5 Combiner glass displacement error. The combining glass shall not cause real world objects to be displaced by more than _____ mr (3 sigma) in the area within 5° of the center of the FOV or ___ mr within the total FOV.

3.2.1.25.4.6 Combining glass distortion error. The combining glass shall not cause real world objects of less than 25 mr subtense to be distorted by more than _____ mr from the true object geometry, established without the combining glass. The distortion requirement shall apply for all eye positions that are required to obtain the total FOV.

3.2.1.25.4.7 Boresighting. The HUD Display Unit shall be designed to provide simple, reliable preboresighting such that when installed in the air vehicle on precisely located factory adjustable mounting pads, a combined boresight accuracy of _____mr (3 sigma) shall be achieved. Alignment, interface matching, or adjustment of the HUD projection unit shall not be required when this unit is removed and replaced after the original factory installation is complete, providing that its mounting assembly is not disturbed.

3.2.1.25.5 Canopy distortion compensation. The HUD shall compensate the position of the following symbols for optical deviations through the aircraft canopy ________________.

3.2.1.25.6 HUD combiner windloads. The combining glass and its mounting structure shall withstand without breakage the windloading and temperature differentials associated with the sudden removal of the canopy in flight. The operational environment preceeding removal of the canopy is the normal cockpit environment. Immediately following removal, the windloading on the combiner will be and the surface temperature will increase immediately to ___°C.

3.2.1.25.7 HUD combiner transmission and reflection. The HUD combining glass shall conform to __________. Transmissibility shall be a minimum of percent for both directions through the glass with a design goal of 85 percent. The outer surface of the combining glass shall have a reflectivity of _____ percent or less.

3.2.2 Physical characteristics. The physical characteristics of the display system shall be ________________.

3.2.2.1 Weight. The weight of the equipment shall be kept to a minimum. The weight shall not exceed ________________.

3.2.2.2 Volume. The equipment shall not exceed the volume of _______.

3.2.3 Reliability. The equipment shall have a mean time between failures of _______________ hours at a percent confidence level when installed and operating in the environment specified herein. The CRT shall have a minimum life of _______________ hours when operating at a continuous symbol brightness of _______________ cd/m² measured at _________.

3.2.4 Maintainability. The design of the equipment shall be such that the unscheduled active corrective maintenance times at the organizational and intermediate levels shall not exceed the following:

a. Mean corrective maintenance time:
   Organizational level: _______________ hours

   Intermediate level: _______________ hours

b. Maximum corrective maintenance time (95th percentile):
   Organizational level: _______________ hours

   Intermediate Level: _______________ hours

3.2.4.1 Maintenance concept. The equipment shall be designed for a maintenance concept. This maintenance concept consists of _________.

3.2.4.2 Scheduled maintenance. The equipment shall be designed to minimize scheduled preventive maintenance. Scheduled preventive maintenance shall not be allowed for any parts replacement unless it is established that such parts have a wear-out characteristic which results in a determinable life span with non-random life distribution characteristics.

3.2.4.3 Self tests. The equipment shall have the capability to display and/or report faults and out-of-tolerance conditions by employing an automatic, non-interruptive self-test. Self-tests shall be capable of detecting _____ percent of all faults. Self-test false alarms shall not exceed _____ percent of indicated faults. Faults or out-of-tolerance conditions that are obvious by looking at the display are considered "detected" even if they are not electronically reported.

3.2.4.4 Built-in-tests (BIT). Operator-initiated BIT, supplemented by self-test, shall be capable of detecting at least _____ percent of the malfunctions and out-of-tolerance conditions (at their predicted frequencies) with a false alarm rate of less than _____ percent. BIT, supplemented as necessary by self-test, shall be capable of isolating to the faulty LRU a minimum of _____ percent of the detected malfunctions and out-of-tolerance conditions. The BIT shall isolate to the faulty SRU _____ percent of the time. Built-in-tests may require interruption of normal equipment operation. If applicable, selection of the BIT shall result in the equipment self generation and display of the appropriate test pattern on the display surface. BIT results shall be easily interpretable without the use of table look-ups. Faults or out-of-tolerance conditions that are obvious by looking at the display are considered "detected" even if they are not electronically reported.

3.2.4.5 Testability. Each LRU shall contain test points in accordance with __________. Each SRU shall have test access points in accordance with __________. These test points shall be adequate to allow the following levels of fault detection:

a. The minimum acceptable level of fault detection shall be _____ percent of all failures of digital SRU's and percent for analog SRU's.

b. Fault isolation to a single circuit element (component) in _____ percent of the detected failures for digital SRU's and _____ percent to 3 active components on analog SRU's.

3.2.4.6 Fault reporting. The equipment shall report self-test and BIT-detected faults to the __________ via the data bus.

3.2.5 Environmental conditions. All equipment shall perform within specifications and not sustain damage when subjected to any simultaneous combinations of operational environmental conditions specified herein. The equipment shall not sustain damage while fully energized under any simultaneous combination of the endurance requirements specified herein. Also, the equipment shall perform within specifications after being subjected to any simultaneous combinations of the specified endurance environments. The equipment shall also not sustain damage and shall perform within all specifications after exposure to any combination of the non-operational environments specified herein. An environment is assumed to be an operational environment unless it is specifically identified as being either a non-operational or an endurance environment.

3.2.5.1 Temperature and altitude environments. The equipment shall meet the temperature and altitude requirements of _______________.

3.2.5.2 Humidity. The equipment shall meet the humidity requirements of _________.

3.2.5.3 Rain. The equipment shall withstand exposure to water dripping from overhead structure, equipment, etc., and rain per the extremes of __________ as may occur when __________. The 55-degree drip-proof requirements of _______________ are applicable.

3.2.5.4 Vibration. The equipment shall be designed to meet the performance requirements specified herein while being exposed to the vibration environment (performance) as described in __________. The equipment shall not be damaged and shall meet all performance requirements specified herein after exposure to endurance vibration as described in __________. The equipment shall remain operational during, and resume full performance immediately following, gunfire vibration as described in __________.

3.2.5.5 Mechanical shock

3.2.5.5.1 Bench handling. The equipment shall operate within specified performance requirements after being subjected to the shocks described in __________.

3.2.5.5.2 Crash safety. The cockpit equipment shall withstand the crash safety shock of __________. The equipment shall remain in place without failure of the mounting attachment and shall not create a hazard; bending and distortion are permitted.

3.2.5.6 Sand and dust. Sand and dust conditions of _______________ shall apply.

3.2.5.7 Fungus resistance. Fungus conditions of _________ shall apply.

3.2.5.8 Salt fog. Salt–sea–atmosphere conditions of __________ shall apply.

3.2.5.9 Explosive conditions. Explosive atmosphere conditions of _______________ shall apply.

3.2.5.10 Acoustic noise. The equipment shall be capable of satisfactory operation after and during exposure to an acoustic noise environment of __________dB.

3.2.5.11 Design acceleration loads. The equipment shall be designed for normal aircraft operating, limit, ultimate, and crash landing load factors.

a. Normal operating load factors. The equipment shall meet all performance requirements of this specification during application of normal operating load factors in the range between _______________ g positive and _______________ g negative acceleration.

b. Limit load factors. The equipment shall meet the performance requirements of the specification after application of limit load factors between _______________ g positive and _______________ g negative, _______________ g forward combined with _______________ g positive, and ± _________ g side combined with _______________ g positive. (Limit load factors for LRU's weighing less than 20 pounds shall be 10.0 g's in all 3 axes acting individually.) The equipment shall operate during the application of the limit load factors. No physical distortion or permanent set of the equipment is permitted after application of limit load factors.

c. Ultimate load factors. The equipment shall withstand ultimate load factors with no failure of the structural supporting elements and the units shall remain in place. Distortion and permanent set are permitted and operation is not required during or after application of ultimate loads. The ultimate load extremes for all units shall be 1.5 times the limit load factors.

d. Crash landing load factors. Equipment located in the crewstations so that structural failure of the equipment or its mounting would endanger the crew in event of a crash landing, shall have sufficient static strength to withstand the following ultimate load factors:

Longitudinal, forward	__________g
Longitudinal, aft	__________g
Vertical, positive	__________g
Vertical, negative	__________g
Lateral, left and right	__________g

These load factors shall act separately or in combination, whichever produces the most critical loading. Equipment will not be required to function after being subjected to crash landing loads.

3.2.5.12 Sunshine and ultraviolet radiation. No functional degradation or deterioration of finish or materials on parts which may be subjected to prolonged exposure to sunshine shall occur as a result of such exposure over the life of the equipment. The equipment shall deliver specified performance when operating in the maximum heat dissipating mode in any applicable combination of surrounding air temperature and pressure while the area which is exposed to sunlight while installed in the aircraft is subjected to solar radiation at an intensity of up to ______________ watts per square meter on the exposed projected horizontal area.

3.2.5.13 **Explosive decompression.** The shall not be damaged and shall perform as specified after an explosive decompression of the surrounding air. The pressure change shall be ______________.

3.2.5.14 **Fluids.** Where entrapment of fluids can occur and cause deterioration of equipment or cause equipment malfunction, drain holes shall be provided to prevent such entrapment of fluids. The equipment shall withstand contact with the following fluids without damage or permanent degradation of performance:

a. Water

b. __________

c. __________

3.2.5.15 **Combining glass bird strike.** The canopy is such that it can deflect and impact the HUD combiner when bird strike occurs. Therefore, the HUD combiner and its mounting shall be designed to prevent large, sharp, or high velocity fragments from disabling the pilot when the combiner is struck along its upper edge.

3.3 **Design and construction.**

3.3.1 **Materials, processes, and parts.** Materials, processes and parts shall be in accordance with ______________.

3.3.2 **Electromagnetic interference and compatibility.** The equipment shall meet the following requirements: ______________.

3.3.3 **Nameplates and product marking.**

a. Marking of parts and assemblies. Equipment, parts, and assemblies shall be marked in accordance with ______________.

b. Nameplates. Nameplates shall be permanently attached to the equipment and shall conform to the requirements of ______________.

c. Nomenclature. Nomenclature shall be in accordance with ______________.

3.3.4 **Workmanship.** (Reserved)

3.3.5 **Interchangeability.** (Reserved)

3.3.6 **Safety.** The equipment shall incorporate design features in accordance with ______________ which promote the health and safety of those personnel who will use and maintain the system. Hazards which may cause adverse explosive, fire, mechanical, or biological effects on personnel during system operation, test, maintenance, and training shall be eliminated or controlled.

3.3.6.1 Escape clearance. The design of cockpit/crewstation equipment shall be compatible with the escape envelope and ingress/egress requirements as described by ______________. Final escape envelope clearance shall be approved by the procuring activity.

3.3.6.2 Acoustic noise generation. Cockpit equipment shall not generate noise in excess of ______________ dB.

3.3.6.3 X-ray emmissions. The equipment shall not produce x-ray emissions of more than __________milliroentgen per hour under normal operating conditions.

3.3.7 Human engineering.

3.3.7.1 Handles and grasp areas. Handles and grasp areas, for ease of handling and installation, shall be provided in accordance with ______________.

3.3.7.2 Keyboard requirements.

a. Key travel and pressure. The operating travel for the keys shall be ______________. The operating pressure shall be ______________. Key operation shall provide tactile feedback such that an operator wearing gloves can clearly tell when a key is actuated.

b. Key operation. All keys shall operate in a __________ mode.

c. Key size and spacing. The keys shall be __________ and shall be no closer than __________ edge to edge from any other key, switch, or knob.

4. VERIFICATIONS

4.1 General. The verifications (inspections/analyses/tests/demonstrations) shall verify the ability of the airborne display to meet the requirements of section 3 herein. All verification shall be the responsibility of the contractor. The Government reserves the right to witness, or conduct, any verification.

4.1.1 Verification of diagrams. (reserved)

4.1.2 Verification of system interface. The equipment interface shall be verified as described in the following paragraphs.

4.1.2.1 Verification of electrical interface. The presence and function of all electrical interfaces shall be verified by exercising each input and monitoring each output signal for correct response. Details of interfaces, such as tolerances, shall be verified by ____________.

4.1.2.1.1 Power input. Power input requirements shall be verified by performing an electrical power test in accordance with __________. Volt-ampere measurements shall be based on measurement of "true rms Amperes".

4.1.2.1.2 Verification of video interface. Compatibility with the specified video interface shall be demonstrated by __________.

4.1.2.1.3 **Verification of data bus.** Compatibility with the specified data bus interface shall be verified by __________.

4.1.2.2 **Verification of mechanical interface.** Inspection and __________ shall be used to verify compliance.

4.1.2.3 **Verification of cooling.** Compliance with the cooling requirements shall be verified by __________.

4.1.2.4 **Verification of display recording interface.** Compliance shall be verified by __________.

4.2.1 **Verification of performance.** Compliance shall be verified as specified herein.

4.2.1.1 **Verification of redundancy.** The display system redundancy requirements shall be verified by __________.

4.2.1.2 **Verification of lighting color.** Compliance shall be verified by __________.

4.2.1.3 **Verification of symbology.** Capability to display each of the required symbols shall be visually checked. Details on symbol dimensions and tolerances shall be verified by analysis, visual inspection, and measurement of a representative sample (see 4.2.1.3.1).

4.2.1.3.1 **Verification of symbol size and movement.** Symbol size and minimum line movement capability shall be verified by measurement or design audit.

4.2.1.3.2 **Verification of symbology freeze.** __________ shall be used to determine compliance.

4.2.1.3.3 **Verification of symbol line width.** Symbol line width shall be measured.

4.2.1.3.4 **Verification of primary symbology checking.** __________ shall be used to verify that primary flight symbology is checked and presented properly.

4.2.1.4 **Verification of display modes.** Operation in all display modes shall be demonstrated.

4.2.1.5 **Verification of video resolution.** Vertical and horizontal resolution shall be measured with a scanning slit photometer, with the display adjusted to meet the luminance and contrast requirements herein, all in the presence of a __________ lm/m^2 ambient. Contrast modulation may be measured in the dark and mathematically corrected for ambient illumination effects if the results can be demonstrated to be equivalent. Contrast modulation is defined as $(L_t - L_b)/(L_t + L_b)$. The test shall be performed using a square wave video signal, and using a measurement aperture no greater than 20% of the display's linewidth.

4.2.1.6 **Verification of display luminance and contrast.** Display luminance and contrast shall be measured by __________.

4.2.1.6.1 Verification of HUD stroke-written line luminance. The requirements of 4.2.1.6 apply.

4.2.1.6.2 Verification of HUD raster luminance. The requirements of 4.2.1.6 apply.

4.2.1.6.3 Verification of luminance and contrast. Display luminance and contrast shall be measured using the test setup shown in figure 1 and using the diffuse illumination and glare source luminance specified in section 3 herein. Light sources used shall have a color temperature between 3000 and 5000 Kelvins. The following measurements shall be taken and used to calculate the required contrast ($[L_t - L_b]/L_b$):

L_t, the total luminance of the image, or brighter area, including any background or reflected light.

L_b, the luminance of the background, or dimmer area, measured in the specified lighting conditions, including any reflected light and any stray display emissions.

ΔL, (delta luminance, or difference luminance) the difference between the higher luminance (L_t) and the lower luminance (L_b).

Measurements shall be taken with a photometer having a sensing aperture equivalent to at least 1.8 minutes of arc, as measured from the normal operator viewing distance. If luminances of smaller areas are measured, then a series of measurements shall be taken within an area equivalent to the 1.8 minute of arc area and the luminance of the active areas shall be averaged with the luminance of any inactive areas on an area-weighted basis.

On large displays, such as a CRT, measurements shall be taken at 5 positions distributed over 80% of the screen area and averaged.

If the dimensions of the image elements are large enough to permit several nonoverlapping measurements to be made within the image element boundaries, multiple luminance readings shall be taken and averaged to establish the average element luminance.

If it can be demonstrated that ΔL does not change under varying lighting conditions, L_t can be calculated by measuring ΔL and L_b and adding them. If it can be demonstrated that equivalent results can be obtained by measuring in lower ambients (e.g., 54,000 lux rather than 108,000 lux), then scaling up the results, then the test may be done in the lower ambient.

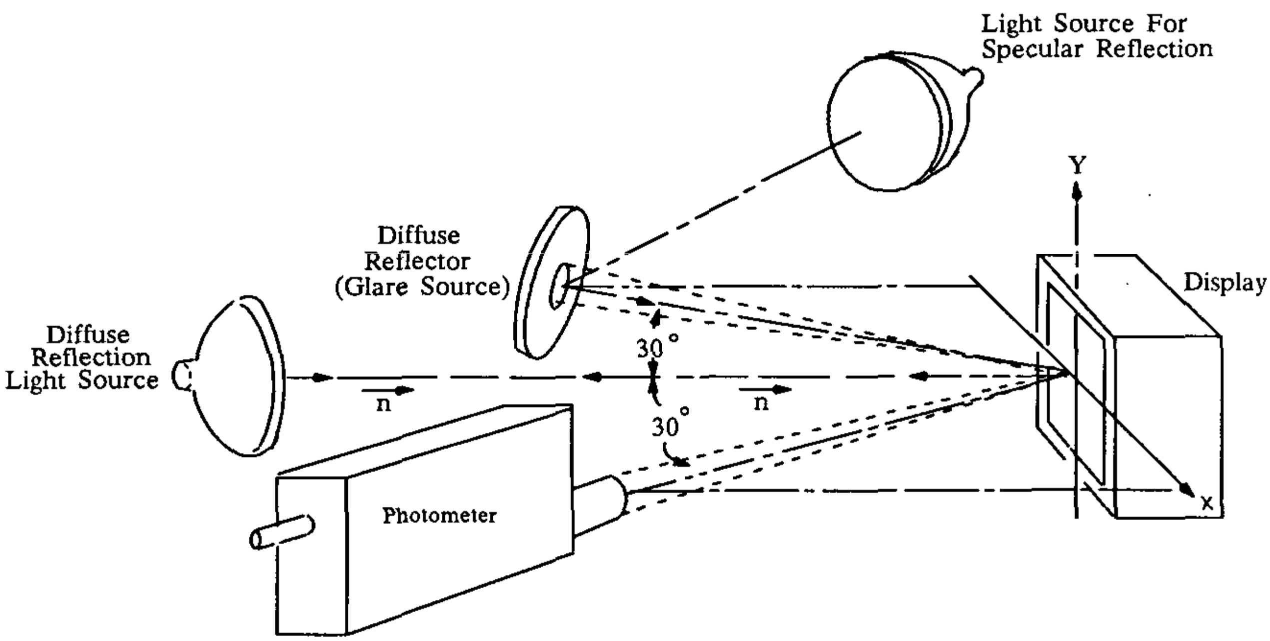

FIGURE 1. Combined specular and diffuse measurement setup.

Notes: 1. Luminance of the glare source is measured by putting a mirror 7 (preferably front–silvered) in place of the display and leaving the photometer focused at the display surface.

2. The diffuse ambient should be measured by substituting a diffuse surface of known reflectance for the display surface and measuring its luminance, then calculating the illumination level.

3. The diffuse and specular reflected light can be measured separately and summed or measurements can be taken directly with both light sources on at once.

4. Ordinary photo studio flood lights are not purely diffuse light sources, but are an acceptable approximation in this test.

5. Contrast shall not degrade more than 20% from specified values when measured at angles smaller than the 30 degrees shown in Figure 1, or when the diffuse reflected luminance is measured with the photometer and light source interchanged (that is, photometer on the axis of the display).

4.2.1.6.4 Verification of night brightness mode. The requirements of 4.2.1.6 apply.

4.2.1.6.5 Verification of color difference. The requirements of 4.2.1.6 apply.

4.2.1.6.6 Verification of luminance uniformity. Display luminance test data shall be used to determine compliance.

4.2.1.7 Verification of display size. Compliance with the display size requirements may be determined approximately by measuring the active display area, or by analysis of design data.

4.2.1.8 Verification of display color. Display color shall be measured using __________ in a __________ ambient.

4.2.1.9 Verification of phosphor characteristics. Phosphor type shall be verified by audit of contractor drawing data.

4.2.1.10 Verification of video/symbology overlay. Video/symbology overlay shall be demonstrated.

4.2.1.11 Verification of video size. Video size shall be measured by __________.

4.2.1.12 Verification of viewability during gunfire. Degradation of the symbology shall be monitored visually during gunfiring vibration test. If significant degradation occurs, the apparent line width and positional variations shall be measured.

4.2.1.13 Verification of flicker, jitter and noise. The display shall be monitored for visible flicker, jitter, and noise. Any objectionable effects noticed shall be measured.

4.2.1.14 Verification of dimensional stability. Symbol and test pattern dimensions shall be measured to determine compliance.

4.2.1.15 Verification of positional stability. The position of symbols and video shall be measured to determine compliance.

4.2.1.16 Verification of raster distortion and linearity. Raster distortion and linearity shall be tested by __________.

4.2.1.17 Verification of reflections. Intensity of reflections shall be measured to determine compliance.

4.2.1.18 Verification of solar effects. Solar effects shall be measured by __________.

4.2.1.19 Verification of automatic brightness control (ABC). Compliance shall be verified by __________.

4.2.1.20 Warm-up time. Warm-up time shall be measured.

4.2.1.21 Verification of controls. Operation of all required controls will be demonstrated.

4.2.1.22 Verification of nuclear survivability. Nuclear survivability or vulnerability shall be evaluated by ______________.

4.2.1.23 Verification of processor standards. Processor characteristics shall be verified by ______________.

4.2.1.24 Verification of damage protection

4.2.1.24.1 Verification of overload protection. Compliance shall be verified by ________.

4.2.1.24.2 Verification of CRT protection. Compliance shall be verified by ________.

4.2.1.24.3 Verification of high voltage protection. Compliance shall be verified by ________.

4.2.1.25 Verification of HUD specific requirements

4.2.1.25.1 Verification of HUD field of view (FOV). Measurements of look angles from specified eye positions to field positions shall be used to determine compliance.

4.2.1.25.2 Verification of parallax. Eye position and field angle data shall be taken to determine compliance.

4.2.1.25.3 Verification of HUD standby reticle. Standby reticle luminance, line width, and color shall be measured.

4.2.1.25.4 Verification of HUD accuracy. Accuracy of symbols and symbol positions shall be evaluated by ____________.

4.2.1.25.4.1 Verification of flight symbol accuracies. The requirements of 4.2.1.25.4 apply.

4.2.1.25.4.2 Verification of algorithm accuracies. The requirements of 4.2.1.25.4 apply.

4.2.1.25.4.3 Verification of symbol/video registration error. The requirements of 4.2.1.25.4 apply.

4.2.1.25.4.4 Verification of standby reticle positional accuracy. The requirements of 4.2.1.25.4 apply.

4.2.1.25.4.5 Verification of combiner glass displacement error. The requirements of 4.2.1.25.4 apply.

4.2.1.25.4.6 Verification of combining glass distortion error. The requirements of 4.2.1.25.4 apply.

4.2.1.25.4.7 Verification of boresighting. The requirements of 4.2.1.25.4 apply.

4.2.1.25.5 Verification of canopy distortion compensation. The intentional displacement of symbols for distortion compensation shall be evaluated by __________.

4.2.1.25.6 Verification of HUD combiner windloads. Force and temperature loadings equivalent to those shown in shall be applied to the HUD combiner. Breakage of the combiner or its mountings shall constitute failure of the test.

4.2.1.25.7 HUD combiner transmission and reflection. Measurements shall be taken or procurement data shall be evaluated to determine compliance.

4.2.2 Verification of physical characteristics. The physical characteristics of the display system shall be verified by ____________.

4.2.2.1 Verification of weight. The equipment shall be weighed.

4.2.2.2 Verification of volume. The dimensions of the equipment shall be measured.

4.2.3 Reliability verification

a. Burn-in (preproduction). As part of, and prior to the remainder of, acceptance testing, each deliverable system shall be subjected to a _______________ hour operational period. The hours are equipment "ON" time. The operating environment shall be the same as that used for the reliability qualification test. Upon completion of this operation, the system shall be submitted to the remainder of the acceptance test procedures without benefit of cleaning, realignment, or adjustments.

b. Reliability qualification test. Reliability qualification testing shall be conducted in accordance with _______________ to demonstrate compliance with the reliability requirement specified herein. The equipment shall be tested to test plan _______________ accept/reject criteria and operation during this testing shall simulate service usage. Only equipment "ON" time is to be used in computing total test time. A mission/environmental profile shall be developed in accordance with _______________. The temperature extremes and vibration levels specified herein shall be used in the cycle. No unit shall accumulate less than _______________ "ON" test hours. A minimum of systems shall be subjected to the reliability qualification test.

c. Reliability verification (production). Reliability production tests shall be performed in accordance with. All equipment shall be tested to test plan _______________. Test time for each equipment shall be _______________ "ON" hours and the test conditions shall be the same as those used in the reliability qualification test.

d. CRT life. CRT life shall be verified by _______________.

4.2.4 Maintainability verification. Maintainability demonstration testing shall be conducted in accordance with _______________, to demonstrate that the maintainability requirements specified herein have been satisfied. The conditions of the maintainability demonstration and tasks demonstrated shall represent those which can be expected to occur in the operational environment. Task selection shall be in accordance with _______________. A single simulated or induced fault or failure may be counted as a maintenance action at both the organizational and intermediate levels when practical.

4.2.4.1 Verification of maintenance concept. Compliance shall be verified by analysis.

4.2.4.2 Scheduled maintenance. Compliance shall be verified by audit of maintenance data.

4.2.4.3 Verification of self tests. Compliance shall be verified by _____________.

4.2.4.4 Verification of built-in tests. The BIT capability shall be verified by analysis and by data gathered during the maintainability demonstration test and flight tests.

4.2.4.5 Verification of testability. Testability design shall be verified by use of analytical/statistical data prepared either manually or by making use of available computer aided test analysis programs such as the Navy/Air Force Logic Stimuli and Response (LASAR) program.

4.2.4.6 Verification of fault reporting. Compliance shall be verified by _____________.

4.2.5 Verification of environmental conditions. The following environmental tests shall be performed in accordance with _______________, with the exceptions or additions listed below. The equipment shall be subjected to the baseline functional tests before, during (unless otherwise specified), and after each environmental test to demonstrate compliance with the requirements of section 3.

4.2.5.1 Verification of temperature and environments. The equipment shall be subjected to the temperature-altitude test of __________, with the following modifications: __________________________.

4.2.5.2 Verification of humidity. The equipment shall be subjected to the humidity test of __________, except ________________.

4.2.5.3 Verification of rain. The equipment shall be subjected to the rain drip test in accordance with ________________.

4.2.5.4 Verification of vibration. The equipment shall be subjected to performance, endurance, and vibration tests. The equipment shall meet the performance requirements of this specification during application of the performance level vibration, and following endurance and ______. Test details and techniques shall be in accordance with __________. The performance and endurance vibration levels of ______ shall be used. Vibration shall be applied along each of the 3 mutually perpendicular axes with duration in each axis as follows: ______hours at performance level, _____ hours at endurance level, followed by an additional ______hours at performance level. The equipment shall be tested to the gunfire vibration levels of _____. The vibration shall be applied for ______ minutes at each frequency in each of the 3 axes.

4.2.5.5 Verification of mechanical shock

4.2.5.5.1 Verification of bench handling. The equipment shall be subjected to a shock test in accordance with ________________.

4.2.5.5.2 Verification of crash safety. Cockpit equipment shall be subjected to the crash safety test as described in ________________.

4.2.5.6 Verification of sand and dust. The equipment shall be tested in accordance with _________.

4.2.5.7 Verification of fungus resistance. Fungus resistance tests shall be required only on those parts, subassemblies, or assemblies which use fungus nutrient materials in their construction. If no fungus nutrient materials are used a certification to this effect shall be provided. The tests shall be accomplished in accordance with ________________.

4.2.5.8 Verification of salt fog. The equipment shall be subjected to a salt fog test in accordance with ________________.

4.2.5.9 Verification of explosive conditions. The equipment shall be subjected to an explosive atmosphere test in accordance with ________________.

4.2.5.10 Verification of acoustic noise. The equipment shall be subjected to an acoustic noise susceptibility test unless analysis indicates that vibration tests provide a more severe environment.

4.2.5.11 Verification of design acceleration loads. A centrifuge test shall be accomplished in accordance with ________________.

4.2.5.12 Verification of sunshine and ultraviolet radiation. Equipment which is subject to exposure to sunshine shall be tested in accordance with ________________.

4.2.5.13 Verification of explosive decompression. Crewstation equipment shall be subjected to an explosive decompression test or analysis. The initial altitude shall be ______________ and the final altitude ______________. The rate of change of pressure shall be at least ______________.

4.2.5.14 Verification of fluids. Analysis of design data or performance of a submersion test shall be used to determine compliance.

4.2.5.15 Verification of combining glass bird strike. The combining glass, along with a windscreen mounted in the aircraft configuration, shall be subjected to a bird strike test in accordance with ______________.

4.3 Verification of design and construction.

4.3.1 Verification of materials, processes and parts. Materials processes and parts shall be verified by ______________.

4.3.2 Verification of electromagnetic interference and compatibility. Compliance shall be verified by ______________.

4.3.3 Verification of nameplates and product marking. The equipment shall be inspected to determine compliance.

4.3.4 Verification of workmanship. (Reserved)

4.3.5 Verification of interchangeability. (Reserved)

4.3.6 Verification of safety. The equipment shall be inspected to determine compliance.

4.3.6.1 Verification of escape clearance. Escape clearance shall be verified by ______________.

4.3.6.2 Verification of acoustic noise generation. Personnel exposure protection from acoustic noise shall be verified on the A scale of a standard sound level meter at slow response. If the alternate octave band analysis method is used, the equivalent A-weighted sound level may be determined from ______________. This test may be waived if the equipment does not produce significant noise.

4.3.6.3 Verification of x-ray emmissions. TBD

4.3.7 Human engineering verification.

4.3.7.1 Verification of handles and grasp areas. The equipment shall be inspected to determine compliance.

4.3.7.2 Verification of keyboard requirements. The key travel distance, pressure, operation mode, size, location, and tactile feedback shall be verified by ______________.

5. PACKAGING

5.1 Packaging. All deliverable items shall be prepared for shipment as directed by the procuring activity.

6. NOTES

6.1 Intended use. The electronically generated airborne display is intended for use in aircraft.

6.2 Definitions

6.2.1 Average luminance. The average of two or more luminance measurements.

6.2.2 Contrast definitions. There are numerous expressions for contrast, contrast ratio, modulation, and various other similar quantities, with very little standardization of meaning or usage. The following definitions form a consistent set; most of the other definitions which are found are actually equivalent to one of these (but may be expressed differently) or are so rarely used that they should be avoided. These definitions are based on the following measurable quantities:

L_t, the total luminance of the image, or brighter area, including any background or reflected light, as measured in the specified lighting conditions.

L_b, the luminance of the background, or dimmer area, including any reflected light and any stray display emmissions, measured in the specified lighting conditions.

ΔL, (delta luminance) the difference between the higher luminance (L_t) and the lower luminance (L_b). For a CRT, this is only light emitted by the display, that is, measured directly in a dark room. For devices which rely on reflectance changes (such as LCDs or painted-on instrument faces), ΔL cannot be measured directly; but it can be calculated as $L_t - L_b$.

L_{ul}, the luminance of an unlighted element; this will be the same as L_b for a CRT, but will be different for a device with discrete image elements, like an illuminated switch cap or a segmented LCD.

a. Luminance ratio or contrast ratio (CR). $CR = L_t / L_b$, numerically equal to $(\Delta L + L_b)/L_b$, also $= 1.0 + \Delta L / L_b$. This quantity ranges from 1.0 (no contrast) to infinity, and is commonly used in CRT and HUD specifications. It is used not only because it is larger (more impressive) by one than the contrast definition (below), but because it makes sense and is easy to use where two luminances are being compared, such as between shades of grey on a CRT.

b. Contrast (C). $C = \Delta L / L_b$, numerically equal to $(L_t - L_b)/L_b$, also $= CR - 1.0$. This quantity ranges from 0.0 (no contrast) to infinity, and is commonly used in instrument and control panel specifications. It is used in lieu of the contrast ratio definition only because it starts at zero, which is more logical to some people. Sub-definitions include C_l, which is the contrast of a lighted element against an unlighted element, and C_{ul}, which is the contrast of an unlighted element against its background.

c. Contrast as modulation (C_m). $C_m = (L_t - L_b)/(L_t + L_b)$, numerically equal to $\Delta L/(L_t + L_b)$. This quantity ranges from 0.0 (no contrast) to 1.0, and is often found in human factors research, such as in discussions of contrast sensitivity of the eye. It has been called contrast, contrast ratio, modulation, luminance modulation, or, when multiplied by 100, percent contrast, depending on the author. This quantity is consistent with "modulation" as defined in communications theory.

d. Luminance Contrast. $LC = (L_t - L_b)/L_t$, numerically equal to $\Delta L / L_t$. This quantity ranges from 0.0 (no contrast) to 1.0, and is called luminance contrast in MIL-STD-1472C. It is equal to the C_m definition (above) for C_m =1.0 or 0.0, but is larger than C_m elsewhere. It is luminance difference divided by (normalized to) maximum luminance, rather than mean luminance or minimum luminance, and is rarely used.

6.2.3 Line pair. One bright line and the adjacent darkened space between that bright line and the next bright line, comprising a portion of a group of alternating bright and dark parallel lines. Note there are two lines per line pair, and each line must be active, i.e. can be turned "on" or "off".

6.2.4 TV lines per picture height. Units of horizontal resolution on a CRT. The maximum number of black and white vertical lines that can be resolved within a horizontal expanse of raster equal to the picture height; often stated simply as "lines." Note that there are twice as many lines as there are line pairs; for example, a 4-inch square display with a resolution of 50 line pairs per inch has a horizontal resolution of 400 lines. This definition is consistent with the definition in the EIA video standards.

6.2.5 Line rate. In raster scanned systems, the total number of horizontal line times which occur in one complete frame. Note that this is different than the number of active lines (those that appear on the screen) and the horizontal resolution (also dependent on things like bandwidth and spot size). For example, commercial TV in the US is 525 line rate, 485 active raster lines and has a resolution of around 300 lines.

6.2.6 Minutes and milliradians. Units of angular measurement. 60 minutes of arc = 1 degree. 2 π radians = a circle (360°), therefore 1 radian = 57.3°, 1/1000 radian (milliradian) = 3.44 minutes of arc. Milliradians are convenient units for small angles because the size of the object, divided by the distance to the object (in the same units), gives its angular subtense in radians.

6.2.7 Self-tests. Automatic, non-interfering performance testing employing either continuous or iterative monitoring techniques.

6.2.8 Built-in tests (BIT): Those automated internal tests which interrupt normal operation and require participation of either aircrew or maintenance personnel.

6.2.9 Malfunctions. Equipment failures which render the equipment or equipment modes unusable.

6.2.10 Out-of-tolerance condition. Equipment faults which cause the equipment to perform below specified performance limits but do not render the equipment modes unusable.

6.3 Quantities of light

6.3.1 Candela per square meter (cd/m²). The cd/m² (formerly called nit for normalized intensity), is the metric unit for luminance. Luminance is used to measure light radiating or reflecting from a surface, such as the face of a CRT. A cd/m² is approximately 0.29 foot Lambert (1 fL approx= 3.4 cd/m²).

6.3.2 Lumens per square meter (lm/m²). The lm/m², or lux (light flux) is the metric unit for illuminance (commonly called illumination). Illuminance is used to measure light falling on a surface, such as a desk or display surface. A lux is approximately equal to 0.093 foot candles (1 fc approx = 10.8 lux).

6.3.3 Candelas (cd). The cd is the metric unit of luminous intensity (commonly called just intensity). Intensity is used to measure light coming from a point source in a given direction, such as the light coming from a landing light or anticollision light on an aircraft. It is roughly equal to the obsolete units of candles and candlepower. A candela = 1 lumen per steradian.

6.3.4 Lumens (lm). The lm is the metric unit of luminous flux. Luminous flux is used to measure the total light coming from a source, such as an ordinary light bulb.

6.4 Responsible engineering office. The office responsible for development and technical maintenance of this specification is ASD/ENASI, Wright-Patterson AFB OH 45433-6503. Requests for additional information or assistance on this specification can be obtained from James C. Byrd, ASD/ENASI, Wright-Patterson AFB OH 45433-6503, AUTOVON 785-4130, commercial (513) 255-4130. Any information obtained relating to government contracts must be obtained through contracting officers.

6.5 Subject (key word) listing.

Displays
Airborne Displays
Cathode Ray Tube
Cockpit Displays
CRT
Head Up Display
Multi Purpose Display
Multi Function Display
Sunshine Legibility

6.6 Changes from previous issue. Asterisks (or vertical lines) are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Custodian:
Air Force - 11

Preparing activity:
Air Force - 11

Project No. 6610-F239

APPENDIX

DISPLAYS, AIRBORNE, ELECTRONICALLY/OPTICALLY GENERATED

HANDBOOK FOR

10. SCOPE

10.1 **Scope.** This appendix provides rationale, background criteria, guidance, lessons learned, and instructions necessary to tailor section 3 and 4 of the basic specification for a specific application.

10.2 **Purpose.** This appendix provides the section 3 and section 4 paragraphs of the specification, along with information to assist the Government procuring activity in the tailoring and use of AFGS-87213A.

10.3 **Use.** This appendix is designed to assist the project engineer in tailoring AFGS-87213A. The blanks of the basic specification shall be filled in to meet the operational needs of the equipment being developed.

10.4 Format

10.4.1 **Requirement/verification identity.** Section 30 of this appendix parallels section 3 and section 4 of the basic specification; paragraph titles and numbering are in the same sequence. Section 30 provides each requirement (section 3) and associated verification (section 4) as stated in the basic specification. Both the requirement and verification have sections for rationale, guidance, and lessons learned.

10.4.2 **Requirement/verification package.** Section 30 of this appendix has been so arranged that the requirement and associated verification is a complete package to permit addition to or deletion from the criteria as a single requirement. A requirement is not specified without an associated verification.

10.5 **Responsible engineering office.** The responsible engineering office (REO) for this appendix is ASD/ENASI, Wright-Patterson AFB OH 45433-6503. The individual who has been assigned the responsibility for this handbook is James C. Byrd, ASD/ENASI, Wright-Patterson AFB OH 45433-6503, Autovon 785-4130, Commercial (513) 255-4130.

20. APPLICABLE DOCUMENTS

20.1 Unless otherwise indicated, the documents listed herein are referenced solely to provide supplemental technical data.

20.1.1 Government documents

SPECIFICATIONS

Military

MIL-C-675 Coating of Glass Optical Elements (Antireflection)

MIL-B-5087	Bonding, Electrical, and Lightning Protection for Aerospace Systems
MIL-E-5400	Electronic Equipment, Aerospace, General Specifications for
MIL-H-5606	Hydraulic Fluid, Petroleum Base, Aircraft, Missile, and Ordnance
MIL-T-5624	Turbine Fuel, Aviation, Grades JP-4 and JP-5
MIL-R-6771	Reflector, Gunsight Glass
MIL-C-6781	Control Panel, Aircraft Equipment, Rack or Console Mounted
MIL-N-7513	Nomenclature Assignment, Contractors Method for Obtaining
MIL-P-7788	Panel, Information, Integrally Illuminated
MIL-L-7808	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base, NATO Code Number O-148
MIL-A-8243	Anti-icing and Deicing-Defrosting Fluids
MIL-P-15024/5	Plates, Identification
MIL-S-19500	Semiconductor Devices, General Specification for
MIL-M-38510	Microcircuits, General Specification for
MIL-T-83133	Turbine Fuel, Aviation, Kerosene Type, Grade JP-8
MIL-H-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft, Metric NATO Code Number H-537
MIL-P-83335	Panels, Integrally Illuminated, White, Specification for
MIL-C-83723	Connectors, Electrical, (Circular, Environment Resisting), Receptacles and Plugs, General Specification for
MIL-L-85762A	Lighting, Aircraft Interior, AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) Compatible
MIL-E-87145	Environmental Control, Airborne
MIL-L-87240	Lighting Equipment, Airborne, Interior and Exterior

STANDARDS

Military

MIL-STD-210	Climatic Information to Determine Design and Test Requirements for Military Systems and Equipment
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference

MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-471	Maintainability Verification/Demonstration/Evaluation
MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-781	Reliability Testing for Engineering Development, Qualification, and Production
MIL-STD-810	Environmental Test Methods and Engineering Guidelines
MIL-STD-883	Test Methods and Procedures for Microelectronics
MIL-STD-884	Electronically or Optically Generated Displays for Aircraft Control and Combat Cue Information
MIL-STD-1295	Human Factors Engineering Design Criteria for Helicopter Cockpit Electro-Optical Display Symbology
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-STD-1515	Fastener Systems for Aerospace Applications
MIL-STD-1553	Digital Time Division Command/Response Multiplex Data Bus
MIL-STD-1750	Sixteen-Bit Computer Instruction Set Architecture
MIL-STD-1787	Aircraft Display Symbology
MIL-STD-1799	Survivability, Aeronautical Systems
MS25271	Relays, Electromagnetic, 10 Amperes, 4 PDT, Type 1, Solder Hook Hermetically Sealed

PUBLICATIONS

AFR 161-35	Hazardous Noise Exposure

20.1.2 Other publications

EIA-RS-170	Electrical Performance Standards--Monochrome Television Studio Facilities
EIA-RS-343	Electrical Performance Standards for High Resolution Monochrome Closed Circuit TV Camera
NAT-STD-3350	Monochrome Video Standard for Aircraft System Application
NAT-STD-3800	Night Vision Goggle Lighting Compatibility Design Criteria
ARINC 725	Electronic Flight Instruments
CIE	Supplement No. 2 to Publication 15 (E-1.3.1), Recommendations on Uniform Color Spaces--Color Difference Equations, and Psychometric Color Terms

OSHA Code of Federal Regulations Part 19103

30. REQUIREMENTS AND VERIFICATIONS

3.1 Item definition. The display system shall provide all necessary information to the operator clearly, requiring a minimum of operator effort, while operating in the environment specified herein, including laboratory, ground, and airborne operation. The system shall perform the following major functions: ____________.

REQUIREMENT RATIONALE (3.1)

The major functions and parts of the display system must be specified to establish what capabilities the system must have.

REQUIREMENT GUIDANCE

Major system procurements, such as a new aircraft, will generally only have a system specification in the initial request for proposal (RFP), and the contractor will be required to submit prime item development (PID) specifications on each subsystem or unit, either as part of his proposal or as a data item. Procurements for a single unit or a subset of the display system require that the project engineer prepare a PID specification, rather than a portion of a system specification. In this case, the System Description becomes a simple Item Description and all of the appropriate paragraphs under 3.2 herein are used to define the equipment's performance.

An aircraft or avionics system specification generally includes several pages of display system description. For example, the HH-60 Avionics Prime Item Development Specification contained the following list of display-related equipment: multi-function display units; display electronics units (DEU); helmet mounted display system; remote map reader; avionics control panels. Other systems will include other units; for example, all fighter planes currently have head-up displays (HUD) and many use an electronic engine monitor display (EMD) and a separate integrated communication/navigation/identification control/display unit (CNI - CDU) or a keyboard. The system specification would generally include the key performance characteristics of each of these functions or subsystems. These would be pulled from the appropriate parts of section 3.2 herein and made subparagraphs under the display system description paragraph. Examples of key requirements to be included in the system specification are as follows:

a. **MFD**
Quantity, size
Contrast, shades of gray, and lighting environment
Resolution
Format (Video, symbology)
Color requirement

b. **DEU**
Number of channels (unique formats)
Processing capability
Symbology requirements
Number of input and output channels
Bus and video interface
Programmability Provisions for occluding, inverting, overlaying or flashing symbols

c. **Control panels**
Panel lighting

Controls required

d. **HUD**
Brightness
Video capability
Symbol set
Accuracy

REQUIREMENT LESSONS LEARNED

The mission of the aircraft will determine which display functions and characteristics are required. In the early phases of a program, very general guidance will be available in documents such as the Statement of Need and Program Management Direction. Studies, simulations, and meetings with the users must all be used with good engineering judgment to arrive at a suitable set of display requirements.

4.1 General. The verifications (inspections/analyses/tests/demonstrations) shall verify the ability of the airborne display to meet the requirements of section 3 herein. All verification shall be the responsibility of the contractor. The Government reserves the right to witness, or conduct, any verification.

VERIFICATION RATIONALE (4.1)

Compliance with the general display requirements of 3.1 will generally become obvious during other tests and inspections. Any other introductory and general quality assurance provisions should also be put into 4.1. They are located here in order to allow all of the remaining paragraphs of section 4 to exactly parallel the section 3 paragraph with the similar number.

VERIFICATION GUIDANCE

While compliance with the general display system requirements will generally become obvious during other tests and inspection, specific tests, inspections, and analysis should be added for any specific requirements called out in 3.1. For environmental tests, the conditions, tolerances, and accuracies of MIL-STD-810 are often adequate and reasonable and are in general use. Exceptions should be added to account for any program-peculiar requirements. For example, for the F-16, which uses forced-air cooling, specifications include: (a) cooling air standard conditions for temperature (27°C +10°C) and flow rate tolerance (+10, -0 percent); (b) cooling airflow rate tolerance (+5 percent); and other exceptions related to the manufacturer's preferred test conditions.

VERIFICATION LESSONS LEARNED

3.1.1 Item diagrams. (reserved)

4.1.1 Verification of diagrams. (reserved)

3.1.2 Interface definition. The equipment shall be compatible with the electrical, mechanical, and cooling interface requirements of the __________ aircraft and the associated equipment. The equipment shall not be damaged by operation of the associated equipment when in any mode of operation (including off mode); nor shall the equipment, in any mode of operation, be damaged when any or all of the associated equipment or any unit of the __________ is disconnected. The performance of the associated equipment shall not be degraded or interfered with by operation of the equipment covered herein.

REQUIREMENT RATIONALE (3.1.2)

It must be clear which aircraft and other systems the equipment will interface with.

REQUIREMENT GUIDANCE

Names of appropriate aircraft and equipment should be filled in. Where the display equipment will interface with existing aircraft and avionics, these items should be listed specifically to insure that the manufacturer understands the interfaces and does not expect other equipment to be modified to suit him.

REQUIREMENT LESSONS LEARNED

4.1.2 **Verification of system interface.** The equipment interface shall be verified as described in the following paragraphs.

VERIFICATION RATIONALE (4.1.2)

The subparagraphs describe verification methods for each kind of interface.

VERIFICATION GUIDANCE

Verification is described in the subparagraphs below.

VERIFICATION LESSONS LEARNED

3.1.2.1 **Electrical interface.** The equipment shall be compatible with the input signals, and provide output signals as described in __________. Interface signals include ___________.

REQUIREMENT RATIONALE (3.1.2.1)

The numerous electrical interface signals associated with the equipment must be defined; this is often done in an Interface Control Document (ICD) which is generated as a joint effort by the display manufacturer, the system integrator or aircraft manufacturer, and the Air Force.

REQUIREMENT GUIDANCE

For new systems, where the interface is not well defined, a generalized interface description or philosophy should be inserted, along with a statement of who will further define the interface. For equipment which is being retrofitted into an existing system, an ICD or equivalent document describing the existing interfaces should exist. It should be referenced and provided to bidders.

REQUIREMENT LESSONS LEARNED

Proper documentation of all the interfaces is an excellent means of tracing signal flow throughout the system and potential design problems can often be identified. A properly prepared ICD can fully characterize a system.

4.1.2.1 **Verification of electrical interface.** The presence and function of all electrical interfaces shall be verified by exercising each input and monitoring each output signal for correct response. Details of interfaces, such as tolerances, shall be verified by ___________.

VERIFICATION RATIONALE (4.1.2.1)

An exercise of all equipment functions is generally required for acceptance and in the course of this exercise one would normally expect all interfaces to be used. Specific verification of details, such as tolerances on voltages, is needed on signals which are critical or not well understood.

VERIFICATION GUIDANCE

Acceptance tests should exercise all interfaces. One may elect to perform laboratory tests to verify interface details (such as voltage tolerances) but in most cases it is more cost-effective to wait until integration or flight tests indicate that a problem exists and then use detail signal requirements to determine which equipment is at fault.

VERIFICATION LESSONS LEARNED

Interaction of equipment in a System Integration Lab (SIL) environment has often produced effects which were not provided for or understood when interface control documents were developed. Where this is likely to happen, a test-and-fix approach in the SIL is the only way to reach successful interface because, even if a detailed interface test were designed and performed, it could not correct problems due to documentation oversights and mistakes.

3.1.2.1.1 Power input. The equipment shall perform as specified herein when supplied with electrical power in accordance with the requirements of _________ except __________. The equipment shall remain safe, shall automatically recover to full performance, and shall remain unaffected in reliability, when exposed to transient power conditions as described in _________. Power consumption shall not exceed ___________.

REQUIREMENT RATIONALE (3.1.2.1.1)

The electrical power available must be accurately defined, and in many cases limited, to insure compatibility.

REQUIREMENT GUIDANCE

The power specification for the appropriate aircraft and any exceptions to it should be filled in. Currently, this is MIL-STD-704 for most Air Force aircraft. Maximum power consumption should be filled in if it is critical and a power budget or analysis has been performed to establish appropriate numbers. Otherwise, the blanks can be left as "To be proposed (TBP)" during the proposal phase of the program and any reasonable numbers proposed by the manufacturer filled in.

REQUIREMENT LESSONS LEARNED

On many programs, it is power dissipation which is critical rather than power consumption. This was true on the F-16 and A-10, where limited cooling is available in the cockpit display units.

4.1.2.1.1 Power input. Power input requirements shall be verified by performing an electrical power test in accordance with __________. Volt-ampere measurements shall be based on measurement of "true rms Amperes".

VERIFICATION RATIONALE (4.1.2.1.1)

A power consumption test is generally the easiest and best way to accurately determine power consumption and susceptibility to power transients.

VERIFICATION GUIDANCE

Power test techniques are reasonably straightforward; a statement that a power test will be performed to verify compliance with the specified requirement should be sufficient. Testing to verify performance at voltage and frequency extremes is normally appropriate.

VERIFICATION LESSONS LEARNED

Designers are turning to switching-mode power supplies because of their high efficiency and small size and weight. However, they can cause problems because they induce current harmonics on AC power systems. These harmonics can impose significant additional loads on generation equipment and wiring. Volt-ampere measurements must be based on measurement of "true rms Amperes", since this accurately accounts for harmonic effects.

3.1.2.1.2 Video. The equipment shall be compatible with ________ -line, ________ -frame-per-second, ________ -field-per-second, ________ -aspect-ratio video as defined by ________. Video output for a ________ video recorder shall be provided.

REQUIREMENT RATIONALE (3.1.2.1.2)

For video displays only, video interfaces must be specified clearly.

REQUIREMENT GUIDANCE

Video line rate, frame rate, aspect ratio, and the appropriate video standard should be inserted. Many current Air Force aircraft use 525-line, 30-frame, 60-field, 4:3- or 1:1-aspect-ratio video similar to RS-170. Some systems use a higher voltage level (2 to 3 volts) than specified by RS-170 (1.0 or 1.5 volts) to achieve a better signal-to-noise ratio. Some systems use other line rates (mainly 875 or 1023) for better vertical resolution. Future monochrome systems should comply with the NATO standard (NAT-STD-3350) which allows 525-30/60, 625-25/50, and 875-30/60 line-frame/field rates and standardizes on 1.0 volt peak-to-peak. Color displays are in use on commercial aircraft (Boeing 757, 767) which use a stroke presentation with raster fill of some symbols at a 40/80 rate.A draft standard for military aircraft using color has been prepared by ASD/ENASI. It defines color video to be a red-green-blue (RGB) (three-wire) signal having timing and tolerances equivalent to the monochrome signals in NAT-STD-3350. Some systems generating color video will also be required to generate a monochrome video output in order to allow video to be used by monochrome video recorders and backup displays. Since single-channel video recorders are in common use and quality of color video on ground playback is not critical, it is anticipated that color video will be converted to NTSC format for recording.

REQUIREMENT LESSONS LEARNED

The multitude of video formats in use has caused significant problems for displays and recorders. For example, on the F-4E PAVE TACK program, video from TISEO, radar, GBU-15, Maverick, and PAVE TACK is displayed and recorded. After the system was designed, interfaced, and flight tested, problems still occurred because the amplitudes and characteristics were different. For example, PAVE TACK FLIR video is one volt and often has large areas of grey with occasional white areas, while the radar video is three volts and often consists of large areas of black with white spots. The AGC circuit in the display could not correctly compensate for these differences, so the operator had to frequently adjust the display brightness and contrast when switching.

4.1.2.1.2 Verification of video interface. Compatibility with the specified video interface shall be demonstrated by ________.

VERIFICATION RATIONALE (4.1.2.1.2)

Video interfaces must be tested or demonstrated to assure compatibility.

VERIFICATION GUIDANCE

The video signal voltage and timing characteristics can be measured if deemed necessary, but it is sometimes adequate to rely on (a) laboratory demonstrations of compatibility with standard video generation equipment, and (b) integration laboratory or aircraft demonstration of system compatibility.

VERIFICATION LESSONS LEARNED

3.1.2.1.3 Data bus. The equipment shall interface with the ________ data bus.

REQUIREMENT RATIONALE (3.1.2.1.3)

For equipment on aircraft which have a data bus, use of the bus and characteristics of the bus must be specified.

REQUIREMENT GUIDANCE

To simplify and standardize interfaces, current Air Force policy is to make maximum practical use of the MIL-STD-1553B, Notice 1, multiplex bus. System considerations such as bus loading and the amount and type of data to be interfaced will indicate which units should operate on the data bus.This can range from putting each unit of a display system on the bus to putting only one electronics unit/symbol generator on the bus.

REQUIREMENT LESSONS LEARNED

Unique data busses, such as were used on the F-15 and F-111, reduce other application possibilities for the equipment, and increases life cycle cost.

4.1.2.1.3 Verification of data bus. Compatibility with the specified data bus interface shall be verified by ________.

VERIFICATION RATIONALE (4.1.2.1.3)

Bus interfaces must be tested or demonstrated to assure compatibility.

VERIFICATION GUIDANCE

All new and modified designs must be tested to insure compatability with MIL-STD-1553B, Notice 1. Any hardware or software changes made in a unit may inadvertently make it non-compliant with the standard. The detailed test plan should be identical to that contained in ENASD 81-1 Systems Engineering Avionics Facility (SEAFAC) Test Plan/Test Report for MIL-STD-1553. Copies of this test plan are available from ASD/ENASF, Wright-Patterson AFB, Ohio 45433. Ideally such testing should be done for both prototype and production versions of a given unit.

The failure to conduct thorough MIL-STD-1553 compliance tests on individual units prior to systems integration results in lengthened integration and flight test activities, slipped schedules, and high costs for design/construction error correction. In addition, future system growth options may be closed off due to non-compliance problems which are too costly to correct; or worse yet, problems may remain undetected until the future modifications are attempted.

VERIFICATION LESSONS LEARNED

3.1.2.2 Mechanical interface. The equipment shall be designed to be ________ mounted. Mounting interface details and tolerances shall be in accordance with ________.

REQUIREMENT RATIONALE (3.1.2.2)

Mechanical interface must be defined to assure compatibility.

REQUIREMENT GUIDANCE

Any mounting details which are known should be inserted. "Hard" mounting (no shock mounts) is generally required for avionics units which can be designed to tolerate the vibration and shock environment.

REQUIREMENT LESSONS LEARNED

4.1.2.2 Verification of mechanical interface. Inspection and ________ shall be used to verify compliance.

VERIFICATION RATIONALE (4.1.2.2)

Interface must be verified by analysis and demonstration for installation and interchangeability of units in the aircraft.

VERIFICATION GUIDANCE

A dimensional tolerance analysis comparing the two sides of the interface may be required for complicated or precision interfaces. System integration and flight tests are the ultimate test of the interface and are often adequate by themselves to verify compliance.

VERIFICATION LESSONS LEARNED

3.1.2.3 Cooling. The equipment shall be cooled by ________.

REQUIREMENT RATIONALE (3.1.2.3)

Cooling method must be established.

REQUIREMENT GUIDANCE

Free convection cooling is preferred where low dissipation and adequate ambient air make it practical. When forced air cooling is available, better reliability and lower equipment cost can generally be achieved by using it, and information on temperature, pressure, flow rate, interface hardware and contamination limits should be inserted in the specification. Use of internal fans or conductive heat transfer to the mounting base is also appropriate in some situations. Requirement 52 of MIL-STD-454 prohibits blowing ambient air over electronics components, so most new avionics which use cooling air are "cold plate" designs. MIL-R-87155 should be consulted for additional guidance.

REQUIREMENTS LESSONS LEARNED

4.1.2.3 Verification of cooling. Compliance with the cooling requirements shall be verified by ___________.

VERIFICATION RATIONALE (4.1.2.3)

Compliance with cooling requirements must be verified, usually by test.

VERIFICATION GUIDANCE

Cooling provisions should be simulated during temperature-altitude tests. Separate cooling air tests are generally performed on forced-air-cooled equipment to measure flow rate, pressure drop, and susceptibility to dirt and water contamination.

It is important to account for any special cooling apparatus in tests demonstrating compliance with cooling requirements. If the display needs a fan, for example, to meet the cooling requirements, it is important that all acceptance tests be run with the fan in operation and that any fan failures be counted as relevant failures.

VERIFICATION LESSONS LEARNED

3.1.2.4 Display recording interface. The equipment shall provide the following interface for cockpit TV video recording ___________.

REQUIREMENT RATIONALE (3.1.2.4)

Most HUD's must interface with a cockpit TV camera to provide a recording capability.

REQUIREMENT GUIDANCE

The Cockpit TV System (CTVS) is currently the standard camera for Air Force use. Most HUD's provide a CTVS mounting surface which must be specified. For a HUD using conventional refractive optics, the CTVS is mounted aft of the combiner where it "sees" all HUD symbology as well as the outside scene. In HUD's which use a diffraction optics combiner, the CTVS is mounted forward of the combiner and the symbology is electronically overlayed.

REQUIREMENT LESSONS LEARNED

4.1.2.4 **Verification of display recording interface.** Compliance shall be verified by ____________.

VERIFICATION RATIONALE (4.1.2.4)

Proper camera interface must be verified to assure adequate video recording.

VERIFICATION GUIDANCE

Mechanical or electrical tests or inspections should be specified, depending on the type of interface.

VERIFICATION LESSONS LEARNED

3.2.1 **Performance.** The following performance requirements shall be met under the full range of environmental conditions specified herein except _________.

REQUIREMENT RATIONALE (3.2.1)

The conditions under which performance requirements are to be met must be defined.

REQUIREMENT GUIDANCE

Performance requirements are generally met over the full range of environments specified, except degraded performance may be allowed during gunfire vibration. Other exceptions are sometimes appropriate, such as allowing deviations from full accuracy during the first 5 to 15 minutes after turning on at cold temperature extremes. If MIL-E-5400 references are used, the equipment class and category must be specified using the definitions in MIL-E-5400.

REQUIREMENT LESSONS LEARNED

4.2.1 **Verification of performance.** Compliance shall be verified as specified herein.

VERIFICATION RATIONALE (4.2.1)

Performance requirements must be verified over appropriate environmental conditions.

VERIFICATION GUIDANCE

Compliance can be verified by evaluation of test plans and procedures.

VERIFICATION LESSONS LEARNED

3.2.1.1 Redundancy. The display system shall provide redundant features or redundant units such that _________ in the event of any single-point failure.

REQUIREMENT RATIONALE (3.2.1.1)

If not properly designed, integrated electronic systems used for collection and presentation of data can have catastrophic failures caused by a single-point electronics failure. Redundancy of data paths and/or hardware is required to provide a safe and reliable system.

REQUIREMENT GUIDANCE

It should be possible to complete a mission with a single-point failure. This is often possible with a reasonably small amount of redundant hardware and wiring if a degraded mode of operation is allowed. This may require workarounds, such as sharing a display, which increases workload. For flight critical information, a separate, independent system is generally required. For example, in the HH-60 display system at least two of the four CRT displays will continue to work and will be capable of displaying any sensor in the event of a single-point failure. There is also a set of electromechanical backup instruments which will provide adequate data for instrument flight even if all computers and displays fail.

REQUIREMENT LESSONS LEARNED

The need for a fail-operational or at least fail-safe design has always been recognized for primary flight displays. Fortunately, current improvements in electronic technology are making this easier to achieve.

4.2.1.1 Verification of redundancy. The display system redundancy requirements shall be verified by ___________.

VERIFICATION RATIONALE (4.2.1.1)

This requirement must be verified to insure that the system will operate adequately under failure conditions.

VERIFICATION GUIDANCE

Verification method will depend on the level of redundancy required and the criticality of the fail-operational performance. In some systems, simply disconnecting certain units or signals will be adequate to demonstrate the effects of failure. In a more complex or critical system, a failure mode effects analysis coupled with a thorough demonstration with a large number of simulated failures will be needed.

VERIFICATION LESSONS LEARNED

3.2.1.2 Lighting color. Displays and control panel lighting shall ________. Emitted light shall be compatible with ________.

REQUIREMENT RATIONALE (3.2.1.2)

Color of display presentations and panel lighting must be controlled for consistency and, in some cases, to insure compatibility with night vision goggles.

REQUIREMENT GUIDANCE

The appropriate panel lighting requirements should be inserted. For many existing Air Force aircraft, integrally illuminated panels, using white light in accordance with MIL-P-7788, are appropriate. MIL-L-85240, Lighting Equipment, Airborne, Interior and Exterior, should be used to develop the system lighting requirement; if it is, the display lighting paragraph should merely reference the system lighting requirement. On aircraft where the crew will use night vision goggles (NVG's), the spectrum of all emitted light must be closely controlled. The goal is to prevent excessive red and infrared light from the cockpit from being sensed by the NVG's, causing their sensitivity to the extremely dim outside scene to be reduced. On the HH-60, it was required that less than one percent of the CRT display's total light output would be in the spectral range beyond 600 nanometers (red and infrared). This is achievable with monochrome CRT's using P-43 phosphor and a narrow bandpass green filter.

The recently developed tri-service specification MIL-L-85762A, Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS), defines units for measuring energy which the NVGs are sensitive to ("NVIS Radiance" or NR) and specifies the color and NR content allowed for NVG crewstation equipment. There is also a NATO document (NAT-STD-3800) which defines a different set of NVG compatibility criteria.

Some systems have a requirement for "secure lighting". Secure lighting is designed to eliminate near-IR radiation (700-1100 nm) as far as possible and minimize radiation of visible light by making lights green (peak eye sensitivity), only using lights where required for the mission, and making lights dimmable. Secure lighting is important for systems which may be exposed to hostile ground troops who now use NVG's and other Image Intensification (I^2) devices.

REQUIREMENT LESSONS LEARNED

Lighting color tolerances of ± 0.02 x and y units (CIE 1931 color system) were used in the past but were restrictive, especially in the green part of the spectrum. The new colors defined in MIL-L-85762 for use in night vision compatible cockpits use larger tolerances (for example, a radius of 0.037 for NVG green in CIE 1976 u' v' coordinates). This tolerance is easier to meet, but allows colors which are different enough to be noticeable if they are physically close together and are reasonably bright.

4.2.1.2 Verification of lighting color. Compliance shall be verified by ________.

VERIFICATION RATIONALE (4.2.1.2)

Color of lighting must be verified to assure that it is uniform and aesthetically pleasing, and in some cases to assure that it is compatible with night vision imaging systems.

VERIFICATION GUIDANCE

Radiometric measurements are normally taken to verify compliance. Additional guidance is contained in MIL-L-85240, MIL-L-85762, and in MIL-P-7788.

VERIFICATION LESSONS LEARNED

3.2.1.3 Symbology. The equipment shall be capable of displaying each of the symbols shown and described in __________. All symbols shall be limited to the viewable display area. Symbols at the edge of the display area shall not be distorted and shall not "wraparound" to the opposite side. The equipment shall simultaneously display symbols in each of its modes as follows: _______________.

REQUIREMENT RATIONALE (3.2.1.3)

For equipment which generates and displays symbology, the symbology characteristics must be specified.

REQUIREMENT GUIDANCE

An appropriate symbology set must be established and documented, usually in a series of figures within the specification. MIL-STD-1787, Aircraft Display Symbology, should be used as far as possible for fixed wing aircraft. Symbols used in existing systems should be used as far as possible, with consistent meanings, since this minimizes retraining and can prevent fatal confusion in emergencies. Additional guidance may be found in old standards MIL-STD-884 and MIL-STD-1295 (helicopter).

REQUIREMENT LESSONS LEARNED

Current trends in electronics have made it generally easy to build symbol generators to be programmable; therefore, it is often not necessary to accurately describe symbol shapes and details before equipment design. The advantage of trying to define the symbol set early is that it allows a reasonable estimate of the number and complexity of the symbols to be made, which is essential to the person attempting to size the symbol generator and make an accurate proposal. Once a symbol set has been chosen, changes to it will generally affect memory and processing requirements on a stroke-by-stroke basis rather than symbol-by-symbol.

While many existing systems have a separate symbol generator unit, some have the symbol storage and/or generation built into the display unit or the central computer. If this can be done without creating complex interfaces or excessively large boxes, it can reduce the total amount of hardware.

People seem to enjoy inventing symbols and will often come up with new and unique symbols if given the chance. The documentation and training problems created by this can be spectacular, so it is essential that the symbol set be based on existing standards and systems.

Symbols that are calculated using backup or reversionary sources (such as calculating the velocity vector from air data when inertial data input is lost should be clearly indicated to the pilot.

Symbols that are incorrectly positioned because of field of view (FOV) limitations should be clearly indicated to the pilot. Particular care should be taken so that two symbols which are positioned relative to each other do not change this relationship when placed at or near the limit of the FOV. An example would be a flight director and the velocity vector symbols on a HUD. When the velocity vector is limited by the FOV limit, this should not affect the position of the director steering symbol relative to the velocity vector. This might be accomplished by limiting the velocity vector slightly inside the FOV limit so the director could move around it.

The use of flashing symbols to indicate degraded or FOV-limited data is not acceptable by itself. Flashing symbols are discouraged except where it is intended to annoy, such as a breakaway cross.

HUD symbology must be "compatible" with the head-down display (HDD) information.

Symbols that can be deleted by declutter should have a secondary warning when they are deleted because of faulty data. An example might be the annunciation "DATA DELETED" somewhere in the FOV if such a symbol is deleted because of invalid data.

4.2.1.3 Verification of symbology. Capability to display each of the required symbols shall be visually checked. Details on symbol dimensions and tolerances shall be verified by analysis, visual inspection, and measurement of a representative sample (see 4.2.1.3.1).

VERIFICATION RATIONALE (4.2.1.3)

Proper symbology capabilities must be verified.

VERIFICATION GUIDANCE

Visual checks and symbol measurements are usually used for verification.

VERIFICATION LESSONS LEARNED

3.2.1.3.1 Symbol size and movement. Alphanumeric symbols shall be at least _____ cm high by _____ cm wide. The symbology shall be capable of a minimum displacement of __________.

REQUIREMENT RATIONALE (3.2.1.3.1)

Minimum size of symbols is specified to insure readability under all conditions. Minimum line movement must be specified to assure that symbols appear to move smoothly.

REQUIREMENT GUIDANCE

The following size/resolution relationships should be met. They are based on numerous human factors studies and the need to achieve fast, accurate reading under a variety of ambient and stress conditions. Note: 60 minutes of arc = one degree, 17.45 milliradians (mr) = one degree, 3.44 minutes of arc = 1 mr. Size in degrees = arctan(symbol size/viewing distance).

a. Stationary or nonrotating raster alphanumeric symbols shall subtend a minimum of 16 minutes of arc and consist of a minimum of 16 scanning lines of symbol height and 12 horizontal resolution elements for symbol width .

b. Raster alphanumeric symbols oriented other than vertically, and other video shapes shall subtend a minimum of 22 minutes of arc and consist of a minimum of 20 horizontal scanning lines for symbol height and 20 horizontal resolution elements for symbol width. This does not apply to raster symbols such as small circles, tick marks, scales, and indices that are in compliance with the symbology requirement.

c. Stroke-written alphanumeric symbols should subtend a minimum of 16 minutes of arc.

d. Stroke-written alphanumeric symbols on a HUD should subtend a minimum of 24 minutes of arc vertically and 14 minutes of arc horizontally.

e. Color symbols must be larger if color coding is important. Studies have shown the need for larger symbols (up to 45 minutes of arc for alphanumerics) to allow color identification from among six possible colors.

Design eye for most cockpit designs is normally around 71 cm (28 inches) to primary flight displays. At that distance the size of an alphanumeric 16 minutes of arc in height and 12 minutes in width will be 0.33 x 0.26 cm. If 16 horizontal scan lines are required for a raster symbol then the display will require 48 lines per cm if the smallest acceptable symbols are chosen.

One system which was well accepted by pilots used 875-line (808 active lines) alphanumerics and symbology overlayed on sensor video on a 17-cm (6.8-inch) square CRT. Alphanumerics were 26 raster lines high (approximately 0.5 cm or 0.2 inch high) and subtended 23 minutes of arc at the normal viewing distance.

A minimum increment of movement of 1/2 line width has been used for a HUD. Increments this small or smaller will allow symbols to appear to move smoothly. Raster symbology generators normally store symbol information in a memory matrix map of pixels (for example 512 x 512 for 525-line video, 808 x 808 for 875-line video or 512 x 1024 for high resolution 525-line video), and each pixel represents the minimum line movement. Text-type alphanumerics (those that do not rotate or move around the screen with the symbols) are often constrained to appear only in fixed "character cells" and need not meet the minimum movement criteria.

REQUIREMENT LESSONS LEARNED

Raster alphanumerics and symbology having horizontal lines only one raster line thick will flicker noticeably in a conventional 30-frame/60-field per second interlaced raster. This problem can be reduced by making all lines at least two raster lines thick, or using a 60-hz non-interlaced format. A non-interlaced format will allow the use of pixels only one raster line high, allowing thinner lines to be drawn, but requires twice the video band width, and makes the video incompatible with standard monitors and VCR's.

4.2.1.3.1 Verification of symbol size and movement. Symbol size and minimum line movement capability shall be verified by measurement or design audit.

VERIFICATION RATIONALE (4.2.1.3.1)

Symbol size and minimum movement must be verified to assure that symbols are easily readable and move smoothly.

VERIFICATION GUIDANCE

On head-down displays, such as CRT's, it is generally easy to make approximate measurements of symbols on the display with an ordinary ruler. Where parallax errors are large (due to a thick faceplate) or accurate measurement of small detail is required, an inspection microscope with a built-in scale can give much better accuracy. For a HUD, a theodolite (a telescope with reticle and calibrated pivot base, like a surveyor's transit) is used. It is not necessary to measure symbols if their size can be verified from other fixed characteristics, such as the number of raster lines per symbol height or a fixed array of pixels.

VERIFICATION LESSONS LEARNED

Symbol dimensions can be verified by analysis and one-time gain measurements. Current symbol generators use digital techniques and precision digital-to-analog converters to generate accurate deflection and video waveforms for symbology. If the symbol is programmed correctly, and all analog gains are correct, the symbol will be displayed correctly. If the gains are incorrect, all the symbols will be the wrong size, so measurement of a known vector in X and Y for accuracy and comparison with the rest of the screen is adequate.

3.2.1.3.2 Symbology freeze. The symbology shall not lock up or freeze when sensor parameters are changing except in special cases where a symbol is intentionally frozen. If a lockup or freeze occurs, that symbol shall be __________.

REQUIREMENT RATIONALE (3.2.1.3.2)

Important flight symbols must never be allowed to freeze, since this might provide false and unsafe information to the pilot.

REQUIREMENT GUIDANCE

Most specifications require that symbols be removed from the display, rather than be allowed to freeze; this forces the pilot to get his information from another instrument, rather than use incorrect information. Some systems only remove part of the symbol, such as the alphanumerics on airspeed and altitude scales, to indicate that they are incorrect.

REQUIREMENT LESSONS LEARNED

Given the requirement to remove "locked" symbols, most designs have used symbol generation schemes which inherently provide for erasure of symbols at a regular interval (should be less than 1 second), unless they are updated by current data.

4.2.1.3.2 Verification of symbology freeze. __________ shall be used to determine compliance.

VERIFICATION RATIONALE (4.2.1.3.2)

Prevention of symbol freeze must be verified for safety.

VERIFICATION GUIDANCE

Equipment demonstration, with input data removed or internal faults introduced, is usually appropriate to determine compliance. Since this function is usually implemented in software in new systems, it may be appropriate to audit the software to verify that appropriate steps have been taken.

VERIFICATION LESSONS LEARNED

3.2.1.3.3 Symbol line width. The symbol line width shall be ________ when measured at the 50 percent intensity points with symbol luminance set at _______ cd/m^2.

REQUIREMENT RATIONALE (3.2.1.3.3)

Symbol line width must be wide enough to make symbols easily visible, but narrow enough to produce clean-looking symbols.

REQUIREMENT GUIDANCE

Line width specification of 1 mr at 3400 cd/m^2 (1000 fL) has been used for HUD's with good results. Another HUD required that the stroke width be between 0.12 and 0.2 times the symbol height and that stroke width be 1 ± 0.2 mr measured at the 1/e (37%) intensity point and at 3400 cd/m^2 (1000 fL) luminance. Assuming a Gaussian spot profile, the width at 1/e is 1.2 times the width at 50%. Line width should be specified and measured based on the 50% amplitude point, since this is common practice and easiest to measure. However, this is an indirect control of line width as seen by the eye; the eye will see the line width near the 5% point.

REQUIREMENT LESSONS LEARNED

HUD's which display raster video (for night use) have had difficulty meeting a video resolution requirement (requiring a small spot size) and the minimum stroke symbol line width (which requires a larger spot size). These two requirements must be made compatible, otherwise "tricks" such as defocussing the spot in stroke mode will be required. Precisely controlling and measuring line width is difficult, and since line widths from 0.5 to 1.5 mr are visually acceptable, a wider tolerance such as 1 +0.5 mr may be appropriate.

4.2.1.3.3 **Verification of symbol line width.** Symbol line width shall be measured.

VERIFICATION RATIONALE (4.2.1.3.3)

Symbol line width must be verified to assure that symbols are clearly visible and aesthetically pleasing.

VERIFICATION GUIDANCE

The usual method of measuring line width is to electronically move the line on the HUD past the slit in a slit-aperature photometer.

VERIFICATION LESSONS LEARNED

3.2.1.3.4 **Primary symbology checking.** Primary symbology consists of altitude, airspeed, pitch, roll, heading, vertical velocity, velocity vector (flight path marker); horizon line, and ________. When incoming data or processing that affects the primary symbology is identified as invalid (for example, a fail indication from a self-test), the affected primary symbology shall be removed from the display. The processor shall check the information (incoming data) needed to generate the primary symbology to determine if it is reasonable with respect to the physical aircraft parameters (rate of change, maximum value, minimum value, period between change, etc.). The equipment shall also cross-check related data for predetermined difference if more than one source is available. If the incoming data isn't reasonable or doesn't fall within the predetermined differences, then the symbology associated with the data shall ________.

REQUIREMENT RATIONALE (3.2.1.3.4)

Primary flight symbology must be checked for accuracy, since it is critical to safety.

REQUIREMENT GUIDANCE

This requirement applies to any display which is designated as a primary flight instrument or is likely to be used as such. In the past, HUD's were generally not designated as primary flight instruments. But pilots tend to use the HUD symbology as if it were their primary instruments, so the accuracy of that symbology becomes critical to flight safety. The requirement to remove defective or "locked-up" symbols has been used on several HUD's. Checking for reasonable values and cross-checking between data sources has only been required in special cases.

REQUIREMENT LESSONS LEARNED

Criteria for accepting an electronic display as the primary flight display have not been well documented. (For further discussion, see "Criteria to be Considered for Approving the Head Up Display as the Primary Flight Control Instrument", paper by William Augustine et al, WPAFB, 15 Dec 1986.)

4.2.1.3.4 **Verification of primary symbology checking.** ___________ shall be used to verify that primary flight symbology is checked and presented properly.

VERIFICATION RATIONALE (4.2.1.3.4)

Symbology must be checked for safety.

VERIFICATION GUIDANCE

Verification of a fault-checking system's capabilities can get very involved. The verification should include insertion of faults or incorrect data bits to demonstrate appropriate removal of symbols. If an extensive software validation is being performed, some of the functions may be verified by analysis. If the display is to be certified as a primary flight instrument, the test and validation will have to be very thorough to insure safe operation.

VERIFICATION LESSONS LEARNED

3.2.1.4 Display modes. The equipment shall provide the following modes of operation: ___________.

REQUIREMENT RATIONALE (3.2.1.4)

Display modes must be specified to assure that the display performs all of its desired functions.

REQUIREMENT GUIDANCE

Description of display modes should come out of system design and configuration studies. For example, a HUD might have a landing mode, a navigation mode, two or three weapon delivery modes, and a built-in test mode. An integrated control and display unit (ICDU) might have navigation, communication, system status, and built-in-test modes.

REQUIREMENT LESSONS LEARNED

4.2.1.4 Verification of display modes. Operation in all display modes shall be demonstrated.

VERIFICATION RATIONALE (4.2.1.4)

Proper operation of equipment modes can be verified by a demonstration.

VERIFICATION GUIDANCE

A demonstration can show that each of the equipment modes functions as required.

VERIFICATION LESSONS LEARNED

A system integration lab or "hotbench" is an excellent means of evaluating whether the display modes are adequate for the mission. The KC-135 fuel savings advisory/cockpit avionics system (FSA/CAS) ICDU paging scheme and operator interface was thoroughly exercised and debugged on a hot bench throughout its development. The testing was accomplished using ASD engineering and SAC tanker crews, and resulted in identification and correction of software design flaws early in the program.

3.2.1.5 Video resolution. The vertical resolution shall be sufficient to produce ten percent minimum modulation when one half of the scan lines are "on" while operating in ____________ raster format. The horizontal resolution shall be ____________ TV lines per picture height (see section 6) minimum with a 10-percent line modulation. These requirements are to be met while simultaneously meeting the contrast, luminance, and ambient requirements of 3.2.1.6.

REQUIREMENT RATIONALE (3.2.1.5)

The visibility of the symbols and video drives the resolution and the display size. This paragraph applies to CRT displays; for a flat panel matrix display, a statement of the number of pixels, pixel spacing, and pixel shape may be appropriate. A separate specification of line width in addition to resolution requirements on CRT displays is redundant, unless the CRT is also used for stroke-written formats (see 3.2.1.3.3). Resolution patterns are seen by the eye in a manner directly analogous to the resolution measurement.

REQUIREMENT GUIDANCE

The raster format of the display must be compatible with the system, and will generally be one of the accepted standards (525-line, 485 active or 875-line, 809 active). The number of active raster lines is generally the limiting factor in vertical resolution. The useful vertical resolution on analog video can be obtained by multiplying the number of active raster lines by the Kell factor, which is normally accepted to be 0.7. The Kell factor accounts for the fact that raster lines represent a "sampling" of the actual analog image. *The Kell factor does not apply to information which is digitally inserted on raster lines.*

An ideal raster should have the vertical spot size (at 50% point) equal to or a little smaller than the raster line spacing, since this will produce very little vertical modulation with all the raster lines turned on, but will produce a noticeably dark line when one line is turned off. Thus the typical requirement would be to present ten percent modulation with one half the raster lines turned on and the alternate ones turned off.

Horizontal resolution is normally specified in "lines", which is short for "TV lines per picture height", and should not be confused with the number of raster lines. "TV lines per picture height" are the accepted units for CRT horizontal resolution (see EIA-RS-170). Resolution is sometimes specified in line pairs per cm (or per inch). Since one "line pair" is the same as two "TV lines", line pairs per cm can be converted to "TV lines per picture height" by multiplying line pairs per cm by two times the picture height. Note that for a 4:3 aspect ratio display (normal rectangular TV), this means the number of lines per inch is multiplied by the (smaller) vertical screen dimension to get "TV lines per picture height".

It is common practice to specify resolution at a 10 percent contrast modulation point. This is actually just one point on the contrast transfer function (CTF) curve. The CTF curve is a plot of contrast modulation measured on the CRT versus spatial frequency (resolution). CTF is measured using a square wave input waveform. A similar measurement, modulation transfer function (MTF), uses a sine wave input. CTF and MTF can be related, using Fourier analysis, but the easiest approach is to use square waves and keep everything in terms of CTF. A typical display unit CTF curve approaches 100 percent modulation (100 x C_m, see section 6) at low spatial frequencies , then gradually rolls off at higher frequencies and passes through the 10 percent contrast modulation point at the specified resolution. An ideal CTF curve would remain high out to the frequency of the highest spatial frequency in the image and then roll off sharply to reject high frequency noise. Therefore it is best to specify several points on the CTF curve, requiring high modulation capabilities at the low and medium spatial frequencies and 10 percent modulation at the stated resolution. This is normally difficult to do because of the general lack of data on the required shape of the curve and lack of data on what curve is achievable by current displays. An alternative would be to specify resolution at lower frequencies, but require higher modulation; for example, 70 percent modulation at 400 lines rather than 10 percent modulation at 800 lines. This philosophy has never caught on in practice since it makes the stated resolution of a system a lower, less impressive number.

For highly dynamic scenes, such as might occur on a helmet mounted display, a valuable extension to CTF is the concept of dynamic CTF. It measures contrast transfer as a function of image motion (fraction of subtense moved per second) and allows one to analyze and compare smearing/blurring caused by various lags, persistances, and frame rates.

Some criteria used to establish the horizontal resolution requirement are as follows:

a. Display resolution should be better than the best sensor being used in the system to prevent the display from seriously limiting system performance. For example, for a FLIR providing resolution of 400 TV lines per picture height, the display should have resolution (at 10 percent modulation) 20 to 50 percent better than this to insure that it will provide good modulation at the frequencies contained in the FLIR video. Note that a display whose CTF is less than unity at any spatial frequency where the sensor's CTF is not zero will reduce the system CTF.

b. Display resolution must meet or exceed the criteria for number of lines per symbol height and width for symbology and alphanumerics (see symbology paragraph herein).

c. Horizontal resolution must not be specified so high as to cause gaps between raster lines (due to small spot size). Tricks, such as using a CRT spot which is elongated in the vertical axis or is "wobbled" vertically while it scans horizontally, have been devised to overcome this problem. This should only be necessary in a display which operates over a wide range of line rates. To require a horizontal resolution significantly greater than the number of active raster lines serves no practical purpose, since the resolution of most sensors is no better in the horizontal axis than in the vertical.

d. Horizontal resolution should not be specified much higher than the human eye's ability to resolve. Normal visual acuity ranges from about 30 to 60 cycles per degree under varying brightness and contrast conditions, but rarely exceeds 40 cycles per degree outside the laboratory conditions. This leads to a maximum useful display resolution under good viewing conditions of approximately 67 lines per cm (170 lines or 85 cycles per inch) at a normal 76 cm (30 inch) viewing distance. The useful display resolution under inflight conditions will actually be somewhat less than this due to vibration, stress, low brightness and contrast, etc. A display with high modulation at this frequency would provide the sharpest detail resolvable by the eye. Current display technologies or sensors rarely achieve this.

Examples of specified resolution on some existing equipment are as follows: (some are based on limiting resolution rather than 10 percent modulation.)

Commercial VHS VCR	280
NTSC TV	350
Super 8 movie film	350
5-inch color CRT (.21 mm pitch shadow mask)	500
Common module FLIR	480
16 mm film	600
19-inch Sony lab monitor	650
F-111 AMP 4-inch CRT display	800
Remote map reader (875-line)	500
HH-60 6.8-inch x 6.8-inch CRT (875-line)	808
35 mm film	1300

REQUIREMENT LESSONS LEARNED

4.2.1.5 Verification of video resolution. Vertical and horizontal resolution shall be measured with a scanning slit photometer, with the display adjusted to meet the luminance and contrast requirements herein, all in the presence of a __________ lm/m^2 ambient. Contrast modulation may be measured in the dark and mathematically corrected for ambient illumination effects if the results can be demonstrated to be equivalent. Contrast modulation is defined as $(L_t - L_b)/(L_t + L_b)$. The test shall be performed using a square wave video signal, and using a measurement aperture no greater than 20% of the display's linewidth.

VERIFICATION RATIONALE (4.2.1.5)

Resolution must be verified; there are numerous testing methods which can be used, and results are generally different depending on the one used, so one common, repeatable test is defined here.

VERIFICATION GUIDANCE

At the specified resolution, the display should provide a minimum of 10% contrast modulation, both horizontally and vertically when measured with the scanning photometer technique. This test must be done on a bright patch of video (meeting the luminance and contrast requirements herein, under worst case lighting conditions) to be representative of display performance under these conditions. There has been no consistent application of this rule in the past, which helps to explain some of the great variation in specified resolution among displays. In some cases it may be necessary to also specify resolution in a dark ambient to satisfy everyone's desire for a large, impressive display resolution number.

It can be very difficult to measure the resolution in the specified high ambient conditions, since the photometer must normally be very close to the display and will cause shadows. Therefore, it is acceptable to measure symbols, background, and reflected ambient seperately, then analytically find the modulation at high ambient.

This test is done with a photometer equipped with a small slit (typically 0.4 x 10 minutes of arc), or a very small aperture and a scanning device, which can either be part of the photometer or a translating table. The photometer can be connected to an X-Y plotter to give an output record, a plot of luminance versus position on the screen. Contrast modulation (C_m) is defined as the (max - min) / (max + min), multiplied by 100 to get percent. The input signal is assumed to be 100% modulated, ie, the white level is the "peak video voltage" the display specification or interface calls for and the black level is the specified black level, so there is no need to divide by the input modulation when calculating the contrast transfer function.

Accurate, repeatable resolution tests for patterned-screen CRT's (shadow mask or beam index) are not in general use. While the scanning slit test might be useful at low resolutions on these CRT's, airborne color CRT's are often designed to approach the resolution limit of the color pattern. In this case the CTF data would be good at low frequencies, but would show extreme fluctuations at resolutions near the color pattern pitch. A practical work-around to this has been to specify size of the color pattern (typically 0.3 or 0.2 mm triad pitch for high resolution shadow mask CRT's) and the line width. The line width must then be measured, generally by slowly sweeping a line across the screen and measuring its profile with a photometer. The photometer must have a small enough aperature to be focussed on one phosphor dot and exclude light from other dots.

VERIFICATION LESSONS LEARNED

Measurement of resolution on video which is bright enough to also meet the luminance and contrast requirements is a severe test for a CRT, especially in a full sunshine environment (see 3.2.1.6).

3.2.1.6 Display luminance and contrast. The following luminance and contrast ($[L_t - L_b]/L_b$) requirements shall be met when measured from the design eye position. Luminance shall not degrade more than ___________ percent when measured from anywhere within ___________ cm of the design eye position. The display luminance and contrast shall not change more than ± __________ percent when changing modes. No random bright flashes shall occur during mode switching.

REQUIREMENT RATIONALE (3.2.1.6)

Display viewability with appropriate head motion and mode switching is essential to display usefulness.

REQUIREMENT GUIDANCE

Head motion requirements are important where diffraction optics and/or directional filters are used, since there is generally a one-to-one tradeoff between luminance performance and amount of allowable eye motion. Twenty-five percent maximum luminance degradation within 2 cm of the design eye position has been specified for a HUD; this appears to be a bare minimum. Luminance change associated with mode changes should not exceed 40 percent. For some instruments and displays, it has been required that all information remain readable at any viewing angle up to 30° with respect to a line normal to the display for a complete 360° revolution around the normal line.

REQUIREMENT LESSONS LEARNED

4.2.1.6 Verification of display luminance and contrast. Display luminance and contrast shall be measured by ____________.

VERIFICATION RATIONALE (4.2.1.6)

Luminance, contrast, and luminance degradation must be measured to assure display usefulness.

VERIFICATION GUIDANCE

A spot photometer should be used to measure luminance of the various shades of gray, from each of the eye positions defined. Contrast can then be calculated, using the definition in section 6. Chromaticity measurements must be taken with a spectroradiometer.

VERIFICATION LESSONS LEARNED

3.2.1.6.1 HUD stroke-written line luminance. The luminance of all stroke-written symbols shall be such that projected images are clearly defined when superimposed on a background luminance of 34,000 cd/m^2 (10,000 footlamberts) and color temperature of 3000 to 5000 Kelvin. The average line luminance over the total symbol area shall be a minimum of ___ cd/m^2 with a design goal of __________ cd/m^2 when viewed through the HUD combiner glass. The contrast ($[L_t - L_b]/L_b$) of the symbology with a 35,000 cd/m^2 ambient background shall be a minimum of _________ with a design goal of 0.5.

REQUIREMENT RATIONALE (3.2.1.6.1)

HUD brightness is critical for performance in sunshine.

REQUIREMENT GUIDANCE

This requirement applies only to HUD's. Line brightness of 5440 cd/m^2 (1600 foot-lamberts) and contrast of 0.2 (contrast ratio of 1.2:1) is quite feasible and provides symbols viewable in full sunshine. Design goals of 170 00 cd/m^2 (5000 footlamberts) and contrast of 0.5 would provide more comfortable viewing in very bright conditions.

REQUIREMENT LESSONS LEARNED

Symbol brightness is achieved at the cost of other parameters such as CRT life and combiner see-through clarity. Tests have shown that there is a definite reduction in CRT life expectancy when operated at very high luminances. It is important to verify that this reduction in CRT life can be tolerated.

4.2.1.6.1 The requirements of 4.2.1.6 apply.

3.2.1.6.2 HUD raster luminance. The raster video luminance shall be such that _________ shades of gray (____ steps, ____ levels) are visible against a ___________ cd/m^2 background luminance with an equivalent color temperature of 3000 to 5000 Kelvin. The contrast ($[L_t - L_b]/L_b$) of the peak raster video with a _________ cd/m^2 ambient background shall be a minimum of _________. The ratio between adjacent gray shades shall be a minimum of 1.4:1 (contrast of 0.4).

REQUIREMENT RATIONALE (3.2.1.6.2)

This requirement is needed (on HUD's with video) to assure that HUD video is visible against appropriate background brightnesses.

REQUIREMENT GUIDANCE

Visibility of 6 shades of gray against a 170 cd/m^2 (50 footlamberts) background with a contrast of 7.0 has been demonstrated. This is not bright enough for viewability in full sunshine. Note that the number of steps is one less than the number of levels or shades.

REQUIREMENT LESSONS LEARNED

There may be systems that would benefit from a full sunshine HUD video capability, but current technology makes this difficult to achieve in a practical design.

4.2.1.6.2 The requirements of 4.2.1.6 apply.

3.2.1.6.3 MFD luminance and contrast. The luminance and contrast of all displayed data shall be adequate for easy visibility in illumination environments from _______ to _______. The following contrast requirements shall be met in a combined environment consisting of _____ lux (____ fc) diffuse illumination and the specularly reflected image of a ____ cd/m^2 (____ fL) glare source. The contrast ($[L_t - L_b]/L_b$) of stroke-written symbols shall be _____ minimum. The display shall be capable of presenting a minimum of _____ shades of gray (____-1 steps) and the overall contrast of raster video shall be _____ minimum. The ratio between adjacent gray shades shall be a minimum of 1.4:1 (contrast of 0.4). The difference luminance (ΔL) between the brightest image and the dimmest in this environment shall be at least ____ cd/m^2 (____ fL.). The minimum contrast and shades of gray requirements above shall also be met in any less bright environment. The contrast between an "off" element and its background shall be less than ______.

REQUIREMENT RATIONALE (3.2.1.6.3)

This requirement is needed to assure that stroke-written symbols and/or raster video on head down displays is visible in appropriate lighting environments. It includes a dual (specular and diffuse) lighting environment to simulate lighting in the real world and avoid some of the disparity which has existed between test results and real experience. The illumination and glare source luminance are left as blanks, since they vary for different aircraft types, as discussed below. The difference luminance capability of the display is specified in order to limit the shift in luminance which an operator experiences when shifting his gaze from the surroundings to the display and also to overcome veiling glare which occurs when high luminance levels (eg. white clouds, sun, etc.) are in the operator's field of view.

REQUIREMENT GUIDANCE

This requirement should be applied to all head-down or panel displays. It addresses only luminance contrast; evaluation of color difference on multi-color displays should be based on the "color difference" paragraph herein. The first sentence should be filled in with a generic description of the lighting environment, for example, "full sunshine to full darkness" for a fighter cockpit.

The combined diffuse and specular environment described herein has not been widely used in the past. The use of diffuse-only tests in the past appears to account for some of the variation in test results for different devices and general disagreement on what contrast values are acceptable. Since both the specular component and the diffuse component affect readability, testing to one or the other is often inadequate. Note that a diffuse ambient illumination level falling on a display should always be specified in units of illumination (lux, lm/m^2, or fc) while light radiating from a surface, such as the face of a CRT or a reflective surface should be in luminance units (nits, cd/m^2, or fL).

The following table contains suggested values for illumination and glare source luminance based on measurements taken in several aircraft cockpits. Note that the traditional fighter cockpit environment specification of 108 ,000 lux (10,000 fc) diffuse illumination has a 6,800 cd/m^2 (2000 fL) glare source added to it. The glare source represents objects such as the pilot's helmet or flight suit, illuminated by sunshine, being reflected in the display. Much brighter glare sources are possible, especially if the display is not optimally positioned in the cockpit. For example, if the face of a display is positioned at such an angle that, from the design eye point, the "angle of incidence = angle of reflectance" rule allows the pilot to see reflections of the sky, the glare source could be a white cloud at 34,000 cd/m^2 (10,000 fL) or even the sun itself (several million fL).

An 86,400-lux (8000-fc) diffuse illumination level may be adequate for instrument panel displays in some fighters. This is based on actual cockpit measurements in a T-38 and an F-16, which showed that the high illumination levels outside the cockpit are generally attenuated to less than this by passing through the canopy and hitting the instrument panel at oblique angles.

In the past, separate specification requirements for anti-reflection coatings on CRT faces prevented excessive specular reflections. This provided adequate results in many cases, but the desire in this document is to state the performance required (in terms of contrast in the presence of a glare source) without describing a specific design or presenting a solution that might only apply to CRT's.

TABLE I. Suggested requirements for illumination and glare source luminance.

	Bubble canopy	Cockpit with roof	Enclosed cabin
Diffuse illum.			
lux 108,000	108,000	86,000	540
foot candles	10,000	8,000	50
Glare source			
cd/m^2	6,800	6,800	3,400
foot Lamberts	2,000	2,000	1,000

NOTES: 1. The bubble canopy (fighter cockpit) environment assumes a bubble canopy and good display placement (ie, no specular reflection of the sky). Where specular reflections of the sky are a problem, such as on console-mounted lighted legend switches, the glare source should be increased to 34,000 cd/m^2 (10,000 fL).

2. The cockpit with roof (transport) environment assumes an opaque roof overhead, such that direct sun can only hit the display a small percentage of the time and only at large angles off axis.

3. The enclosed cabin environment is like an office: the glare sources are ceiling lights and small windows.

4. Sunshine at noon at high altitude can reach 154,440 lux (14,300 fc) or more. This table assumes the display is inside a canopy (typically less than 85% transmission) and the sun cannot hit the display within about 30 degrees of perpendicular.

The following table provides suggested contrast requirements based on a variety of human factors tests and practical experience with existing aircraft displays.

TABLE II. Suggested contrast requirements.

	Required contrast	Goal contrast	Contrast compensations for other character h and SW
Numbers only	≥ 1.5 for h = 0.2 inch and $0.12h \leq SW \leq 0.2h$	2–10	Multiply Required contrast by 0.2/h for $0.1 \leq h \leq 0.3$ and by 0.12h/SW for $0.01h \leq SW \leq 0.12h$
Alpha-numerics	≥ 2.0 for h = 0.2 inch and $0.12h \leq SW \leq 0.2h$	3–10	
Graphics and alpha-numerics	≥ 3.0		
Video	≥ 4.66	10–30	

NOTES:

1. h is character height, SW is character stroke width. Character height should never be less than 0.1 inch. This table assumes a 30-inch viewing distance.

2. The 4.66 overall contrast for video represents 6 shades of gray (5 steps), each a minimum of 1.41 times the next. At least eight 1.41:1 shades should be visible under other than worst-case illumination environments. This requirement has been applied to CRT's, with the understanding that a CRT is an analog device and it can actually produce an infinite number of shades between the ones specified. Systems which quantize the luminance levels must be able to produce a greater number of smaller shades, assuming the goal is to display video without objectionable contouring.

3. These minimums have been used in CRT display specifications when being tested in the high brightness environment, with the assumption that contrast will improve from the "minimum" to the "goal" range when in a less bright environment; this assumption may not be valid for a reflective device, such as an LCD or painted instrument. If this specification is being applied to devices other than CRT's, the worst-case environment for that device should be substituted.

4. These minimums have been met with current monochrome CRT's, but not necessarily with color devices.

5. For a display device where unlighted characters shouldn't be noticeable, the contrast between unlighted segments and the background (C_{ul}) should not exceed 0.1. C_{ul} – 0.25 may be acceptable where visible segments are not objectionable.

6. On hybrid (stroke and raster combined) CRT's, stroke-written symbols are normally brighter and higher contrast than raster symbols and video, due to inherent characteristics of CRT's. They are generally specified as having a higher contrast ratio (relative to black) than the video, with the understanding that they will be written over the video and may only achieve the minimum contrast there.

7. When raster symbols are written over video, they must be a shade of gray brighter then the video; otherwise it is difficult to achieve adequate contrast between the symbol and bright video. Enhancement techniques, such as blocking out surrounding video or shadowing (blocking out one pixel all around the symbol), may be required.

The performance goal is to limit the shift in luminance to about 20:1 when the operator looks from the display to the ambient and back. So far it has been possible to achieve about 100:1. To get a 100:1 value, specify a difference luminance (ΔL) of 340 cd/m^2 (100 fL) between the environment and the cockpit display at its brightest setting. When a display is located high in the cockpit, where the outside scene is in the eye's instantaneous field of view at the same time as the display, the problem of veiling glare also becomes severe, and this number should be increased to 680 cd/m^2 (200 fL). In an office or enclosed cabin environment, luminance difference of 50 fL is appropriate.

As with most other performance requirements, improvements in luminance and contrast can often be achieved only at the cost of other parameters (cost, reliability, resolution, etc.) in an equipment design.

REQUIREMENT LESSONS LEARNED

The need for high luminance output (difference luminance in displays used by an operator exposed to sunshine (even if the display is in a shadow) has not been widely recognized in specifications. This can be a real problem for devices like LCD's that have adequate contrast ratio but do not emit or reflect enough light to overcome veiling glare.

4.2.1.6.3 Verification of luminance and contrast. Display luminance and contrast shall be measured using the test setup shown in figure 1 and using the diffuse illumination and glare source luminance specified in section 3 herein. Light sources used shall have a color temperature between 3000 and 5000 Kelvins. The following measurements shall be taken and used to calculate the required contrast ($[L_t - L_b]/L_b$):

L_t, the total luminance of the image, or brighter area, including any background or reflected light.

L_b, the luminance of the background, or dimmer area, measured in the specified lighting conditions, including any reflected light and any stray display emissions.

ΔL, (delta luminance, or difference luminance) the difference between the higher luminance (L_t) and the lower luminance (L_b).

Measurements shall be taken with a photometer having a sensing aperture equivalent to at least 1.8 minutes of arc, as measured from the normal operator viewing distance. If luminances of smaller areas are measured, then a series of measurements shall be taken within an area equivalent to the 1.8 minute of arc area and the luminance of the active areas shall be averaged with the luminance of any inactive areas on an area-weighted basis.

On large displays, such as a CRT, measurements shall be taken at 5 positions distributed over 80% of the screen area and averaged.

If the dimensions of the image elements are large enough to permAit several nonoverlapping measurements to be made within the image element boundaries, multiple luminance readings shall be taken and averaged to establish the average element luminance.

If it can be demonstrated that ΔL does not change under varying lighting conditions, L_t can be calculated by measuring ΔL and L_b and adding them. If it can be demonstrated that equivalent results can be obtained by measuring in lower ambients (e.g., 54,000 lux rather than 108,000 lux), then scaling up the results, then the test may be done in the lower ambient.

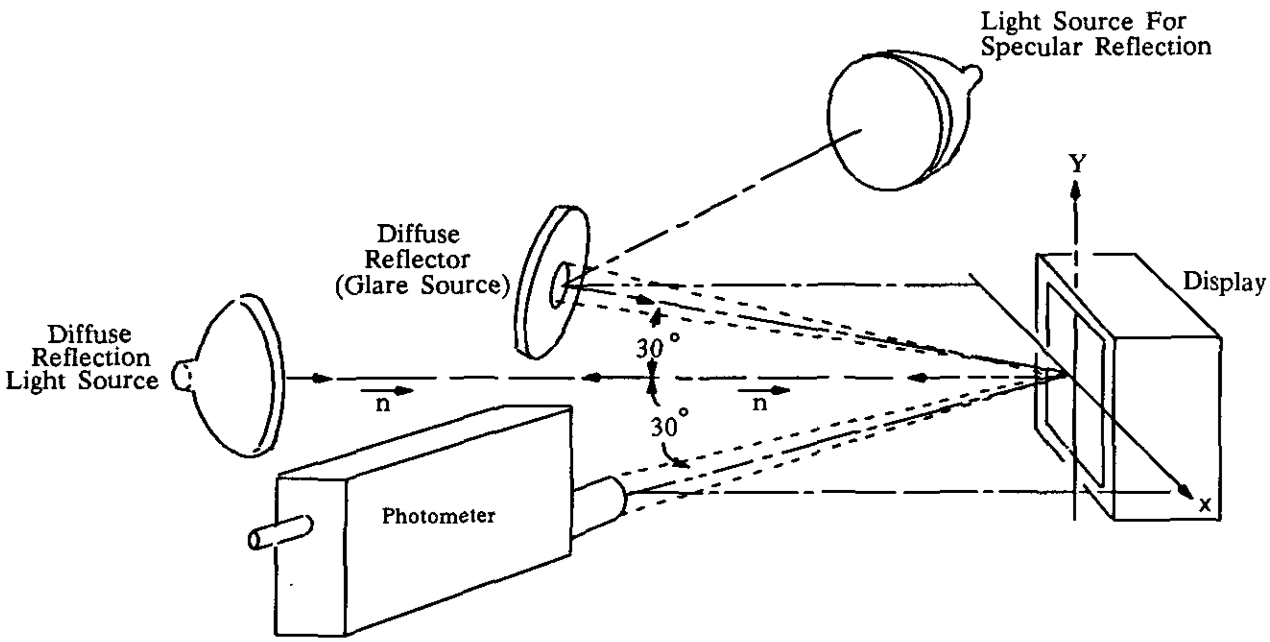

FIGURE 1. Combined specular and diffuse measurement setup.

Notes: 1. Luminance of the glare source is measured by putting a mirror 7 (preferably front-silvered) in place of the display and leaving the photometer focused at the display surface.

2. The diffuse ambient should be measured by substituting a diffuse surface of known reflectance for the display surface and measuring its luminance, then calculating the illumination level.

3. The diffuse and specular reflected light can be measured separately and summed or measurements can be taken directly with both light sources on at once.

4. Ordinary photo studio flood lights are not purely diffuse light sources, but are an acceptable approximation in this test.

5. Contrast shall not degrade more than 20% from specified values when measured at angles smaller than the 30 degrees shown in Figure 1, or when the diffuse reflected luminance is measured with the photometer and light source interchanged (that is, photometer on the axis of the display).

VERIFICATION RATIONALE

Contrast and luminance must be verified to assure good legibility. A specific test technique is described in an attempt to make the test results repeatable and consistent. This procedure is intended to give a good representation of real world lighting conditions without requiring the use of expensive or exotic equipment.

VERIFICATION GUIDANCE

This paragraph should be used intact whenever specific display unit luminance, contrast, and combined environment requirements are imposed in section 3 of the specification.

The test setup shown in figure 1 is designed to simulate a typical display installation. The photometer is near the display operator's normal viewing position, representing the operator's eye. The diffuse light source represents the sun and/or bright clouds illuminating the crewstation. The glare source represents objects in the crewstation, such as the operator's helmet or flight suit, (or, in some cases, the sky) which can be reflected directly back to the operator's eye.

The color temperature requirement on the light sources requires that the light be approximately white. Normal incandescent photo studio lights are the easiest to obtain and some of them meet this requirement. Fluorescent or arc lamps should not be used without careful analysis, since some of them radiate most of their light at one wavelength, which may or may not be close to the color of the "notch" filter used on many displays, and can therefore produce erroneous results.

Measurement of L_t and L_b is all that is necessary to calculate the contrast (as defined in paragraph 6.2 herein). ΔL is commonly measured and discussed in connection with CRT's, (it may be called by several other names) since it is simply the light being generated by the CRT, which doesn't change with different ambients. This quantity cannot be measured directly on a reflective-type display (for example, an LCD or painted instrument face), since the contrast on these displays is at least partially produced by selectively reflecting the ambient light. For CRT's, it is generally easier and more accurate to measure ΔL (with the lights turned off) and calculate L_t by adding this to L_b.

The photometer should measure an area at least as large as the area that the human eye normally averages over. Many spot photometers include a 2-minute-of-arc (1/30 degree) measurement setting which meets this requirement when the photometer is positioned at the normal viewing distance. This is important in any case where the surface being measured is not continuous. For example, the luminance inside the phosphor dots of a shadow mask CRT is much higher than the area-averaged luminance seen by a person (or a photometer with a 2-minute-of-arc measuring aperture).

Where character segments are being measured, non-uniformity within a segment can cause inconsistant measurements. In this case, several measurements should be taken and averaged to obtain an average reading.

The notes under figure 1 describe how the combined ambient lighting should be measured. While these techniques may not be as technically precise as putting the photometer in place of the display and taking measurements, they will be much easier and generally just as accurate in practice because they eliminate the need to move any of the test setup except the display. A typical test jig might provide a display support with rollers/tracks under it so the display can be slid back to permit the mirror and diffuse reflector to be accurately positioned in its place.

An ordinary photo studio floodlight is not really a diffuse light source, but in this test setup, with small off-axis angles, it is a reasonable approximation, and is probably more realistic because it more closely simulates direct sunshine mixed with diffuse light from clouds and sky. Use of a diffuse illuminating sphere may also be appropriate, but it does not allow independent adjustment of the specular and diffuse reflections, because when the photometer is positioned on-axis, it sees a specular reflection of its own lens, and when it is positioned off-axis, it sees a specular reflection of the internal surface of the sphere.

VERIFICATION LESSONS LEARNED

Numerous different (and often contradictory) measurement techniques have been used in attempts to specify and measure contrast. It has always been difficult to compare results for different display technologies, not only be cause of the different terminology and techniques, but because of the different display media. For example, minimum contrast requirements for CRT's are always specified in a high ambient, since this is the most difficult environment for them and they actually achieve much better contrast most of the time, in less severe environments. A person not realizing this might wonder why an LCD having the same specified contrast looks more "washed out" in normal room light.

3.2.1.6.4 Night brightness mode. The equipment shall provide a night brightness mode as follows:__________ .

REQUIREMENT RATIONALE (3.2.1.6.4)

Night brightness must be specified to assure that an appropriately dim display is available for night missions.

REQUIREMENT GUIDANCE

This requirement applies to displays which are used in an environment where the eyes must be at least partially dark-adapted and/or where the display must not create excessive light which can cause canopy reflections at night.

This mode is activated by a "day/night" or "day/auto/night" switch, which changes the range of brightness and contrast controls.

The following specific requirements have been used for a HUD for a night mission: "The HUD shall be capable of providing a very dim, easily controllable image, free of background 'glow' in areas not displaying information in the night brightness mode. This mode shall allow the pilot to adjust the HUD such that symbology on the HUD, while being clearly and uniformly displayed, does not obscure outside vision of a dimly lit scene such as a horizon lighted only by moonlight. If this requirement cannot be met by accurately controlling the drive to the display in the night brightness mode, an optical filter shall be used which is automatically inserted in the optical train in the night brightness mode. This requirement will be considered to be met when the following is achieved: In a dark ambient (less than 0.107 lux) with symbols and peak white video adjusted to 1.7 + 0.35 cd/m^2, a minimum of six shades of gray ((1.4 $\pm$ 0.2) :1 ratio) shall be visible and the areas of the raster which are blank shall be less than 0.07 cd/m^2."

REQUIREMENT LESSONS LEARNED

4.2.1.6.4 The requirements of 4.2.1.6 apply.

3.2.1.6.5 Color difference. The color difference (CD) between ________ and _________ shall be adequate for easy discrimination of __________ and be a minimum of__________ units on the 1976 CIE diagram defined in CIE Publication 15 Supplement 2 (1978), under lighting conditions of __________.

REQUIREMENT RATIONALE (3.2.1.6.5)

For color displays, simple contrast is not adequate to specify color differences. Work performed by Silverstein and Merrifield, et. al., for air transport displays has addressed color display luminance and contrast requirements in the avionics environment. Those data show that the introduction of color contrast greatly alters the luminance and contrast parameters as compared to monochromatic displays.

REQUIREMENT GUIDANCE

For color displays, color differences (CD) can be used to quantify the discriminability of various colors. While many color difference measures have been proposed, distance between the two colors on the 1976 CIE UCS diagram is the easiest to use and seems to be a reasonable approximation to human perception of difference. Color difference (ignoring luminance difference) should be calculated as a simple vector (Euclidean) distance, like this: $CD=(\Delta u'^2+\Delta v'^2)^{1/2}$. The u' and v' values should be measured in the presence of the worst ambient in which the display is expected to achieve full performance.

A system of color difference equations, the CIE $L^*u^*v^*$ color space (abbrieviated CIELUV) is defined in CIE publication 15 supplement 2. It is designed around the use of a reference light source shining on a reflective surface, and is therefore not clearly defined for an emissive display such as a CRT. (Reference "U.S. Air Force Color Display Issues", by David L. Post, S.A.E. paper 0148-7191/&86/&1013-1695). It has only recently come into use. There is still a great deal of uncertainty as to what values of ΔE^* are adequate under various conditions, as well as uncertainty as to how well it correlates with human perception in various parts of the color gamut.

The CIE LUV equations of CIE Publication 15 Supplement 2 (1978) are repeated here for information:

$$L^* = 116\ (Y/Y_n)^{1/3}-16 \qquad Y/Y_n \text{ greater than } 0.01$$

$$u^* = 13L^*\ (u' - u'_n)$$

$$v^* = 13L^*\ (v' - v'_n)$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2\ ]^{1/2}$$

Y is the luminance of the color sample and Y_n is the luminance of a reference stimulus. u' and v' are chromaticity coordinates of the sample in the 1976 UCS system, u'_n and v'_n are chromaticity coordinates of a reference stimulus. These definitions assume the sample is being compared against a reference stimulus, such as CIE standard D-65.

Another measure of color capability is "color area", defined as the area within the triangle formed by the three primary colors plotted in CIE 1976 u' v' chromaticity coordinates. For example, a typical color CRT (in a dark ambient) has a color area of about 0.045 u' v' square units.

REQUIREMENT LESSONS LEARNED

Color differences have not been specified in existing systems, as mentioned in the "display color" paragraph herein. It is not clear what values should be used in the blanks above.

4.2.1.6.5 The requirements of 4.2.1.6 apply.

3.2.1.6.6 Luminance uniformity.

a. Symbol luminance uniformity. The difference in luminance between any two symbols or symbol segments within any circle whose diameter is one-fourth the display's minimum dimension shall not exceed _____ percent of the average value. Total variation across the display shall not exceed _____.

b. Raster luminance uniformity. The difference in luminance between any two points within any circle whose diameter is one-fourth the display's minimum dimension shall not exceed _____ percent of the average value when a flat field signal is applied. Total variation across the display shall not exceed _____ percent.

REQUIREMENT RATIONALE (3.2.1.6.6)

Symbols and video must appear uniform for aesthetic reasons and to avoid "dropout" of portions of symbols.

REQUIREMENT GUIDANCE

Uniformity of ± 20 percent relative to the average of several measurements within 1/4 of the display or ± 40 percent overall has been required for CRT displays. Tighter tolerances are usually not necessary since the eye is not very sensitive to brightness variations over large areas. Abrupt changes (discontinuities), however, are objectionable. It may be necessary to apply a much tighter requirement to adjacent pixels or segments in a display made up of discrete elements, especially if the non-uniformities form patterns, such as rows or columns.

REQUIREMENT LESSONS LEARNED

4.2.1.6.6 Verification of luminance uniformity. Display luminance test data shall be used to determine compliance.

VERIFICATION RATIONALE (4.2.1.6.6)

Uniformity must be verified to assure display is usable.

VERIFICATION GUIDANCE

Verification should be based on luminance measurements.

VERIFICATION LESSONS LEARNED

3.2.1.7 Display size. The active display area shall be at least _____ cm by _____ cm. Rounding of display corners shall not exceed _____.

REQUIREMENT RATIONALE (3.2.1.7)

Display size must be specified to assure that it is large enough to assure rapid assimilation of displayed data.

REQUIREMENT GUIDANCE

Display size must be determined first of all on the basis of physical limits of the cockpit or panel on which it is designed to fit. However, after those limits are known, it is important to provide the user the required symbol size, picture size, and clarity stipulated in the resolution paragraph. Use of standard size displays should be at least encouraged, if not directly specified.

REQUIREMENT LESSONS LEARNED

It is generally assumed that the larger the display is, the better it is. However, there is a very definite limit to how large a display should be. For example, on the F-111F PAVE TACK system, a virtual image lens is used to magnify a 14.5-cm diagonal (5.7-inch diag) CRT by approximately 1.8, giving the equivalent of a 25.4-cm diagonal (10-inch diag) display at a 33-cm (13-inch) viewing distance. Operators using this display with 525-line PAVE TACK video occasionally had trouble finding targets at long range because of the large area they had to scan, and the fact that raster lines and noise in the picture were clearly visible with this display size. They also occasionally failed to see flashing status indicators on the edges of the picture when they were tracking a target in the center of the display.

At normal cockpit viewing distances (70-80cm), video in a 525-line format will generally provide adequate image quality on small displays (less than 15 cm or 6 inches square); however, an 875-line format should be used on larger displays. A higher resolution format, such as the EIA-RS-343 1023-line format, should be used for very large (30- to 50-cm) displays.

4.2.1.7 Verification of display size. Compliance with the display size requirements may be determined approximately by measuring the active display area, or by analysis of design data.

VERIFICATION RATIONALE (4.2.1.7)

Approximate display size can be verified by direct measurement. On devices with thick or curved faceplates (like CRT's), measurement will not be accurate and evaluation of design data/engineering drawings may be needed.

VERIFICATION GUIDANCE

Verification is normally by measurement.

VERIFICATION LESSONS LEARNED

3.2.1.8 Display color. The display color shall be __________ when measured in __________ ambient lighting.

REQUIREMENT RATIONALE (3.2.1.8)

Display color must be specified on some systems to insure that equipment built by different contractors or at different times is aesthetically compatible. It is also important in some applications in order to be compatible with night vision goggles. For color displays, the various colors used must be easily separable and must take into account the "reserved" colors (red and yellow).

REQUIREMENT GUIDANCE

Most fighter aircraft displays must be visible in sunlight, and currently this is best achieved with a green (P-43) phosphor CRT.

Monochrome airborne CRT displays are generally green because:

a. P-43 phosphor is very efficient and durable, and happens to produce green light.

b. The human eye is most efficient with green light.

c. Narrow bandpass filters are readily available which pass most of the green light and absorb most of the non-green sunlight, thus enhancing contrast.

d. Green light can be made compatible with night vision goggles (NVG's).

The goal in full color displays is to have the color primaries widely separated (in CIE chromaticity coordinates) and/or provide filtering such that they will stay widely separated when exposed to and mixed with ambient light. Present color CRT projects have simply specified the color coordinates of the most appropriate, currently available phosphors. It is not yet clear how the colors should be specified on flat panel devices, such as LCD matrix displays. They may have inherently different characteristics; for example, the saturation of colors does not change appreciably with ambient light levels on a purely reflective display.

REQUIREMENT LESSONS LEARNED

Specifying the color coordinates of the phosphors on color CRT's has been adequate, since the phosphor colors are widely separated and allow a large gamut of colors to be generated on the CRT, by mixing the primaries in any desired ratio. Where symbology uses color coding, and the operator must be able to easily name the color he sees, regardless of the background or lighting conditions, only a few (5 to 8, depending on which study you believe) uniquely identifiable colors can be used. Color difference criteria (see 3.2.1.6.5) can be used to try to optimize the distribution of the colors used. Colors are generally specified and measured in a dark ambient because this makes testing easier and repeatable, but this ignores the major effects of ambient light on color saturation. See 3.2.1.11.5 for more on this subject.

In color CRT displays, the color coordinate tolerances for the blue phosphor primaries need to be slightly greater than for red or green phosphors due to the chemical sensitivity of the P-22 blue phosphor most widely used. In addition, color coordinates for mixed colors (e.g., cyan, yellow, and white) must be enlarged in order to allow for variations resulting from the combination of color ratioing accuracies (electronic) and variations in individual primary phosphor screen colors.

A color tolerance radius of 0.015 (1976 CIE UCS) units has been suggested where color-coding is used on multiple color CRT's in the cockpit. 0.02 units was used on one CRT, and 0.03 units may be the tightest tolerance practical in production for some phosphors (such as P-22 blue).

4.2.1.8 Verification of display color. Display color shall be measured using __________ in a __________ ambient.

VERIFICATION RATIONALE (4.2.1.8)

Display color must be evaluated to assure that it is fully usable and aesthetically acceptable.

VERIFICATION GUIDANCE

On monochrome CRT systems, review of technical data may be adequate to determine that a standard phosphor of known color is being used. For color CRT systems or systems using other display media, spectroradiometer measurements should be performed to establish chromaticity coordinates of at least the primary colors.

VERIFICATION LESSONS LEARNED

3.2.1.9 **Phosphor characteristics.** Phosphor type and persistence shall be ________.

REQUIREMENT RATIONALE (3.2.1.9)

In some CRT applications, a particular phosphor is needed because of durability, wavelength, or persistence considerations.

REQUIREMENT GUIDANCE

For CRT applications where a particular phosphor or a particular persistence time is required, they should be inserted. This requirement is generally not needed in situations where color, luminance, frame rate and reliability requirements adequately define phosphor requirements.

P-43 phosphor (designated "GY" in the world wide phospher designation system) is specified in many cockpit CRT applications; it is a high efficiency, bright yellowish-green phosphor with a narrow spectrum light output which works well with wavelength-selective filters and diffraction optics. P-1 (GJ), P-3 (YB), P-44 (GX),and P-53 (KJ) are also appropriate in some cases. Color CRT's often use P-22 (X) which is available in red, green, and blue formulations.

REQUIREMENT LESSONS LEARNED

4.2.1.9 **Verification of phosphor characteristics.** Phosphor type shall be verified by audit of contractor drawing data.

VERIFICATION RATIONALE (4.2.1.9)

Use of the appropriate phosphor must be verified.

VERIFICATION GUIDANCE

Verification can normally be verified by audit of contractor data.

VERIFICATION LESSONS LEARNED

3.2.1.10 **Video/symbology overlay.** The equipment shall be capable of displaying ________ symbols while displaying video.

REQUIREMENT RATIONALE (3.2.1.10)

Where systems requirements necessitate overlay of symbols on video, the appropriate requirements must be specified.

REQUIREMENT GUIDANCE

This requirement applies to systems requiring symbols overlayed on video. The following requirements have been used for a HUD with raster capability: "The equipment shall be capable of displaying all symbols and symbol combinations required herein while displaying video. During display of video, selected symbols may be displayed in raster rather than by stroke. Primary symbols and symbols whose appearance is substantially degraded by being placed in raster shall be displayed by stroke. Use of stroke during retrace may be extended by 'stealing' (deleting) up to 30 lines of video. Such 'line stealing' shall be controlled dynamically, such that no more video is deleted than necessary at any given time. Symbol quality during display of video shall meet all requirements herein, except that symbols displayed in raster may be degraded as required by the physical limitations of quantifying them into raster lines." This system has both stroke and raster symbol generation capability, which adds significant complexity and may not be needed for other systems.

Where raster symbols are overlayed on video, they must be a shade brighter than the video or be otherwise enhanced (see 3.2.1.6.3).

REQUIREMENT LESSONS LEARNED

On color CRT's, when the symbols are overlayed on a different color backgrounds, the colors of the symbol and background mix, producing another color. This can be avoided by electronically substituting the symbols for video, rather than adding them to the background. This procedure adds complexity to the symbol generator.

4.2.1.10 Verification of video/symbology overlay. Video/symbology overlay shall be demonstrated.

VERIFICATION RATIONALE (4.2.1.10)

Proper display of combined video and symbols must be verified.

VERIFICATION GUIDANCE

Verification by demonstration is generally adequate.

VERIFICATION LESSONS LEARNED

3.2.1.11 Video size. The equipment shall display video from the __________. The __________ aspect ratio raster shall be centered horizontally and subtend at least __________. The center of the raster shall be __________.

REQUIREMENT RATIONALE (3.2.1.11)

The size of the video, if different than the display size, must be defined.

REQUIREMENT GUIDANCE

This requirement applies to systems where video is displayed at other than the exact display size. For example, on a HUD with video capability, the video may fill the instantaneous or total field of view vertically or horizontally, but will not, in general, match the total symbology display area. The paragraph should also specify the location of the video on the display, in terms of degrees below the horizontal datum for a HUD and centimeters from the center on other displays. Where 4:3 aspect ratio video is displayed on a 1:1 screen (or vice versa), this paragraph should describe whether the screen is overscanned in one direction or underscanned in the other direction to make the video fit.

REQUIREMENT LESSONS LEARNED

4.2.1.11 Verification of video size. Video size shall be measured by __________.

VERIFICATION RATIONALE (4.2.1.11)

Appropriate sizing of video must be verified.

VERIFICATION GUIDANCE

Normally, measurements taken during acceptance test would be adequate.

VERIFICATION LESSONS LEARNED

3.2.1.12 Viewability during gunfire. During periods of gunfire, any apparent displayed image size change or symbology movement (or combination of both) shall not degrade the pilot's capability to use critical symbology and shall not exceed ____ percent of the jitter values specified herein. The equipment shall return to full performance immediately upon cessation of gunfire.

REQUIREMENT RATIONALE (3.2.1.12)

On aircraft which have a gun, the level of performance during gunfire must be specified.

REQUIREMENT GUIDANCE

This requirement, which actually serves to relax accuracy requirements during gunfire, has been used on F-16 and A-10 HUD's with "200 percent" filled in. Because of the severity and short duration of gunfire, full performance during gunfire may be difficult and expensive to achieve and be of very little value.

REQUIREMENT LESSONS LEARNED

4.2.1.12 Verification of viewability during gunfire. Degradation of the symbology shall be monitored visually during gunfiring vibration test. If significant degradation occurs, the apparent line width and positional variations shall be measured.

VERIFICATION RATIONALE (4.2.1.12)

Viewability must be verified to assure that the pilot can see critical symbols during gunfire.

VERIFICATION GUIDANCE

Verification is generally done by visual observation backed up by measurements if necessary.

VERIFICATION LESSONS LEARNED

3.2.1.13 **Flicker, jitter, and noise.** The display shall not exhibit flicker which is discernible to the eye. Jitter shall be less than __________(3 sigma). The effects of electrical noise shall not cause any visible distortion, positional or dimensional instability, or luminance variation in any symbology, reticle, or raster and shall not interfere with proper presentation or usability of the display. Motions at frequencies above 0.25 Hz are considered jitter, while lower frequency movements shall meet the requirements of the stability paragraphs herein.

REQUIREMENT RATIONALE (3.2.1.13)

Flicker, jitter, and noise in a display degrades accuracy, can cause confusion or errors in a tense, high workload environment, and is aesthetically objectionable.

REQUIREMENT GUIDANCE

It is always desirable to reduce artifacts in the display, such as flicker, jitter, and noise, to a level that is not noticeable to the operator. Flicker is very difficult to quantify and measure. A properly designed CRT display should have no flicker other than the barely perceptible fading of alternate lines which can usually be seen in an interlaced raster display at high brightness. For other display technologies, more specific flicker criteria may have to be developed. Jitter should be limited to much less than the minimum line width to be displayed. For example, a HUD with a 1-mr nominal stroke width should have less than 1 mr (0.074 cm at 71.1 cm viewing distance) of jitter. In fact it may be limited to much less; for example, ARINC Characteristics 725 limits jitter to 0.018 cm (0.007 inch). Noise which is noticeable when the display is in normal operation should not be allowed, although in some situations (for example, a display for a special project where only a few will be built), the time and cost required to design out all noise is excessive compared to the aesthetic value of a "clean" display.

REQUIREMENT LESSONS LEARNED

4.2.1.13 **Verification of flicker, jitter and noise.** The display shall be monitored for visible flicker, jitter, and noise. Any objectionable effects noticed shall be measured.

VERIFICATION RATIONALE (4.2.1.13)

Compliance must be verified for aesthetic and accuracy reasons.

VERIFICATION GUIDANCE

Verification should be based on visible observations backed up by measurements if necessary.

VERIFICATION LESSONS LEARNED

Where the jitter is present in an electronic signal, such as a composite video signal from a signal generator, jitter can be measured by displaying the signal on an oscilloscope synchronized from an accurate time base and comparing the timing of video from line to line and/or frame to frame. Measuring jitter on a display surface is more difficult and might require taking repetitive photographs and comparing them. It is rarely necessary to measure jitter since nearly everyone agrees that visible jitter is objectionable and it is generally possible to design systems so none is visible, in which case it need not be measured.

3.2.1.14 Dimensional stability.

a. Symbology dimensional stability. The dimensional stability of the symbology shall be ± _____ for symbols less than _____in height or width and for larger symbols, ±_____ per _____ of height or width.

b. Raster dimensional stability. The raster shall be dimensionally stable so that in the course of normal operation, during mode switching, or aircraft power variation, the total display image size shall not change more than _____ percent in height or _____ percent in width.

REQUIREMENT RATIONALE (3.2.1.14)

Symbol and raster dimensions must be stable for aesthetic reasons and for accuracy.

REQUIREMENT GUIDANCE

Dimensional stability of ± 1 mr for symbols less than 50 mr in height, and ± 1 mr per 50 mr in height have been used for HUD symbols. Comparable stabilities for an MFD would be ± 0.7 mm for symbols less than 50 mr in height, and ± 0.7 mm per 50 mr in height. Display image size changes are generally limited to less than ± 2 percent.

REQUIREMENTS LESSONS LEARNED

4.2.1.14 Verification of dimensional stability. Symbol and test pattern dimensions shall be measured to determine compliance.

VERIFICATION RATIONALE (4.2.1.14)

Dimensional stability must be verified for accuracy and aesthetic reasons.

VERIFICATION GUIDANCE

Verification should be based on measurements.

VERIFICATION LESSONS LEARNED

3.2.1.15 Positional stability.

a. Symbology positional stability. The positional stability of the symbology shall be ±_____.

b. Raster positional stability. Displayed video data variation shall not exceed plus or minus ____ percent azimuth or elevation under any combination of environments.

REQUIREMENT RATIONALE (3.2.1.15)

Symbol and video position must be stable for aesthetic reasons and for accuracy.

REQUIREMENT GUIDANCE

Symbol positional stability of ± 1 mr has been used for a HUD. Stability of raster position of ± 2 percent has been used for a HUD.

REQUIREMENT LESSONS LEARNED

4.2.1.15 Verification of positional stability. The position of symbols and video shall be measured to determine compliance.

VERIFICATION RATIONALE (4.2.1.15)

Positional stability must be measured to assure an accurate and aesthetically pleasing display.

VERIFICATION GUIDANCE

Verification is normally done by measurement.

VERIFICATION LESSONS LEARNED

3.2.1.16 Raster distortion and linearity. No picture element shall be displaced by more than _____ percent of the picture height from its true position referenced from the center of the picture.

REQUIREMENT RATIONALE (3.2.1.16)

Raster distortion must be limited for accuracy and aesthetic reasons.

REQUIREMENT GUIDANCE

Distortion and linearity error requirements of less than 1 percent have been applied to CRT based systems. Distortion of 2 percent has been allowed for many systems, and is normally adequate.

REQUIREMENT LESSONS LEARNED

Distortion and linearity errors of less than 1 percent are achievable with modern circuitry. Devices with large optics, such as the WFOV HUD, may have serious optical distortion which adds to the display image distortion. Errors which are spread over a large area are much more tolerable than small-area distortions, just as large-area brightness nonuniformities are tolerable.

4.2.1.16 Verification of raster distortion and linearity. Raster distortion and linearity shall be tested by ___________.

VERIFICATION RATIONALE (4.2.1.16)

Raster distortion must be measured to assure accuracy and aesthetic quality.

VERIFICATION GUIDANCE

The "ball" chart defined in EIA-RS-170, has been used for linearity measurements. It is made in the form of a transparency with circles of radius equal to 2 percent of the display height. This chart is overlayed on a raster containing a grid of white lines; all line intersections should fall within the circles.

VERIFICATION LESSONS LEARNED

3.2.1.17 Reflections.

a. The relative intensity of second surface reflections visible in the HUD field-of-view shall not exceed _____ percent of the primary symbol or video luminance.

b. Reflectivity of the display face shall not exceed _____ percent.

REQUIREMENT RATIONALE (3.2.1.17)

Secondary reflections must be controlled to prevent reflections from interfering with the primary displayed information.

REQUIREMENT GUIDANCE

The secondary reflection requirement applies to equipment having optics. Secondary reflections have been limited to 2 percent in current HUDs. This is achievable and reduces interference between secondary reflections and the displayed information. A limit of 1/2 percent reflectivity on the display face is generally appropriate for displays used in sunshine, and implies that an anti-reflective coating will be used. Note that the contrast requirements herein indirectly require control of reflections.

REQUIREMENT LESSONS LEARNED

4.2.1.17 Verification of reflections. Intensity of reflections shall be measured to determine compliance.

VERIFICATION RATIONALE (4.2.1.17)

Reflections must be measured to assure that they are not objectionable.

VERIFICATION GUIDANCE

Verification should be by measurement.

VERIFICATION LESSONS LEARNED

3.2.1.18 Solar effects. The optical design shall limit images and background illuminations arising from solar illumination to less than _____ percent of the luminance of the illuminating source when viewed from anywhere within the eye motion box. Continuous direct sun illumination on the equipment within the cone of acceptance shall not result in damage to any subcomponent whether operating or not.

REQUIREMENT RATIONALE (3.2.1.18)

Solar effects must be limited to assure that bright sun images do not interfere with use of the display or degrade the equipment.

REQUIREMENT GUIDANCE

Solar images have been limited to less than 2.5 percent on existing HUD's. Note that 2.5 percent of the sun's brightness is still bright enough to produce a very objectionable sun image in the display, but because the sun is only in the correct place to produce the image a small percentage of the time, and there is often no practical way to prevent the image, it has been accepted. A tighter requirement (0.5 percent) should be a design goal.

REQUIREMENT LESSONS LEARNED

4.2.1.18 Verification of solar effects. Solar effects shall be measured by __________.

VERIFICATION RATIONALE (4.2.1.18)

Solar effects must be measured to insure display usability.

VERIFICATION GUIDANCE

Measurement techniques appropriate for the display should be inserted.

VERIFICATION LESSONS LEARNED

3.2.1.19 Automatic brightness control and sensor. An automatic brightness control (ABC) shall be provided to maintain visual contrast on the display as the ambient changes. The range of the ABC shall be suitable for ambient light levels in the range of _____. As a further design goal, the ABC shall automatically increase brightness during night mode operation when bright lights are in the operator's forward field-of-view.

REQUIREMENT RATIONALE (3.2.1.19)

An ABC has been used on displays which are exposed to sudden or frequent changes in ambient light in a high workload environment.

REQUIREMENT GUIDANCE

An ABC suitable for use against ambient backgrounds from 340 to 34000 cd/m^2 (100 to 10,000fL) has been used for a HUD. An ABC for a head-down display in a fighter cockpit might be suitable for ambient illuminations from 1080 to 108,000 lux (100 to 10,000 fc).

Although ABC sounds like a great idea, implementations are expensive, difficult to test, and of relatively little value in actual aircraft use. Problems which should be resolved include:

1. Multiple sensors are needed to prevent fluctuations due to shadowing, such as by the operators hand.

2. On head-down displays, a forward-looking sensor is needed to account for the pilot's eye adaptation level due to the scene luminance outside (rather than just cockpit illumination).

3. Sensors with increased sensitivity are needed to make ABC work in the 1-100 fc range (dusk and dawn transition) where they would be most useful.

4. It's now practical to have software control the brightening and dimming time constants, and the nonlinear relationship between ambient levels, control settings, and display drive signals, but proven algorithms and parameters may not be available.

REQUIREMENT LESSONS LEARNED

The ABC used on the F-15 head-down displays has caused problems and may be eliminated; ABC appears to be most useful on HUD's. ABC's are being used on the Boeing 757/767 commercial aircraft where sensors are provided to measure both the cockpit illumination level and the forward scene luminance. Operation over a wider range (down to 10.8 lux) is desirable but may not be achievable with existing technology.

4.2.1.19 Verification of automatic brightness control (ABC). Compliance shall be verified by ________.

VERIFICATION RATIONALE (4.2.1.19)

Performance must be evaluated to assure that the ABC provides the required brightness adjustment.

VERIFICATION GUIDANCE

Laboratory brightness tests can be performed to verify that the ABC works as designed. The actual-ambient-brightness-versus-display-brightness function must often be determined experimentally during flight test of the hardware, since the desired characteristic is greatly affected by the surroundings in the cockpit. Wide tolerances should be used in this test, since accuracy is difficult to control and of very little value.

VERIFICATION LESSONS LEARNED

3.2.1.20 Warm-up time. The equipment shall be functionally operational and conform to all accuracy and performance requirements within ____ minutes of being switched on when operated in the environment specified herein, including temperature extremes. Transient power loss for up to _____ seconds shall not require re-warm-up longer than the period of power loss.

REQUIREMENT RATIONALE (3.2.1.20)

Prompt warm-up is required to prevent delays when starting up the aircraft and avoid wasted maintenance time when operating the equipment for checkout or repair.

REQUIREMENT GUIDANCE

A warm-up time of two minutes is generally adequate. Some systems have also allowed degraded performance for up to five minutes after turn-on at cold temperature extremes. Others, such as engine instruments on an aircraft which will be on alert, must provide a reasonable display immediately, but may not need to meet full specifications for two minutes. Power transients of up to one second should be tolerated without requiring a full re-warmup period.

REQUIREMENT LESSONS LEARNED

CRT's have an inherently slow warm-up because of their vacuum tube nature. The major problems associated with warm-up of analog circuitry and mechanical devices have mostly disappeared with current digital hardware.

4.2.1.20 Warm-up time. Warm-up time shall be measured.

VERIFICATION RATIONALE (4.2.1.20)

Warm-up must be checked to assure that the display equipment does not delay aircraft start-up or maintenance.

VERIFICATION GUIDANCE

Verification is normally done by timing with a stopwatch.

VERIFICATION LESSONS LEARNED

3.2.1.21 Controls. Brightness, Contrast, and _______________ shall be provided. Brightness and contrast shall change logarithmically with linear control movement, to give the subjective impression of linear control.

REQUIREMENT RATIONALE (3.2.1.21)

Several controls are normally included on display equipment. Brightness and contrast are required to make the display characteristics compatible with the ambient lighting.

REQUIREMENT GUIDANCE

Nearly all displays have potentiometer type controls for brightness and contrast, plus several other controls depending on the system application and configuration. MIL-STD-1472 (and the new AFGS-1800) contains guidance on controls. See also 3.3.7.2.

REQUIREMENT LESSONS LEARNED

Several new display units use push buttons or "digital potentiometers" to adjust brightness, contrast, etc. This technique will result in discrete steps in control settings, which can be objectionable unless the steps are made sufficiently small.