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DISPLAYS, AIRBORNE, ELECTRONICALLY/OPTICALLY GENERATED

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FIGURES

TABLES

1. SCOPE

1.1 Scope. This specification establishes the development requirements for electronically generated displays for airborne use, including head-up displays (HUDs), helmet-mounted displays (HMDs), and multi-function displays (MFDs), including displays for TV, FLIR, and radar video, and the associated electronic display generation equipment. It is designated 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 handbook (appendix) 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. In the event a projected design for a given application results 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, the issue shall be brought to the attention of the procuring activity for consideration of change.

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 Characteristics

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. Control panel lighting shall ____________. Emitted light shall be compatible with ____________.

3.2.1.3 Symbology. The equipment shall be capable of generating and displaying each of the symbols shown and described in ____________. All of the symbols in figure ____________ shall be displayable simultaneously at sufficient update rate to prevent visible jerking and sufficient refresh rate to prevent flicker. The equipment shall be capable of generating:

a. ____________ polygons

b. ____________ layers of occlusion

c. ____________ flashing symbols

d. ____________ shadowing (for contrast enhancement)

e. ____________ colors

f. ____________ alphanumeric characters

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 incoming data is 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 and a positive indication of the failure condition provided. 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 10% minimum modulation when one half of the scan lines are "on" while operating in ____________ raster format. The horizontal resolution shall be ____________ lines per ____________ minimum with a 10% 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, contrast, and viewing angle. The luminance, contrast, and viewing angle requirements of the following subparagraphs shall be met when measured from the design eye position. The display luminance and contrast shall not change more than ± ____________% 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/m^2 (10,000 fL) and color temperature of 3,000 to 5,000 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 34,000 cd/m^2 ambient background shall be a minimum of ____________ with a design goal of 0.5. Luminance shall not degrade more than ____________% when measured from anywhere within ____________ cm of the design eye position.

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 3,000 to 5,000 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).

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 (between brightest and darkest shade) 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 ____________.

3.2.1.6.4 Dimming range. The equipment shall be dimmable to a level of ____________ cd/m^2 (peak brightness) in a dark ambient.

3.2.1.6.5 Chromaticity difference. The chromaticity 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 symbol or symbol segment and the average within any circle whose diameter is one-fourth the display's minimum dimension shall not exceed ____________% of the average value. Total variation across the display shall not exceed ____________.

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

3.2.1.6.7 Viewing angle. Viewing angle shall be at least +____________° up, -____________° down, ____________° left, and ____________° right, relative to the central axis of the display. Criteria for "viewing" are:

a.

b.

c.

3.2.1.6.8 Blemishes. There shall no visible blemishes on the display face when viewed from the normal viewing distance. Blemishes shall be defined as any area where____________.

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 Night Vision Imaging System (NVIS) requirements. The display unit shall be operationally compatible with Class ____________ NVIS and shall not produce an NR value equal to or greater than ____________.

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 ____________% 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 discernible to the eye. Jitter shall be less than ____________ (3σ). 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 ____________% in height or ____________% 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 ± ____________ 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 ___________% of the primary symbol or video luminance.

b. Reflectivity of the display face shall not exceed ___________%.

3.2.1.18 Solar effects. The optical design shall limit images and background illuminations arising from solar illumination to less than ___________% 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 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 Warmup 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-warmup 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 or hazards to personnel from high voltage power supply and CRT high voltage arcs by use of arc suppressors or ___________.

3.2.1.25 Head-up display (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 FOV and its relationship to the horizontal datum shall be as described in ____________. The above requirements are to be met with the eyes centered on the design eye. The total FOV shall be viewable from within the eye motion limits (box) shown in ____________ and the IFOV shall not decrease to less than 75% 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% 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 3,000 to 5,000 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 3σ 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 ___________% of the display width, plus ___________% 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 (3σ) 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 with out 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, a combined boresight accuracy of ___________ mr (3σ) 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 system 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 preceding 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 ___________% for both directions through the glass. The outer surface of the combining glass shall have a reflectivity of ___________% or less.

3.2.1.26 Helmet mounted display (HMD)-specific requirements. A HMD system with the following characteristics shall be provided: ___________.

3.2.1.26.1 Sunshine video capability. The HMD shall be capable of displaying video, with contrast, resolution, and brightness as specified herein, in a ___________ ambient.

3.2.1.26.2 Image intensifier (I^{2}) capability. The HMD shall include I^2 capability with the following FOV, resolution, gain, ___________.

3.2.1.26.3 Head supported weight and center of gravity (CG). Weight of the helmet including display hardware and ___________ feet of interconnecting cable shall not exceed ___________. CG shall be below ___________ and forward of ___________.

3.2.1.26.4 Personal equipment compatibility and interface. The HMD shall be compatible with ___________.

3.2.1.26.5 Compatibility with ejection seat. TBD

3.2.1.26.6 Head tracking system. A head tracking system shall be provided which provides helmet look angle, roll angle, and position to the following accuracies: ___________. Lag time between motion of the helmet and output of angles and positions within the above tolerances shall not exceed ___________.

3.2.1.26.7 Eye relief and exit pupil. Sufficient eye relief for comfortable viewing and viewing with eyeglasses on shall be provided. Exit pupil shall be sufficient to prevent vignetting of the image with normal helmet shifting due to G loading, and shall be at least ___________ mm.

3.2.1.26.8 Monocular/Biocular/Binocular capability. The HMD shall provide ___________ image(s), meeting the following requirements: ___________.

3.2.1.26.9 Peripheral vision. The operator's unaided peripheral vision shall cover at least ___________% of the area available with the standard ___________ helmet.

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. See 3.2.5.

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 wearout 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 ___________% of all faults. Self test false alarms shall not exceed ___________% 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 ___________% of the malfunctions and out-of-tolerance conditions (at their predicted frequencies) with a false alarm rate of less than ___________%. BIT, supplemented as necessary by self test, shall be capable of isolating to the faulty LRU a minimum of ___________% of the detected malfunctions and out-of-tolerance conditions. The BIT shall isolate to the faulty SRU ___________% 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 lookups. 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 ___________% of all failures of digital SRUs and ___________% for analog SRUs.

b. Fault isolation to a single circuit element (component) in ___________% of the detected failures for digital SRUs and ___________% to 3 active components on analog SRUs.

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 Product integrity. The equipment shall perform within specifications for a service life of ___________ years when subjected to the environments which are expected to occur during the intended usage. The equipment shall perform within specifications after exposure to the expected transportation, manufacture, storage, and maintenance environments. Other product integrity requirements shall be established in accordance with *MIL-A-87244*.

3.3 Design and construction.

3.3.1 (Reserved).

3.3.2 Electromagnetic compatibility. See *MIL-A-87244*.

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 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 ___________.

3.3.5 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 emissions. The equipment shall not produce x-ray emissions of more than ____________ milliroentgen per hour under normal operating conditions.

3.3.6.4 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.

3.3.6.5 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.

3.3.7 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 Verification of characteristics

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 photometer (may use a slit aperture), 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 specular glare source luminance specified in section 3 herein. Light sources used shall have a color temperature between 3,000 and 5,000 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.

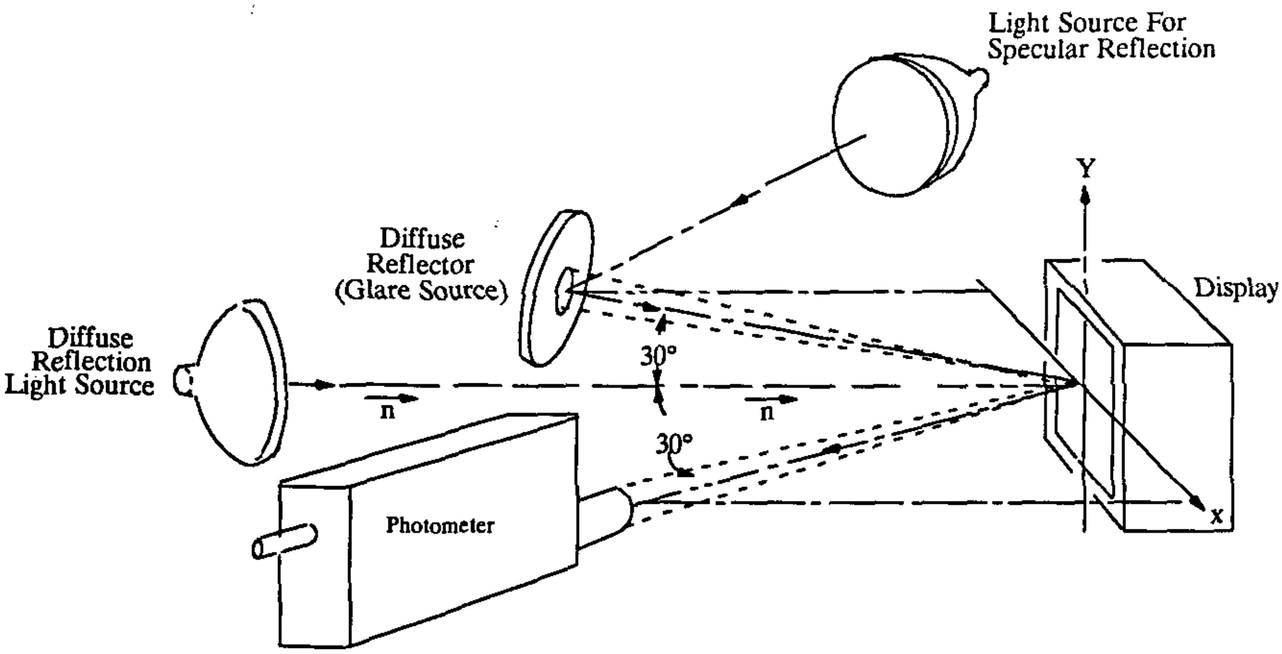

FIGURE 1. Combined specular and diffuse measurement setup.

NOTES:

1. Luminance of the glare source is measured by putting a mirror (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° 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 dimming range. The requirements of 4.2.1.6 apply.

4.2.1.6.5 Verification of chromaticity 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.

4.2.1.6.7 Verification of viewing angle. Viewing angles shall be determined by____________.

4.2.1.6.8 Verification of blemishes. Verification shall be by____________.

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 NVIS. NVIS radiance performance should be performed by individuals or organizations that have demonstrated technical competence to the Joint Aeronautical Commanders Group, Tri-Service Lighting Committee, Naval Air Systems Command, Washington DC or to Naval Avionics Center in Indianapolis, IN. Test methods and equipment of ____________ shall be used.

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 Warmup time. Warmup 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.

4.2.1.26 Verification of HMD-specific requirements. *TBD.*

4.2.1.26.1 Verification of video in sunshine capability. TBD.

4.2.1.26.2 Verification of I^2 capability. TBD.

4.2.1.26.3 Verification of weight and CG. TBD.

4.2.1.26.4 Verification of compatibility with personal equipment. TBD.

4.2.1.26.5 Verification of compatibility with ejection seat. TBD.

4.2.1.26.6 Verification of head tracker system. TBD.

4.2.1.26.7 Verification of eye relief and exit pupil. TBD.

4.2.1.26.8 Verification of monocular/biocular/binocular capability.

4.2.1.26.9 Verification of peripheral vision. Verification of peripheral vision shall be by ____________.

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. See 4.2.5.

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 product integrity. Verification shall be by ____________.

4.3 Verification of design and construction.

4.3.1 (Reserved).

4.3.2 (Reserved).

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

4.3.4 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 ____________.

4.3.5 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 emissions. TBD

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

4.3.6.5 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 ___________.

4.3.7 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 ___________.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

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 taken at appropriate locations over a specified area.

6.2.2 Built-in tests (BIT). Automated internal tests, which may be further defined as continuous or interrupting.

6.2.3 Conformal. An image where the angles between points or objects match the real world. On a HUD, symbols which overlay objects or depict angles as the pilot sees them in the real world are called conformal.

6.2.4 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. Contrast ratio (CR) or luminance ratio. $CR = L_t/L_b$, 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 approaching 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) or luminance contrast. $C = \Delta L/L_b$, numerically equal to $(L_t - L_b)/L_b$, also = CR − 1.0. This quantity ranges from 0.0 (no contrast) to approaching 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, Michaelson contrast, 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 was called luminance contrast in *MIL-STD-1472C* but was replaced , in *MIL-STD-1472D*, by definition *b* above. It is equal to the C_m definition (*c* 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.

6.2.5 Diffuse reflection. Scattered or broken up reflection of light. The $BaSO_4$ reflectance standard used in photometric tests, and ordinary white paper, are examples of diffuse reflectors.

6.2.6 Display element. The smallest addressable entity of the display. In the case of a color matrix LCD, the smallest addressable shutter or dot of an individual color. In the case of a segmented display, any of the shapes, characters or symbols made up of only one individual addressable entity. Sometimes called a "dot", a "segment", or (when a pixel is subdivided to spatially achieve color or gray shades) a "subpixel".

6.2.7 Fill factor. On a matrix display, the transmissive or emissive area divided by the total image area, normally expressed as a percentage.

6.2.8 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."

6.2.9 Line rate. In raster scanned systems, the total number of horizontal line times which occur in one complete frame time. 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 horizontal resolution of around 300 lines.

6.2.10 Lines (of resolution). The maximum number of alternate light and dark lines that can be resolved within a unit dimension, generally "lines per cm" (or inch), "lines per picture height," or just "lines", which can be assumed to be lines per picture width or height. On a device with discrete picture elements (pixels), the number of pixels is stated as the resolution, although it is not strictly equivalent to lines of resolution on an analog display. The units of "lines per picture height" for horizontal resolution, defined in *EIA-RS-170,* were used in many TV systems, but are now rarely used because of the confusion caused by expressing horizontal resolution in terms of vertical screen height, and the fact that it gives a lower (less impressive) number on a 4:3 aspect ratio (standard rectangular) display.

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

6.2.12 Minutes and milliradians. Units of angular measurement. 60 minutes of arc = 1 degree. 2π 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.

6.2.13 Occlude. To block off or cut off, as when one symbol overlaps another and the one "in back" is partially hidden from view. "Occult" has a similar meaning and is sometimes used interchangeably.

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

6.2.15 Pixel. Contraction for "Picture Element". In a matrix display, the smallest element or group of elements which provides spatial information and can produce all of the color and shades-of-grey capabilities of the display. Note that some use "pixel" to refer to a single display element, as defined herein; It may be necessary to use the phrase "color group" or "full color pixel" to clarify. See "Flat-Panel Displays and CRTs", by Lawrence Tannas and *SAE-ARP-4256.*

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

6.2.17 Specular reflection. Mirror-like reflection, with the characteristic that the angle of incidence equals the angle of reflection. An image of your face, seen reflected in a display, is a specular reflection.

6.3 Quantities of light

6.3.1 Candela per square meter (cd/m^2). The cd/m^2 (also called nit for normalized intensity), is the S.I. (Systeme International d'Unites, or international system of units) unit for luminance. Luminance is used to measure light radiating or reflecting from a surface, such as the face of a CRT. A cd/m^2 is approximately 0.292 foot Lambert (1 fL approx= 3.43 cd/m^2).

6.3.2 Lumens per square meter (lm/m^2). The lm/m^2, or lux (light flux) is the S.I. 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 0.0929 foot candles (1 fc approx = 10.76 lux).

6.3.3 Candelas (cd). The cd is the S.I. 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 also used to measure devices which are too small or nonuniform (like LEDs) to be accurately measured in luminance units. 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 S.I. 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 ASC/ENASI, Wright-Patterson AFB OH 45433. Requests for additional information or assistance on this specification can be obtained from James C. Byrd, ASC/ENASI, Wright-Patterson AFB OH 45433; DSN 785-4130, Commercial (513) 255-4130. Any information obtained relating to Government contracts must be obtained through contracting officers.

6.5 International standardization agreements. Certain provisions of this specification are the subject of international standardization agreement *NAT-STD-3504*. When amendment, revision, or cancellation of this specification is proposed that will modify the international agreement concerned, the preparing activity will take appropriate action through international standardization channels, including departmental standardization offices, to change the agreement or make other appropriate accommodations.

6.6 Subject term (key word) listing

displays
airborne displays
cathode ray tube
cockpit displays
CRT
head-up display
helmet-mounted display
LCD
liquid crystal display
multi-purpose display
multi-function display
sunshine legibility

6.7 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.

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-87213B.

10.3 Use. This appendix is designed to assist the project engineer in tailoring AFGS-87213B. 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 ASC/ENASI, Wright-Patterson AFB, OH 45433-6503. The individual who has been assigned the responsibility for this handbook is James C. Byrd, ASC/ENASI, Wright-Patterson AFB, OH 45433-6503, DSN 785-4130, commercial 513-355-4130.

20. APPLICABLE DOCUMENTS

Unless otherwise indicated, the documents listed herein are referenced solely to provide supplemental technical data. The latest edition in effect should be used unless otherwise stated.

20.1 Government documents.

20.1.1 Specifications, standards, and handbooks.

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-85762	Lighting, Aircraft Interior, Night Vision Imaging System (NVIS) Compatible
MIL-E-87145	Environmental Control, Airborne
MIL-E-87235	Emergency Escape, Aircraft

AFGS-87240	Lighting Equipment, Airborne, Interior and Exterior
AFGS-87266	Aircraft Cockpit Transparency System
MIL-A-87244	*Requirements for the Integrity of Avionics*

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-882	System Safety Program Requirements
MIL-STD-883	Test Methods and Procedures for Microelectronics
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
MIL-STD-1800	Human Engineering Performance Requirements for Systems
MIL-STD-1801	User/Computer Interface
MS25271	Relays, Electromagnetic, 10 Amperes, 4 PDT, Type 1, Solder Hook Hermetically Sealed

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, phone (215) 697-2667.)

20.1.2 Other Government documents, drawings, and publications

AFAMRL-TR-83-095	Opticial and Human Performance Evaluation of HUD Systems Design
AFR 161-35	Hazardous Noise Exposure
ASD-TR-83-5019	Optical and Human Performance Evaluation of HUD Systems Design
FAA AC No. 25-1309-1A	System Design and Analysis
FAA FAR-25.1309	Airworthiness Standards, Transport Category Airplanes (Equipment, Systems, and Installation)
FAA-TSO-C113	Airborne Multipurpose Electronic Displays
NAT-STD-3350	Monochrome Video Standard for Aircraft System Application
NAT-STD-3800	Night Vision Goggle Lighting Compatibility Design Criteria
OSHA	Code of Federal Regulations Part 19103

20.2 Non-Government publications

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
EIA-RS-170	Electrical Performance Standards—Monochrome Television Studio Facilities

EIA-RS-343	Electrical Performance Standards for High Resolution Monochrome Closed Circuit TV Camera
EIA-TEPAC-105-9	Line Profile Measurements in Shadow Mask and Other Structured Screen Cathode Ray Tubes
EIA-TEP-116-B	Optical Characteristics of CRTs
RTCA-DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
SAE-ARP-1782	Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays
SAE-AS-8034	Minimum Performance Standard for Airborne Multipurpose Electronic Displays
SAE-ARP-4256	Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft

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30. REQUIREMENTS AND VERIFICATIONS

This section contains guidance for tailoring the requirements in sections 3 and section 4 of the basic specification. The sequence is the same, except that each performance requirement is paired with its associated verification requirement.

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
   Night vision goggle compatibility

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
Field of View
Brightness
Video capability (if required)
Symbol set
Accuracy
Over-the-nose vision
Canopy/HUD interaction

e. HMD
Field of View
Brightness
Video capability (if required)
Symbol set
Accuracy
Field of regard

Additional guidance may be found in *FAA-TSO-C113* and in *SAE-AS-8034*.

The display system is part of both the avionics system and the crew station. It must interface with the crew and with other crewstation equipment.

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%); (b) test condition cooling airflow rate tolerance (± 5%); 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, avionics and equipment, 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. Consult with crew systems engineers when filling in the blank for this requirement to ensure that all crew systems proposed for the aircraft are properly addressed from a compatibility viewpoint. Some interface requirements to be considered are as follows:

a. Compatibility with crew protective systems, including restraint systems, oxygen systems, anti-g systems, and all head mounted personal equipment (Reference MIL-P-87234 and AFGS-87226).

b. Compatibility with ejection system including the ejection sequence, ejection clearance envelope, pitot sensing system, and seat adjustment (Reference AFGS-87235).

c. Compatibility with outside visibility (Reference MIL-STD-1776).

d. Compatibility with crew station geometry and arrangement (Reference MIL-STD-1776).

REQUIREMENT LESSONS LEARNED

Compatibility with the seat/escape system, flight controls, canopy and ingress/egress is often difficult to define, but drives requirements on size and layout of displays.

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

This verification should be performed by a combination of tests and demonstrations and may be conducted together with the verifications of other requirements. Consult with crew systems engineers to determine appropriate verification procedures. Typically, compatibility with crew protective systems is verified by inspection of drawings, windblast testing and ejection sled tests. Compatibility with the ejection system is verified by inspection of drawings, mockup evaluations, windblast testing, and ejection sled tests. Compatibility with outside visibility is verified by inspection of Aitoff plots and actual hardware evaluation of mockups, simulation, and evaluations of the flight test article. Regardless of the number and types of tests that are performed, a full system demonstration of crew systems compatibility must be performed. During this evaluation, the crewmember should be using the full personal equipment ensemble, the equipment should be fully functional and operating and realistic simulations of the cockpit and mission procedures should be used.

VERIFICATION LESSONS LEARNED

None at this time.

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 essential, especially when equipment is not all designed by the same team. Mistakes not only create technical problems but cause serious contractual costs and delays ("finger pointing").

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 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 or simulation have 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 some equipment 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 now use 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-Hz frame, 60-Hz field, 4:3- or 1:1-aspect-ratio video similar to EIA-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 per EIA-RS-343) for better vertical resolution. Current 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 which use a stroke presentation with raster fill of some symbols at a 40/80 rate. Color video should be a red-green-blue (RGB) (three-wire) signal having timing and tolerances equivalent to the monochrome signals. 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, color video will normally be converted to NTSC or the new Y-C (Luminance-Chrominance) format for recording. New digital displays, such as Active Matrix Liquid Crystal Displays, may also use a digital fiber optics interface, such as the one used on the F-22.

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 was 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 2, multiplex bus, although higher speed data buses are being developed. 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, how many busses are needed, and which units should be bus controllers. 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 originally used on the F-15 and F-111, reduce other application possibilities for the equipment and increase 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. Any hardware or software changes made in a unit may inadvertently make it non-compliant with the standard. MIL-HDBK-1553 provides extensive guidance on the design and application of MIL-STD-1553.

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. An outline dimensional drawing or reference to a mechanical interface control document should be inserted.

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

Some equipment also has a requirement to operate for a specified period without cooling.

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

Cooling fans can create excessive noise in the cockpit. Permissible noise levels must be specified and tested if use of fans is anticipated.

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 HUDs must interface with a cockpit TV camera to provide a recording capability. Recordings are used in training, target damage assessment, and in locating system problems which may be impossible to duplicate on the ground.

REQUIREMENT GUIDANCE

A Cockpit TV System (CTVS) (miniature video camera) is currently used in most Air Force fighter aircraft. Most HUDs 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 HUDs which use a diffraction (holographic) optics combiner, the CTVS is mounted forward of the combiner and the symbology is electronically overlayed. Many systems also provide composite video outputs of sensor video and/or display symbology to a video tape recorder. The user's needs, in terms of which displays are to be recorded, and the quality/accuracy to be achieved, should be inserted. A hand-held video camera is also included on at least one aircraft.

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 Characteristics

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)

This paragraph defines the conditions under which the performance requirements in the following subparagraphs are to be met.

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 Verification of characteristics

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. Extensive guidance on the measurement of photometric and colorimetric characteristics is provided in *SAE-ARP-1782*.

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 Combat Talon II 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 are also backup instruments which will provide adequate data for instrument flight even if the main 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.

Redundant or backup modes must be tested periodically; otherwise they may not work when needed.

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

Redundancy requirements and verification may be integrated with a safety analysis, where the probability of a failure which results in a hazardous event is assessed and controlled. FAA FAR part 25, Section 25.1309 and AC No. 25.1309-1A provide guidance on probabilities of failure which should be achieved for functions which have minor, major, or catastrophic consequences.

3.2.1.2 Lighting color. 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.

APPENDIX

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. AFGS-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 (NVGs), the spectrum of all emitted light must be closely controlled. (See Section 3.2.1.9) The goal is to prevent excessive red and infrared light from the cockpit from being sensed by the NVGs, causing their sensitivity to the extremely dim outside scene to be reduced.

On the HH-60, it was required that less than 1% of the CRT display's total light output would be in the spectral range beyond 600 nanometers (red and infrared). This was achieved with monochrome CRTs using P-43 phosphor and a narrow bandpass green filter. While this proved to be operationally compatible with Class A devices, the emissions were higher than allowed by MIL-L-85762.

AFGS-87240 defines requirements (similar to those in MIL-L-85762A, Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible) 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 covers a similar set of NVG compatibility criteria. If NVG compatibility is required, a measurable definition of compatibility must be put in the specification; for example, "as defined in AFGS-87240."

Some systems (particularly Army) 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 NVGs 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. Many programs specify the technology to be used (e.g., electroluminescent or incandescent) in order to achieve more uniform color, brightness, and aging characteristics.

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

Instrumental verification of lighting color can be accomplished in several ways. Measurements with a spectral radiometer are the most accurate, but the measuring systems are expensive and require considerable user expertise. For P-43 CRTs and other spectrally concentrated sources, radiometric measurements are the only reliable means of color determination. This includes other phosphor-lighted displays as well, including flat panel liquid crystal displays illuminated by fluorescent lamps.

Other means of verification have been developed, tailored to specific lighting schemes. For example, Air Force Blue-Filtered White Light and Instrument Panel Lighting(IPL) White light color measurements can be performed using a properly calibrated four filter colorimeter (photometer) as the measuring device. This technique works well for filtered incandescent technology because energy is measurable through each of the four tristimulus color matching functions (filters in the photometer), and the mathematics are straightforward and easy to use. This technique does not work well if energy is not measurable through each of the four filters. A second example is the ratiometric method of measuring Instrument Panel Lighting (IPL) Red, Aviation Red, and Identification Red light to be a minimum saturation level when compared to a calibrated National Bureau of Standards (now the National Institute of Standards and Technology NIST) red limit filter.

When color is relatively consistent from unit to unit, a visual comparison with a reference standard is often used in production acceptance tests to minimize cost. Visual tests are quick and low cost, and have high probability of success when the standard is close to the nominal requirement for color, the standard is the same physical size as the device under test, and the inspector is light adapted suitably for the task at hand. Visual tests are necessarily subjective, so it is important to have an objective test specified as a backup to resolve any disputes. Additional guidance is found in MIL-L-85240, MIL-L-85762, MIL-P-7788, MIL-C-27160, MIL-C-25050, and MIL-L-25467.

VERIFICATION LESSONS LEARNED

3.2.1.3 Symbology. The equipment shall be capable of generating and displaying each of the symbols shown and described in __________. All of the symbols in figure __________ shall be displayable simultaneously at sufficient update rate to prevent visible jerking and sufficient refresh rate to prevent flicker. The equipment shall be capable of generating:

a. __________polygons

b. __________layers of occlusion

c. __________flashing symbols

d. __________shadowing (for contrast enhancement)

e. __________colors

f. __________alphanumeric characters

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 or in a separate cockpit design description document resulting from simulations, pilot inputs, etc. MIL-STD-1787, Aircraft Display Symbology, has been widely coordinated and should be used as far as possible. 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 MIL-STD-1295 (for helicopters).

MIL-STD-1787 (rev. B draft) has specific requirements on primary flight symbology.

Display processor performance in terms of the number of polygons it can process, the number of occlusion layers, etc. is relatively new, and it is not clear what requirements are appropriate for the various types of aircraft displays.

A Helmet Mounted Sight (HMS) or Helmet Mounted Display (HMD) has the unique ability to display symbols over the entire field of regard of the system (up to 4π steradians, i.e., all directions), and can present them stabilized (fixed) relative to the earth, relative to the aircraft, or relative to the pilot's head.

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 for critical alerting functions, 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" in place of the data 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, successful operational systems, 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 or pixels 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 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 3.3 x 2.6 mm. 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 5 mm 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. (See also 3.2.1.3.3, Guidance.)

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 VCRs.

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 CRTs, 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 incoming data is 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% 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 3,400 cd/m^2 (1,000 fL) has been used for HUDs 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 3,400* cd/m^2 *(1,000 fL)* luminance (e = base of natural logarithms, or 2.72). 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.

The concept of "line width" is different on matrix-type displays, such as an LED array or LCD matrix, where lines have sharp edges rather than a gaussian profile. On these displays, the width of a line in pixels should be stated. Crude characters can be made with a one-pixel wide line; two-pixel wide lines allow for smaller "notches" and some fail redundancy, since one stuck pixel or line cannot destroy the character. (See "Improve Character Readability In Spite of Pixel Failures: A Better Font", Jim Uphause et al, NAECON '90) Three- to five-pixel linewidths are needed to produce smooth curves and uniform linewidth at all orientations. SAE ARP 4256, "Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft" recommends that minimum linewith be not less than 70% of maximum linewidth at any orientation.

REQUIREMENT LESSONS LEARNED

HUDs 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 mezuring 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-aperture 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 and a positive indication of the failure condition provided. 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, HUDs 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 HUDs. 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 been developing slowly. For further discussion, see *4.2.1.1* and *3.2.1.3* herein and the specific requirements of MIL-STD-1787.

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.

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 10% minimum modulation when one half of the scan lines are "on" while operating in __________ raster format. The horizontal resolution shall be __________ lines per __________ minimum with a 10% 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)

Resolution represents the display's ability to present sharp edges and details in an image. 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.

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 10% modulation with one half the raster lines turned on and the alternate ones turned off.

Horizontal resolution is normally specified in "lines", either per inch, per picture width, or per picture height, and should not be confused with the number of raster lines. "TV lines per picture height" are the units for CRT horizontal resolution in EIA-RS-170. Resolution is sometimes specified in line pairs per cm (or per inch). Since one "line pair" is the same as two "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% 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% modulation (100 x C_m, see section 6) at low spatial frequencies , then gradually rolls off at higher frequencies and passes through the 10% 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% 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% modulation at 400 lines rather than 10% 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 lines, the display should have resolution (at 10% modulation) 20% to 50% 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% 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	500
CT-II 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 photometer (may use a slit aperture), 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.

APPENDIX

VERIFICATION GUIDANCE

On displays with discrete visible pixels, pixel density can be verified by inspection, counting the pixels with an inspection microscope. However, this does not fully characterize image sharpness. The visual sharpness and image quality on a matrix display (such as an LCD) is dependent on the line-forming algorithm (antialiasing) and spatial, temporal and chromatic noise content, in addition to the actual number of pixels resolution. The pitch-and-linewidth measurement approach discussed below may be used on a matrix display to assess anti-aliased line profile if the software can provide for sweeping a line across the screen in known spatial increments. In this case, a photometer is focused on a single addressable element to make the measurement. As the line is swept past the measured element, each of the gray levels of the line may be measured as a function of the line position. Note, however, that this primarily provides a means of validating the line-writing algorithm, which in turn determines the intended shape of the line's luminance profile. It does not give any indication of other image quality attributes such as spatial noise induced by the sampled reconstruction nature of the x-y matrix, nor of orientation or position dependencies of image quality (resolution, and spatial and chromatic noise).

At the specified resolution, a CRT 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 separately, 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 in section 6. The input signal is assumed to be 100% modulated, i.e., 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.

This test tends to be difficult and time-consuming; visual inspection of a resolution test pattern may be used in production acceptance tests if the specified requirement is consistently met (as verified with the scanning photometer).

Accurate, repeatable resolution tests for patterned-screen CRTs (shadow mask or beam index) are not in general use. While the scanning slit test might be useful at low resolutions on these CRTs, airborne color CRTs 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 CRTs) 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 (See *TEP 105-9*, "Line Profile Measurements in Shadow Mask and Other Structured Screen Cathode Ray Tubes".) The photometer must have a small enough aperture to be focussed on one phosphor dot and exclude light from other dots.

SAE ARP-1782 provides additional guidance on resolution testing technique for CRTs.

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, contrast, and viewing angle. The luminance, contrast, and viewing angle requirements of the following subparagraphs shall be met when measured from the design eye position. The display luminance and contrast shall not change more than ± __________% 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

Luminance change associated with mode changes should not exceed 40%. 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. (See 3.2.1.6.7, Viewing Angle.)

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 and contrast 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

Two major causes have been identified for errors in luminance measurements on test units exhibiting highly saturated color or short spikes of light output (e.g., CRTs with P-43 or P-53 green phosphor).

The first relates to the spectral properties of the light source. The accuracy of a spot photometer can be degraded by as much as 30% (potentially more) if the photopic response of the photometer's filter/photomultiplier tube combination deviates significantly from the ideal CIE Y luminosity function. This problem is most evident for strongly colored light sources, particularly for blue and red primary colors. Luminance correction factors can be generated from the spectral energy distribution of the colored source and the spectral response of the photometer, as follows:

$$\text{Factor} = \frac{\int [(\text{CIE Y luminosity function}) * (\text{Spectral energy distribution of colored source})]}{\int [(\text{Photometer spectral response}) * (\text{Spectral energy distribution of colored source})]}$$

One-nm wavelength increments are needed for sources exhibiting narrow emission bands, while larger wavelength increments (i.e., 5 nm) may suffice for broader band sources (e.g., incandescent). The CIE Y luminosity function ("photopic curve") can be obtained from a photometer manual. The spectral energy distribution of the colored source must be measured on a similar sample using a spectral radiometer. The photometer spectral response can be obtained from the photometer manufacturer.

The second luminance measurement problem arises from the inability of a photometer to respond dynamically to bright, concentrated, light sources such as the moving spot of a CRT. This problem has been observed with monochrome (GY, or P-43) CRTs at luminance greater than 686 cd/m^2 (200 fL). It is possible for a very high momentary peak brightness to cause the photometer electronics to saturate, clipping the signal. All photometers respond differently, but all photometers will read erroneously low in this circumstance. Some photometers give a warning of such an over-range condition.

Most photometers are equipped with neutral density (ND) filters. When measuring CRTs, it is recommended that the highest attenuation filter be used which will still give the needed number of significant digits in the luminance result. This will help ensure that the peak luminance is within the dynamic range of the photometer. However, in some cases (e.g., high luminance CRT displays) the maximum available attenuation may not be sufficient for accurate luminance measurements. For example, an F-117 display produced such an over-range with an ND-4 (four orders of magnitude attenuation). An accurate measurement of luminance could only be obtained with an additional attenuation of ND-2 (total attenuation of ND-6).

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 fL) and color temperature of 3,000 to 5,000 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 34,000 cd/m^2 ambient background shall be a minimum of __________ with a design goal of 0.5. Luminance shall not degrade more than __________% when measured from anywhere within __________ cm of the design eye position.

REQUIREMENT RATIONALE (3.2.1.6.1)

HUD brightness is critical for performance in sunshine.

REQUIREMENT GUIDANCE

This requirement applies only to HUDs. Line luminance of 5440 cd/m^2 (1,600 fL) and contrast of 0.2 (contrast ratio of 1.2:1) is quite feasible and provides symbols viewable in full sunshine. Design goals of 17,000 cd/m^2 (5,000 fL) and contrast of 0.5 would provide more comfortable viewing in very bright conditions. Note that this is a lower contrast than is recommended for head down displays, but is adequate for a HUD because a HUD is much brighter, there is color contrast between green HUD symbols and the background, and large, single-shade graphics are used.

There is normally no need to specify contrast in the dark on a CRT-based HUD, since the CRT can easily achieve contrast of over 100 in the dark. If other display technology is used (such as LCDs) that do not have a very black background, there will be "background glow" projected onto the outside scene, which is very difficult to see through. This can also be a problem on panel (head down) displays, where the "background glow" amounts to stray light being emitted into the cockpit, where it will cause reflections in the canopy/windshields.

Note that the ambient for a HUD is specified in units of luminance (cd/m^2 or fL) of the background rather than the illuminance units used for panel displays. This is because the imagery is projected onto the outside world, and is seen relative to the brightness of that outside scene, not the illumination level in the cockpit.

Head motion requirements are important where diffraction optics and/or directional filters are used, since there is generally a loss of on-axis luminance performance as the exit pupil is made larger (allowable eye motion increased). 25% maximum luminance degradation within 2 cm of the design eye position has been specified for a HUD; this appears to be a bare minimum.

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 Verification of HUD stroke-written line luminance. 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 3,000 to 5,000 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 HUDs 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 fL) background with a contrast of 7.0 has been demonstrated. This is not bright enough for viewability in full sunshine but may be usable against dark backgrounds like dirt or trees in daylight. 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 Verification of HUD raster luminance. 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 (between brightest and darkest shade) shall be __________ minimum. The ratio between adjacent gray shades shall be a minimum of 1.4:1 (contrast of 0.4). The difference luminance (nL) 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 (diffuse and specular) 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 of the worst case environment for the display technology being used and the appropriate aircraft types should be filled in, 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 (e.g., 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 multicolor 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 but is now included in MIL-L-85762 and SAE ARP-1782. 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 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/m2 (2,000 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 (8,000-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 CRTs; it is actually the inner surfaces, rather than the front surface, that contribute most of the specular reflections on an LCD.

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

	Sunshine ambient			Indoor enclosed cabin	Dark
	Bubble canopy	Cockpit with roof	Shaded		
Diffuse illumination					
lux	108,000	86,000	3240	540	0
fc	10,000	8000	300	50	0
Glare source					
cd/m^2	6800	6800	6800	3400	0
fL	2000	2000	2000	1000	0

NOTES:

1. The bubble canopy (fighter cockpit) environment assumes a bubble canopy and good display placement (i.e., 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 "shaded" environment actually occurs most of the time for displays in an instrument panel under a glare shield. (See "Multifunction Displays optimized for viewability", R. Hockenbrock and J. Murch, SPIE vol. 1117, Display system optics II (1989).) The low diffuse ambient makes it impossible for a display without high light output or high reflectance to have the high delta luminance needed for good legibility in this environment. The "10,000 fc" environment has been used by itself as a legibility criteria, leading to displays that are optimized for that rare case but not designed for good legibility in the normal (shaded) environment. It may be more appropriate to require high luminance and contrast capability in the "shaded" environment and only require minimal performance in the sunshine environment.

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

5. 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° of perpendicular.

Table II provides suggested contrast requirements based on a variety of human factors tests and practical experience with existing aircraft displays. They represent the monochrome contrast needed to assure rapid, accurate reading of the information in a wide variety of lighting, stress, and vibration environments—i.e., a fully legible display. Information with lower contrast may still be visible and readable but will look washed out in some situations and may not provide the reading speed and accuracy required.

It is desirable to limit the shift in luminance to about 20:1 when the operator looks from the display to a 34,000 cd/m^2 (10,000 fL) cloud and back. So far it has been possible to achieve about 50:1. To get a 50:1 value, specify a difference luminance (ΔL) of 680 cd/m^2 (200 fL) between the display highlights and the display background at the brightest setting. When a display is located low in the cockpit, where the outside scene is not in the eye's instantaneous field of view at the same time as the display, the problem of veiling glare becomes less severe, and this number can be decreased to 340 cd/m^2 (100 fL). In an office or enclosed cabin environment, luminance difference of 35 cd/m^2 (10 fL) is adequate, although most users prefer higher luminance (170 cd/m^2 or 50 fL).

APPENDIX

TABLE II. Suggested contrast requirements.

	Required contrast	Goal contrast	Contrast compensations for other character h and SW
Numbers only	$\geq$1.5 for h = 5.0mm and 0.12h $\leq$ SW $\leq$0.2h	2-20	Multiply required contrast by 5.0/h for 2.5 $\leq$ h $\leq$ 7.5mm and by 0.12h/SW for 0.01h $\leq$ SW $\leq$ 0.12h
Alpha-numerics	$\geq$2.0 for h = 5.0mm and 0.12h $\leq$ SW $\leq$ 0.2h	3-20	
Graphics and alpha-numerics	$\geq$3.0	3-20	
Video	$\geq$4.66	20-50	

NOTES:

1. h is character height, SW is character stroke width. Character height should never be less than 2.5mm. This table assumes a 76-cm viewing distance.

2. The 4.66 overall contrast for video represents 6 shades of gray (5 steps), each a minimum of $\sqrt{2}$ (approx. 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 CRTs, 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 (e.g., 64 shades of each primary color), 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 a reflective LCD or painted instrument. The worst-case environment for the particular display technology should be substituted.

4. The minimum required contrast for video has been met with monochrome CRTs in sunshine, 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} of up to 0.25 may be acceptable where visible segments are not objectionable.

6. On hybrid (stroke and raster combined) CRTs, stroke-written symbols are normally brighter and higher contrast than raster symbols and video, due to inherent characteristics of CRTs. 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. High display luminance (dL) is required to minimize the time required for the eyes to adapt from high exterior luminance (tops of clouds or fresh snow in sunshine) to the lower luminance of the displays, and to overcome veiling glare (when flying toward the sun). This is a different consideration from contrast in the display, which relates more to detection time for features within the display.

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, power dissipation, etc.) in an equipment design, so tailoring the requirement based on critically of the information being displayed and capability of the display technology available may be appropriate.

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 that have adequate contrast ratio but do not emit or reflect enough light to minimize time required for eye adaptation and 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 specular glare source luminance specified in section 3 herein. Light sources used shall have a color temperature between 3,000 and 5,000 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.

nL, (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 nL does not change under varying lighting conditions, L_t can be calculated by measuring nL 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.

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. A similar procedure is required by *SAE ARP-1782* and by *MIL-L-85762*.

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.

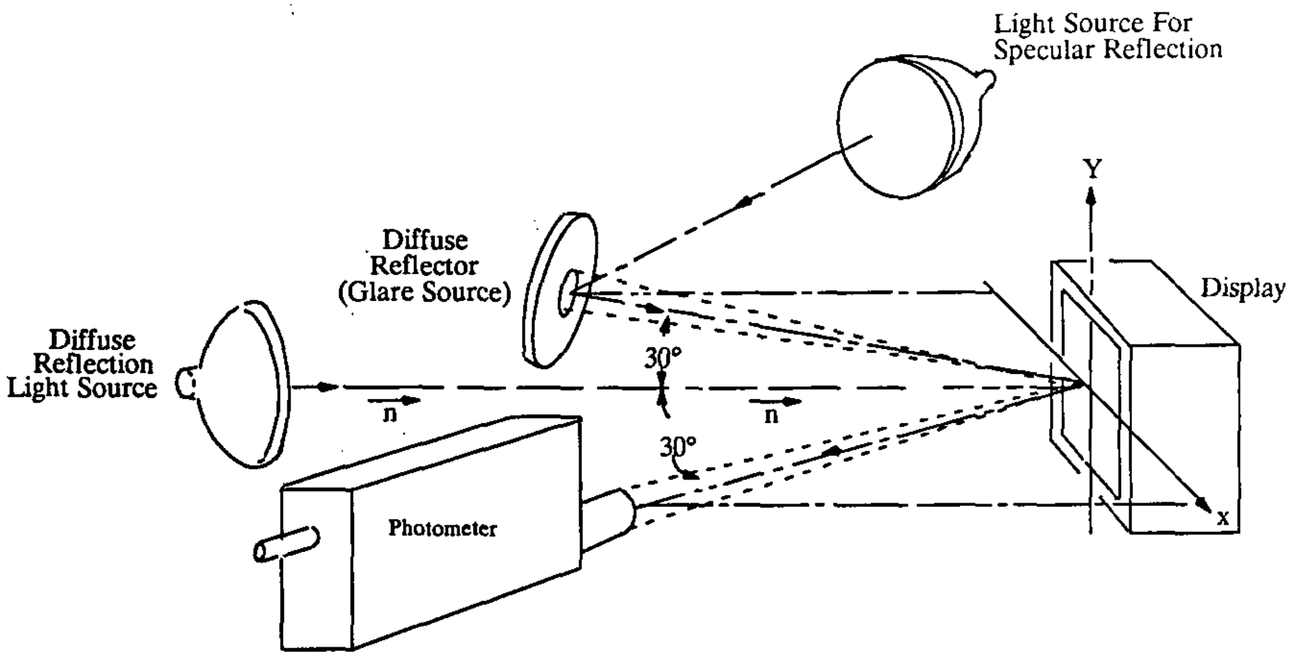

FIGURE 2. Combined specular and diffuse measurement setup.

NOTES:

1. Luminance of the glare source is measured by putting a mirror (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° 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).

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 CRTs, (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 CRTs, 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. Distances and angles in this test setup are not critical.

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. A diffuse illuminating sphere may also be used if it is modified to allow independent adjustment of the specular and diffuse reflections. With a normal diffuse illuminating sphere, 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 because of the different terminology and techniques, but because of the different display media. For example, contrast requirements for avionics CRTs 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 Dimming range. The equipment shall be dimmable to a level of __________ cd/m^2 (peak brightness) in a dark ambient.

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. (Also see *3.2.1.21*.)

In some displays, this is a separate mode activated by a "day/night" or "day/auto/night" switch, which changes the range of brightness and contrast controls.

A dimming range was not generally specified on head-down CRT displays, since adequate range was available as long as suitable controls were provided. Adequate range may be difficult to achieve on other technology displays. Dimming to 0.34 cd/m^2 (0.1 fL) has been used, but it is still too bright to allow fully dark-adapted vision of the outside scene. Measured data indicates that some pilots used electromechanical instruments at settings as low as 0.01 cd/m^2 (0.003 fL). Some existing flat panel displays are specified at 0.034 or 0.102 cd/m^2 (0.01 or 0.03 fL). While this is too dim to make use of the eye's full resolution capability, it allows the display to still provide critical information when turned down to a level that does not produce serious canopy reflections.

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/m2, 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/m2."

REQUIREMENT LESSONS LEARNED

In the F-16, "blank" formats were made available on the MFDs to allow the pilot to eliminate canopy reflections when the MFDs were not in use. A data entry display that produced 0.34 cd/m^2 (0.1 fL) was declared "too bright" by pilots and was changed to 0.034 cd/m^2 (0.01 fl).

Some older CRT-based HUDs had a "background glow" problem at night because the CRT was not properly blanked in areas not presenting symbols. The image source in a HUD or HMD must have a very high contrast to prevent this problem. Special color tracking circuitry was required on some color CRTs because the three color guns did not all dim together.

4.2.1.6.4 Verification of dimming range. The requirements of 4.2.1.6 apply.

3.2.1.6.5 Chromaticity difference. The chromaticity 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, Merrifield, and their colleagues 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, chromaticity 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. Chromaticity 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 (abbreviated 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. (See "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:

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

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

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

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

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 illuminant 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 Verification of chromaticity difference. 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 symbol or symbol segment and the average within any circle whose diameter is one-fourth the display's minimum dimension shall not exceed ___________% of the average value. Total variation across the display shall not exceed ___________.

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

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

Large area uniformity of ±20% within 1/4 of the display and ±40% 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. A much tighter requirement is needed between adjacent pixels or segments in a display made up of discrete elements, especially if the non-uniformities form patterns, such as rows or columns. (See 3.2.1.6.8, Blemishes.) Uniformity must be specified at high and low brightness to assure uniform controllability at low levels.

Note that uniformity is defined as:

$$\frac{\text{max or min luminance} - \text{average luminance}}{\text{average luminance}} \quad \text{(times 100 to get percent)}$$

which is numerically equivalent to:

$$\frac{\text{max luminance} - \text{min luminance}}{\text{max luminance} + \text{min luminance}} \quad \text{(times 100 to get percent)}$$

where average luminance is defined as: (max + min) /2

REQUIREMENT LESSONS LEARNED

Some systems have non-uniformity of ±50% (3:1), or even more, between the center and the edges, and this is not objectionable if it is a uniform brightness falloff over a large area.

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 that the display is usable.

VERIFICATION GUIDANCE

Verification should be based on luminance measurements.

VERIFICATION LESSONS LEARNED

3.2.1.6.7 Viewing angle. Viewing angle shall be at least +__________ degrees up, -__________ degrees down,__________ degrees left, and __________ degrees right, relative to the central axis of the display. Criteria for "viewing" are:

a.

b.

c.

REQUIREMENT LESSONS LEARNED

Displays with thick bezels or protruding controls may block the view of the operator. Certain display technologies, including LCDs and any display using pupil-forming optics or a directional filter, may have narrow viewing angles.

REQUIREMENT GUIDANCE

Required angles depend on the geometry of the planned installation (and any other potential installations) taking into account the need to see the far edge of the display. For example, a display on the centerline of a single seat aircraft can have narrow viewing angles (less than 20°). A side-by-side cockpit may require at least some readability from across the cockpit, which may exceed 45° (depending on viewing distance and width of cockpit). Possible criteria include:

a. No display face blockage by bezel or controls.

b. No critical information blocked by bezel or controls.

c. No contrast reversal or color reversal

d. Contrast does not degrade to less than 70% of the value on axis.

e. Contrast does not degrade to less than 3.0.

f. No visible change in color or loss of contrast.

g. Information remains readable.

The criteria chosen (more than one may be needed) depends on the criticality of the information. Stating angles as up, down, left, and right from normal allows for asymmetrical situations (which are common) and eliminates the confusion over total viewing angle vs. angle from normal.

REQUIREMENT LESSONS LEARNED

LCDs have had difficulty achieving wide viewing angles, especially when driven with shades of gray (video); any viewing angle characteristics specified should be evaluated in a cockpit mockup to verify they are adequate, but not excessive. Devices which reflect or radiate light from a diffuse surface or gas (painted instruments, CRTs, plasma displays) generally have very wide viewing angles, limited only by bezel blockage, curvature of the display face, or off-axis reflections in the cover glass.

4.2.1.6.7 Verification of viewing angle. Viewing angles shall be determined by__________.

VERIFICATION RATIONALE

Angles must be verified to insure the display will be visible from the operators location.

VERIFICATION GUIDANCE

Measurement or evaluation of design data should be used for verification.

VERIFICATION LESSONS LEARNED

3.2.1.6.8 Blemishes. There shall no visible blemishes on the display face when viewed from the normal viewing distance. Blemishes shall be defined as any area where__________.

REQUIREMENT RATIONALE

Blemishes, or small area non-uniformities, are distracting and esthetically undesirable, and, if large and/or high brightness, can obscure information.

REQUIREMENT GUIDANCE

Blemishes include stuck or missing pixels or lines, bubbles, pits, or scratches in glass, and small area nonuniformities in brightness or contrast. The eye is sensitive to "edges," i.e., places where contrast changes over a short distance. Small variations in brightness that do not violate the (large area) uniformity requirement herein are often obvious and objectionable.

The criteria of MIL-E-1 have been used in the procurement of CRT bulbs. Blemishes are sometimes not mentioned in display system specifications, since it is generally understood that visible blemishes are objectionable, and detail blemish criteria should be in the CRT or other display component specifications. Additional blemish specifications relating to the phosphor screens themselves have not been standardized. When present, they are frequently drawn from commercial CRT specifications, or generated in consideration of the needs of the application. In monochrome CRTs, phosphor screen defects are considered and counted the same as defects in the glass. In color CRTs, the screen defects are identified and specified uniquely based on maximum allowable size and number, minimum spacing between blemishes and contrast of the defect with respect to the surround.

For irregular blemishes, their size may be defined as the smaller value given by one of the two relationships,

[1] Size = (Length + Width)/2

[2] Size = Length/10 + 2* Width

The following criteria have been used for an Active Matrix Liquid Crystal Display:

a. Bubbles, transparent or opaque flaws, pits, voids, delaminations, or dark spots shall meet the following criteria:

None exceeding 0.4 mm.
No more than two between 0.25 mm and 0.4 mm, and no less than twelve mm apart.
No more than five between 0.12 and 0.25 mm, and no less than six mm apart.

b. With a flat field signal applied, luminance of the display (including backlight) shall vary no more than ± 10% from the average within any 10-mm diameter zone. Luminance measurements shall be based on an approximately 1-mm diameter area.

c. No two failed pixels within a ten-pixel radius of each other (also precludes any failed rows or columns); No more than three failed pixels within a 25 mm circle; Total number of failed pixels shall not exceed 0.01% (~0.005% in some cases) of all pixels. Any display element within a color pixel that is more than 30% brighter or dimmer than similar nearby elements is considered a failure of the pixel.

d. For an array with less than three pixels per mm (76 pixels per inch), no failed pixels are allowed at delivery; Single pixel failures in the field may not require replacement if they do not degrade character or symbol legibility.

Rectangular targets with contrast of 0.02 are visible when they have an area of 20 x 20 minutes of arc (approx. 4 mm square at 76 cm (30") viewing distance). Targets with contrast = 0.04 are visible when they have an area of 5 x 5 minutes of arc (approx 1 mm square). (Under laboratory conditions—see "Engineering Data Compendium, Human Perception and Performance", Boff & Lincoln, Armstrong Research Labs, 1988, sect. 1.625.)

REQUIREMENT LESSONS LEARNED

A blemish about 2 mm in diameter with contrast of 0.1 darker than its surroundings was observed to be clearly visible and distracting on one display panel.

4.2.1.6.8 Verification of blemishes. Verification shall be by__________.

VERIFICATION RATIONALE

If any blemishes are visible, they must be assessed to determine if they meet the acceptance criteria.

VERIFICATION GUIDANCE

Visual inspection should be used to find any visible nonuniformities. Any nonuniformities found should be measured with a spot photometer to determine compliance.

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 CRTs), measurement will be difficult 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 standard colors. 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.

Monochrome airborne CRT displays are generally green because:

a. GY 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 (NVGs).

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.

Type GY phosphor (designated "P-43" in the old 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. GJ (P-1), YB (P-3), GX (P-44),and KJ (P-53) are also appropriate in some cases. Color CRTs often use X (P-22) which is available in red, green, and blue formulations. See EIA-TEP-116-B, "Optical Characteristics of CRTs", which covers characteristics of all registered phosphors.

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.

LCD matrix displays have inherently different characteristics; for example, the saturation of colors does not change appreciably with ambient light levels on active matrix LCDs (AMLCDs) which have color filters over each subpixel. A color filter is used to give each subpixel its desired primary color, but it also serves to absorb most of the reflected (white) ambient light.

REQUIREMENT LESSONS LEARNED

Specifying the color coordinates of the phosphors on color CRTs 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 3.2.1.6.5 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 CRTs 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

Specific test procedures must acknowledge the limitations (measurement uncertainty) of the measuring instruments. Spectroradiometers will provide the most accurate color measurement, but are also relatively slow in making the determination. At the other extreme, small hand held colorimeters permit rapid color determination, but the accuracy of the measurement depends upon the accuracy with which the color filters and spectral response of the instrument emulates the CIE chromaticity curves. Correction factors have been found useful in the latter case when determined for each color, and provided the colors measured do not vary greatly in color coordinates.

3.2.1.9 Night Vision Imaging System (NVIS) requirements. The display unit shall be operationally compatible with Class __________ NVIS and shall not produce an NR value equal to or greater than __________.

REQUIREMENT RATIONALE (3.2.1.9)

Night Vision Imaging System compatibility is required of many avionic displays, whether to allow immediate use of NVGs, to allow for future growth to use NVGs, or to minimize the emission of IR and light from the cockpit to reduce observability.

REQUIREMENT GUIDANCE

MIL-L-87240 provides extensive guidance on aircraft lighting, including a section on NVIS compatibility which includes the compatibility requirements of the tri-service specification MIL-L-85762A. The requirements in MIL-L-85762A are most often invoked as specified. However, some tailoring may be appropriate. Some user communities feel the NVIS radiance levels specified in MIL-L-85762A are too stringent for their applications, particularly non-helicopter users. Over- specification of NVIS requirements will constrain other important display parameters, most notably maximum display luminance available for daylight operation. State-of-the-art performance available must be considered to avoid mutual conflicts among maximum luminance and contrast (for daylight readability), color (multi-color vs monochrome) and NVIS (Class A or Class B) performance requirements. Display size may also be a consideration, particularly in raster-scanned CRTS where maximum achievable luminance varies as the inverse of display area.

REQUIREMENT LESSONS LEARNED

MIL-L-85762A establishes limits on radiant power of emissions within the sensitivity envelope of NVIS. Two classes of NVIS are specified, Class A and Class B. The difference in the two is the cutoff point of the minus-blue (long pass) filter used on all third generation aviators NVIS to reduce their response to visible light from the cockpit. 50% NVIS response is at approximately 630 nm for Class A and 660 nm for Class B NVIS. Class B NVIS allows limited color capability in the cockpit, but at the expense of reduced sensitivity overall (a consequence of the filter cut-on point). The Class A NVIS radiance limit of 1.7×10^{-10} NVIS Radiance Class A units (NR_A) cannot be applied to a multicolor display that uses red and/or yellow. It has been shown to be mathematically impossible to meet the Class A NVIS limit in the presence of such longer wavelength visible emissions. The higher Class B limits were devised for color displays.

The standard red and green colors called out in MIL-L-85762 have been used as requirements on electronic displays, but these color requirements only apply to the extent that those displays are used to present warnings and cautions which must be of standard color.

A color CRT operating in a monochrome green mode typically will not meet the Class A requirements due to emission of unselected colors cause by scattered electrons. The P-43 and P-53 green phosphors generally used in monochrome avionic displays also have emissions at longer wavelengths which will cause the display to fail a Class A requirement unless properly filtered. The optical absorption necessary to achieve NVIS compatibility per MIL-L-85762A results in absorption of visible light as well, limiting the luminance achievable in the display. For cockpit displays where luminance is a priority, the NVIS Radiance requirement may force a trade off between maximum luminance and level of compatibility achieved.

Monochrome operation of color active matrix liquid crystal displays also may not meet the Class A requirement because the individual color filters are not sufficiently dense in the IR to attenuate the NVIS Radiance. The pixels of the panel all emit similar amounts of infrared energy whether or not the pixels are activated.

4.2.1.9 Verification of NVIS. NVIS radiance performance should be evaluated by individuals or organizations that have demonstrated technical competence to the Joint Aeronautical Commanders Group, Tri-Service Lighting Committee, Naval Air Systems Command, Washington DC or to Naval Avionics Center in Indianapolis, IN. Test methods and equipment of __________ shall be used.

VERIFICATION RATIONALE (4.2.1.9)

Compliance must be verified to insure the required low levels of infrared and red emissions are achieved.

VERIFICATION GUIDANCE

Measurement of NVIS compatibility in accordance with MIL-L-85762A is technically challenging if rigorous accuracy is required. There are several means of determining NVIS compatibility with ease of measurement generally inversely proportional to the accuracy required.

The scanning spectroradiometer may be used to obtain best accuracy. However, a very complete understanding of noise thresholds and other error sources is required, as well as means for error mitigation, in order to successfully use this type of system. In particular, significant errors may be made with narrow-band emitting sources, and with test units which have both fixed and variable infrared emissions (e.g., incandescent filament and phosphor screen, respectively, in a CRT).

The MIL-L-85762A Appendix B measuring system performance validation routines intended to demonstrate the fitness of a measuring system to perform NVIS radiance measurements work well if the measuring system is used to measure broad band emission sources (it was developed around filtered incandescent sources).

Spectroradiometer errors can be serious for highly saturated sources such as a P-43 CRT. In cases where the display performance can be mathematically validated to provide radiance levels below the sensitivity threshold of the measuring system, a direct measurement of NVIS radiance is not in itself adequate to determine display compliance. For example, the mathematical evaluation of the individual components that comprise a P-43 CRT (unfiltered emission spectra of the phosphor and spectral transmittance of the contrast enhancement filter designed to provide NVIS compliance) indicate the NVIS performance of the integrated display unit to be below the Class A limit as specified in MIL-L-85762A. A direct measurement with a good spectroradiometer will not support this because the detectors aren't sensitive enough (noise level is greater than signal level in parts of the spectrum). Radiance values that are calculated from system noise will indicate a small but finite value of emitted power that is three or more orders of magnitude above the actual performance of the display. The mathematical protocol defined in MIL-L-85762A modifies (amplifies) the small but erroneous power (radiance) and causes the display to be measured non-compliant.

MIL-L-85762A also does not accurately account for sources (such as CRTs and flat panel displays) that have both fixed and variable sources of NVIS-sensitive emissions. In a CRT, as well as in the fluorescent tubes used to backlight LCDs, the hot filament produces relatively constant IR emissions, while the phosphor produces emissions proportional to luminance. MIL-L-85762 allows measuring the display at a brighter setting and then scaling down the results to the specified luminance of 1.7 cd/m^2 (0.5 fL). Since the IR emissions do not go down proportionally, this can allow a display with excessive emissions to pass the test.

The quickest and most straightforward validation method is a direct visual comparison of the test object and a carefully calibrated threshold radiance standard, viewed through a properly filtered GEN III NVIS inspection device (GEN III monocular, for example). The threshold radiance standard must be a device that can be accurately characterized. An NVIS compatible, filtered incandescent light source which has measurable energies at all wavelengths within the NVIS sensitivity envelope is ideal for this purpose.

The GEN III NVIS inspection device must also be carefully characterized by a qualified standards house because the exact caracteristics of the minus-blue filter can have a profound effect on the compatibility observations, particularly if the light spectrum of the test object differs significantly from that of the reference standard.

NVIS spot radiance meters may also be used, with more accurate results, when calibrated with a calibrated threshold radiance standard or conventional luminance standard with suitable calibrated attenuators to reduce the light source output appropriately. The spectral output of such a standard need not resemble the unit under test.

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 system 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' should be minimized, 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). Separate brightness controls for symbology and raster are generally needed to optimize the picture. Gamma, or the non-linear relationship between video signal voltage and desired display luminance, must also be specified in some cases.

REQUIREMENT LESSONS LEARNED

On color CRTs, when the symbols are overlayed on a different color background, 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.

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 __________% 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 HUDs with "200%" 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 ___________ (3σ). 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 are 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 may be excessive compared to the aesthetic value of a "clean" display.

REQUIREMENT LESSONS LEARNED

A standard 30-Hz frame, 60-Hz field (2:1 interlaced) raster video is widely used on CRTs. Stroke-written graphics and computer-generated raster graphics with thin lines are written at 50 Hz or higher. LCDs generally must be driven with symmetric drive voltages; any asymmetry in this system results in flicker at 1/2 the frame rate, so they must typically be driven above 75 Hz to prevent visible flicker.

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 __________% in height or __________% 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%.

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 ± __________% 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% has been used for a HUD. In some cases where stroke and raster are used on the same display, the registration between the two is more important.

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 ___________% 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% have been applied to CRT based systems. Distortion of 2% has been allowed for many systems, and is normally adequate.

REQUIREMENT LESSONS LEARNED

Distortion and linearity errors of less than 1% 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% 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 __________% of the primary symbol or video luminance.

b. Reflectivity of the display face shall not exceed __________%.

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% in current HUDs. This is achievable and reduces interference between secondary reflections and the displayed information. A limit of 0.5% 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 __________% 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% on existing HUDs. Note that 2.5% 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%) 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 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 34,000 cd/m2 (100 to 10,000 fL) has been used for a HUD. An ABC for a head-down display in a fighter cockpit was specified to be suitable for ambient illuminations from 1,080 to 108,000 lux (100 to 10,000 fc). However, this is a relatively useless range since there is really no need to dim a display in this environment.

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

1. Multiple sensors and a hysteresis function 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). A system that dims displays while sun is shining in the pilots eyes is doomed to failure.

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 HUDs. ABCs 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 practical with existing technology. Tight tolerances are not necessary.

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 Warmup 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-warmup longer than the period of power loss.

REQUIREMENT RATIONALE (3.2.1.20)

Prompt warmup 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 warmup 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.

LCDs do not function at low temperatures and must have built in heaters if the system is to start up quickly in a cold environment. A requirement that is compatible with LCDs but still provides a useable display during aircraft start is:

Display shall have a visible image within 30 seconds (at least 25% brightness and 1-Hz update rate) and meet specified performance within 5 minutes when starting at -40°C.

REQUIREMENT LESSONS LEARNED

CRTs have an inherently slow warmup because of their vacuum tube nature. The major problems associated with warmup of analog circuitry and mechanical devices have mostly disappeared with current digital hardware.

4.2.1.20 Warmup time. Warmup time shall be measured.

VERIFICATION RATIONALE (4.2.1.20)

Warmup 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 rotary 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.

"Bezel buttons" (also called "soft keys") are used on most multifunction displays. Ten to 24 programmable switches are arranged around the periphery of the display, with the label presented on the display adjacent to the switch.

Advantages of bezel buttons are:
- a. Minimum hardware to buy and maintain
- b. Minimum panel space occupied
- c. Switch labels and functions can be changed in software as design is refined or functions are added
- d. Less finger prints on glass (compared to touch panels)
- e. Tactile feedback (click) when buttons are pushed

Disadvantages are:
- a. Stuck with one switch arrangement
- b. Pushbuttons are not optimum for functions previously performed by rotary switches.
- c. No shape coding of switches
- d. Adds clutter to the video screen

"Soft knobs" have also been used, providing easy adjustment of functions traditionally controlled by a rotary control.

Separate video contrast, video brightness and symbol brightness controls are provided on many MFDs. Others have the relationship between video and symbol brightness fixed (set) by the design. If it is set, it must be changeable (by software or hardware adjustment) since the desired relationship depends upon the lighting environment and the video sources being used, and has had to be adjusted as a result of flight tests.

"Ganged" brightness controls, which adjust several displays at once, are used in some cases where there are several electronic displays of the same technology (similar dimming characteristics) in the cockpit, much as the traditional flight instruments lighting was ganged together.

REQUIREMENT LESSONS LEARNED

Modern display units use push buttons, rocker switches, 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. These devices eliminate the reliability problems of potentiometers and allow software to recall previous settings and automatically set up displays when modes or formats are changed.

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

VERIFICATION RATIONALE (4.2.1.21)

Availability of controls and smooth, easy operation must be verified.

VERIFICATION GUIDANCE

Verification is generally done by demonstration of the operation of the controls.

VERIFICATION LESSONS LEARNED

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

REQUIREMENT RATIONALE (3.2.1.22)

This requirement applies to equipment used on aircraft which are required to operate in a nuclear environment.

REQUIREMENT GUIDANCE

Characteristics of the nuclear effects which will be felt in the area where the equipment is installed should be determined and used in the specification. See also MIL-STD-1799.

REQUIREMENT LESSONS LEARNED

Nuclear effects generally apply to strategic aircraft, but have not been applied to tactical aircraft. Nuclear hardening or shielding will affect cost, weight, choice of materials, etc.

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

VERIFICATION RATIONALE (4.2.1.22)

Mission-critical displays must be tested to verify that they will continue to operate.

VERIFICATION GUIDANCE

Appropriate tests must be developed.

VERIFICATION LESSONS LEARNED

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.

REQUIREMENT RATIONALE (3.2.1.23)

Processor and software design characteristics are specified to promote commonality of hardware and software and the support equipment and training associated with them.

REQUIREMENT GUIDANCE

Air Force policy is to use the minimum number of different instruction sets (for example, MIL-STD-1750 for 16-bit processors) and Ada higher order language (HOL) except where specific circumstances make this impractical. A software specification or other software coding document should be referenced which defines the numerous other software design requirements. Software which controls symbol format should be contained in ultraviolet or electrically erasable PROM's, since it generally gets changed as a result of flight tests and changes to the aircraft or its mission. DoD-STD-2167 and DOD-STD-2168 provides requirements for software development and quality control. MIL-STD-1803C Software Development Integrity provides additional guidance.

The standard processor and higher order language requirement should apply to the general purpose processor portion of a symbol generator and not necessarily to the specialized hardware and software that converts the symbol commands into display primitives. The specialized software and hardware must operate in a high speed, real time environment to generate all the symbology in the required time. Hardware optimized for symbol generation and assembly language software or microcode optimized for speed is often used for this portion of the symbol generator.

REQUIREMENT LESSONS LEARNED

Special-purpose PALs and ASICs are often used in display processors.

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

VERIFICATION RATIONALE (4.2.1.23)

Compliance must be verified to assure that the processor and software can be efficiently maintained.

VERIFICATION GUIDANCE

A processor's compliance with MIL-STD-1750 can be certified by ASC/ENASC. Copies of the MIL-STD-1750 test software can be made available on request through ASD/ENASC. PROM type can be verified by evaluation of design data.

VERIFICATION LESSONS LEARNED

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.

REQUIREMENT RATIONALE (3.2.1.24.1)

Induced failures caused by overload can be greatly reduced by appropriate equipment design.

REQUIREMENT GUIDANCE

MIL-STD-454 provides appropriate overload requirements.

REQUIREMENT LESSONS LEARNED

4.2.1.24 Verification of damage protection

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

VERIFICATION RATIONALE (4.2.1.24.1)

Compliance must be verified to assure that excessive failures are not induced by overload.

VERIFICATION GUIDANCE

Demonstrations or analysis of circuitry should be performed.

VERIFICATION LESSONS LEARNED

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.

REQUIREMENT RATIONALE (3.2.1.24.2)

Equipment containing a CRT must have CRT protection to prevent damage to the expensive CRT.

REQUIREMENT GUIDANCE

The name of the equipment containing the CRT should be inserted, or the paragraph should be deleted if there is no CRT.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE (4.2.1.24.2)

Compliance must be verified to assure CRTs are not damaged.

VERIFICATION GUIDANCE

Data collected during a maintainability demonstration is usually adequate.

VERIFICATION LESSONS LEARNED

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

REQUIREMENT RATIONALE (3.2.1.24.3)

Equipment containing a CRT, with the corresponding high voltage, must have an arc suppression scheme to prevent damage due to arcs.

REQUIREMENT GUIDANCE

Arc suppressors or an equivalent scheme are appropriate for equipment having a CRT.

REQUIREMENT LESSONS LEARNED

This requirement is the most important in initial field reliability. Arc protection must be applied to the focus, G2, cathode, and deflection leads. Careful attention must be paid to the grounding between the CRT and the HV PS.

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

VERIFICATION RATIONALE (4.2.1.24.3)

Compliance must be verified to assure equipment will not be damaged by arcs.

VERIFICATION GUIDANCE

Analysis of circuitry and failure data is sometimes adequate.

VERIFICATION LESSONS LEARNED

Special arcing tests (during development and qualification) should be run on early preproduction equipment to find and fix any failure modes caused by arcs.

3.2.1.25 Head-up display (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 FOV and its relationship to the horizontal datum shall be as described in __________. The above requirements are to be met with the eyes centered on the design eye. The total FOV shall be viewable from within the eye motion limits (box) shown in __________ and the IFOV shall not decrease to less than 75% of the above requirement with up to __________ cm of eye displacement around the central line of sight within the eye motion box.

REQUIREMENT RATIONALE (3.2.1.25.1)

HUD FOV must be large enough to accommodate display of all necessary information.

REQUIREMENT GUIDANCE

This requirement applies to Head-Up Displays (HUDs) only. (Note: "Head" is singular; pilots have only one.) The above paragraph was used in a wide FOV raster HUD specification with the following requirements filled in: 20° vertical, 25° horizontal, 17° x 25° IFOV, relationship to datum shown in a figure, and 1.9-cm (3/4-inch) eye motion allowed. The contractor met the requirements using a diffraction optics combiner. Conventional HUDs (refractive optics) generally have a smaller TFOV and a much smaller IFOV, due to optical limitations. A typical conventional HUD might have a 20-degree TFOV, and a 9-degree by 14-degree IFOV. The maximum TFOV and IFOV obtained from a demonstrated, practical HUD with conventional optics has been 25° and 13 x 20°, respectively.

Conventional optics HUDs with their smaller FOV are adequate for use with weapons which must fire forward (near the aircraft axis). WFOV capability is useful for firing off-axis weapons, and is critically important (along with a video capability) to a system which relies on HUD FLIR video for night navigation (such as LANTIRN).

A guidebook called "HUDs in Tactical Cockpits", written by Jerry Gard of Kaiser Electronics, gives extensive advice on HUD FOV. A Crew Station Ergonomics Information Analysis Center (CSERIAC) State of the Art Report (SOAR) 92-2, "Human Factors Issues in Head-Up-Display Design: The Book of HUD", by Daniel Weintraub and Michael Ensing, provides extensive background on HUDs.

REQUIREMENT LESSONS LEARNED

For the F-16 LANTIRN HUD program, data measured in a real cockpit showing eye location at various times for various operators was used to define a "box" 7 cm high, 14 cm wide, and 25 cm long inside which the operator's eyes remained most of the time. Field of view and luminance degradation limits were then specified for the operators eyes in the box. It is essential that the HUD design be based on actual operator's eye positions, measured in a cockpit, rather than the hypothetical "design eye" point. This is particularly important for a HUD which has optical power in the combining glass (e.g., a WFOV diffraction optics HUD) because the ideal viewing position for these HUDs can only be changed by redesigning the optics. With the more traditional HUDs (flat plate combiner glass) it is possible to modify the combiner to adjust the viewing position.

The interaction of the HUD, the design eye position, and the aircraft canopy requires study and optimization. Some of these issues are discussed in Report AFAMRL-TR-83-095, "Optical and Human Performance Evaluation of HUD Systems Design".

At least one aircraft has used the inside of the windshield as the HUD combiner, but this has proven difficult because:

a. It is too far from the pilot and not at the optimum angle to get adequate FOV.

b. Modern aircraft canopies are curved.

c. Alignment and accuracy are hard to maintain, since other optics need to be precisely positioned relative to the combiner, and the windshield bends under air loads and with heating.

Note that General Motors uses the windshield as a combiner in their automotive HUD, where cost savings and aesthetics are more important than accuracy or FOV.

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.

VERIFICATION RATIONALE (4.2.1.25.1)

FOV must be measured to assure that it is large enough for the appropriate symbology and/or video.

VERIFICATION GUIDANCE

Verification is normally based on measurements taken with a theodolite.

VERIFICATION LESSONS LEARNED

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% 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.

REQUIREMENT RATIONALE (3.2.1.25.2)

Parallax must be limited to prevent eyestrain, double imaging, and loss of (or a false sense of) depth perception. Parallax is defined as the difference in viewing angle between the two eyes when they are both looking at the same point or object. For example, two eyes 6.35 cm apart looking at a point 28.5 meters away will be converging 2.3 mr.

Imperfections in the HUD optics and/or the aircraft windscreen cause either the HUD symbology, the real world or both to not be displayed at an optical distance of infinity (from the pilot's point of view). Since the two eyes cannot simultaneously fuse two images that are at different optical distances (i.e., where the difference in the distance exceeds the tolerance of Panum's area) either the HUD symbology or the real world scene, whichever isn't being fixated upon at the time, will appear doubled. The eyes must then accommodate back and forth between the two sources of visual information, resulting in eye fatigue.

REQUIREMENT GUIDANCE

This requirement applies to equipment which has optics, including HUDs and Helmet Mounted Displays. Parallax limits of 1 mr vertical, 2.3 mr horizontally converging, and 1 mr horizontally diverging have been used on a HUD, and are usually considered adequate.

REQUIREMENT LESSONS LEARNED

Some aircraft require that the HUD have optical power to compensate for the optical power of a curved canopy. In a simple case (the F-15), this is a very slight cylindrical curve ground into the combiner glass. The F-16 has a much more complicated situation because the canopy is a non-uniform compound curve, and has slight optical power. When the Wide Field of View LANTIRN HUD was installed in the F-16, problems with loss of depth perception and double imaging occurred. Anyone designing a similar system should research the work which was done at WPAFB to correct these problems, as it involved tighter windshield specifications, optical modifications to the HUD, and different parallax requirements (ASD-TR-83-5019).

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

VERIFICATION RATIONALE (4.2.1.25.2)

Parallax must be measured to assure that excessive eyestrain, double imaging, or loss of depth perception will not occur.

VERIFICATION GUIDANCE

Verification should be based on measurements.

VERIFICATION LESSONS LEARNED

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 3,000 to 5,000 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% 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 __________.

REQUIREMENT RATIONALE (3.2.1.25.3)

Until recently, a standby reticle has been required on most HUDs that have a targeting function. Higher reliability of modern electronics, and complexity of having duplicate image sources in a HUD, are making this a high cost, low value option in new systems.

REQUIREMENT GUIDANCE

The standby reticle was generated by a mechanical mask and a light bulb, completely independent of the HUD electronics and CRT, in most HUDs built prior to 1980. The complexity of fitting these mechanical components into the optical train added significant cost and degraded reliability, so more recent HUDs have used an independent electronics channel to generate a standby reticle on the same (primary) CRT. This was particularly important on LANTIRN because diffraction optics are used in the combiner and the wavelength of the light source is critical. The level of independence of the standby reticle has generally been established by the users, who naturally want it as independent as possible. The size and shape of the reticle should be defined by a figure included in the specification. It should look like the primary aiming reticle and/or follow the standby reticle guidance.

An alternative to providing a separate standby reticle is to configure the system such that the display will be driven by a backup symbol generator in the event of HUD electronics unit failure. This is particularly attractive in systems which have multiple symbol generators (for head-down displays) which can drive the HUD in a backup mode. It provides a full performance backup mode, rather than the relatively useless manual standby reticle.

A contrast of 0.2 (contrast ratio of 1.2:1), and a minimum luminance of 5,440 cd/m^2 (1,600 fL) has been used and is adequate to assure viewability in sunshine. A contrast of 0.5 would be preferred, but requires serious compromises in other CRT characteristics with current technology.

Reticle line width should be similar to that of the primary symbology; 1 mr width measured at 5440 cd/m^2 (1,600 fL) luminance has been used successfully.

Standby reticles were red in many older HUDs, apparently to distinguish the standby from the primary. With the superior capability of symbol generators today, it will be obvious if a backup reticle is in use. HUDs using wavelength selective optics (diffraction or "holographic" combiners) will only work with one color of light, so it is necessary to make the standby reticle the same color as the primary. Unless a specific color requirement is known, the color requirement should be deleted or a statement that the standby is similar in color to the primary can be used.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE (4.2.1.25.3)

Standby reticle characteristics must be measured to assure that an aesthetically pleasing and clearly visible reticle is provided.

VERIFICATION GUIDANCE

Measurements should be made using the same techniques as those used in measuring primary symbology.

VERIFICATION LESSONS LEARNED

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 3σ 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.

REQUIREMENT RATIONALE (3.2.1.25.4)

Accuracies must be established to insure that HUD symbols allow accurate targeting and to insure that flight and navigation symbols are geometrically correct.

REQUIREMENT GUIDANCE

The name of the equipment requiring the greatest accuracy should be inserted; for example, on the A-10, the GAU-8 gun requires that the gun cross be accurately located. Accuracies of ± 1.7 mr on the optical axis, ± 3 mr within a 12-degree diameter circle, and ± 5 mr anywhere in the FOV have been achieved.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE (4.2.1.25.4)

Symbol accuracy must be measured to assure that the HUD design provides accuracy adequate for flight control and weapon delivery.

VERIFICATION GUIDANCE

Symbol positions are normally measured in the laboratory using a theodolite with the HUD display unit mounted on a precision test fixture. Digital readouts and scales are evaluated by observation.

VERIFICATION LESSONS LEARNED

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

REQUIREMENT RATIONALE (3.2.1.25.4.1)

Primary flight symbols must accurately depict attitude, heading, etc., to prevent the pilot from being disoriented.

REQUIREMENT GUIDANCE

The following flight symbol accuracies are achieved on the F-16 HUD:

a. Pitch angle: ± 1.0°

b. Airspeed: ± 2 KIAS

c. Altitude: ± 7.62 m (25 feet)

d. Roll attitude: ± 1.5°

e. Mach: ± .02 Mach

f. Heading: ± 1°

REQUIREMENT LESSONS LEARNED

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

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

REQUIREMENT RATIONALE (3.2.1.25.4.2)

For a HUD which performs weapon aiming and flight director calculations, the accuracy of the algorithms must be controlled to assure proper weapon delivery and flight director operation.

REQUIREMENT GUIDANCE

The following accuracies are achieved in the F-16 HUD (excluding display errors):

a. Snapshoot: ± 0.5 mr

b. Lead computing optical sight: ± 0.5 mr

c. Flight director: ± 0.5 mr

REQUIREMENT LESSONS LEARNED

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

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

REQUIREMENT RATIONALE (3.2.1.25.4.3)

For systems which overlay video with symbology the relative position must be controlled; this is only important for a display where the spatial relationship between the video and symbology has meaning.

REQUIREMENT GUIDANCE

Alignment of ± 1 mr ± 0.5% of the distance from FOV center was specified for the LANTIRN HUD. This only applied to the symbols whose exact position in the scene was important.

REQUIREMENT LESSONS LEARNED

This paragraph is intended to deal with errors occurring within the display system; a system displaying sensor video on a HUD or HMD will have misregistration relative to the real world due to the fact that the camera is not in line with the HUD. For example, a FLIR mounted under the nose is several feet vertically below the HUD, and the image can only match with the real world (from the pilot's point of view) at one range.

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

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 ________.

REQUIREMENT RATIONALE (3.2.1.25.4.4)

If a standby reticle is provided, its accuracy must be specified to assure it will be useful.

REQUIREMENT GUIDANCE

Standby reticle accuracy is normally equivalent to the primary reticle accuracy.

REQUIREMENT LESSONS LEARNED

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

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 (3σ) in the area within 5° of the center of the FOV or ________ mr within the total FOV.

REQUIREMENT RATIONALE (3.2.1.25.4.5)

A HUD combiner glass must have flat and parallel surfaces in order to prevent displacement of the real-world scene.

REQUIREMENT GUIDANCE

Errors of 0.6 mr in the central part of the FOV, and 0.8 mr overall, are specified for the F-16.

REQUIREMENT LESSONS LEARNED

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

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 with out the combining glass. The distortion requirement shall apply for all eye positions that are required to obtain the total FOV.

REQUIREMENT RATIONALE (3.2.1.25.4.6)

Combiner glass surfaces must be flat to prevent geometric distortion, which degrades appearance and accuracy.

REQUIREMENT GUIDANCE

Distortion of 0.25 mr is used in the F-16 HUD specification. Larger distortions are allowed in some cases, such as at the discontinuity between the two images on a dual-combiner HUD.

REQUIREMENT LESSONS LEARNED

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

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, a combined boresight accuracy of __________ mr (3σ) 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.

REQUIREMENT RATIONALE (3.2.1.25.4.7)

For head-up displays, boresighting is required for accurate symbology positioning. Accurate preboresighting, with no on-aircraft adjustments, reduces maintenance costs and allows HUD replacement to be done quickly without special equipment.

REQUIREMENT GUIDANCE

Preboresighting should not be applied if extremely accurate boresighting is required, since it creates many design constraints. This requirement was applied to the F-16, and made a normal HUD swap-out very easy. However, it is now a major operation to check or reset the factory alignment of the mounting base when it is found to be bad (due to airframe bending).

Where an error budget has been established which goes down to the level of HUD boresight, the appropriate number should be inserted. Alternately, where a system contractor is responsible for accuracy, HUD accuracies should be specified relative to aircraft reference, and the boresight accuracy requirement can be dropped to allow the manufacturer to set up his own error budget.

REQUIREMENT LESSONS LEARNED

Electronic boresighting is now practical. It eliminates the need for a mechanically complex and expensive adjustable mounting tray. This method uses an electronic memory on the aircraft to store alignment numbers which are read by the display at power-up and used to adjust symbol positions (developed on the C-17).

4.2.1.25.4.7 Verification of boresighting. The requirements of 4.2.1.25.4 apply.

3.2.1.25.5 Canopy distortion compensation. The system shall compensate the position of the following symbols for optical deviations through the aircraft canopy: __________.

REQUIREMENT RATIONALE (3.2.1.25.5)

Where a curved canopy is used which introduces significant distortion, it may be necessary to electronically shift the position of symbols on the HUD or HMD to make them accurate relative to the distorted real scene.

REQUIREMENT GUIDANCE

This requirement is often not needed, since it only applies to HUDs or HMDs in aircraft with curved canopies, such as the F-16. AFGS-87266, Aircraft Cockpit Transparency System, should be referenced for other canopy-related requirements.

REQUIREMENT LESSONS LEARNED

Symbol position compensation is used in the F-16. The corrections are done by the HUD processor using a nine-coefficient polynomial correction equation. The coefficients are determined from measurements taken on each windshield when it is manufactured, and are stored in the aircraft computer along with other aircraft weight and configuration data; they are passed to the HUD over the data bus when the system is turned on. This seems to be the most practical way to make the corrections, even though it adds significant complexity to the software. All symbols which must align with the outside scene, such as aiming reticles, target designators, continuously computed impact line, and radar search cues, are compensated. Some aircraft also require compensation to correct parallax errors caused by the canopy. (See 3.2.1.25.2.)

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

VERIFICATION RATIONALE (4.2.1.25.5)

Position correction must be tested to insure that the system provides adequate weapon accuracies.

VERIFICATION GUIDANCE

A test should be performed to measure the corrections made by the HUD and compare them with the corrections mathematically defined by the equations.

VERIFICATION LESSONS LEARNED

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 preceding 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.

REQUIREMENT RATIONALE (3.2.1.25.6)

This requirement applies only to aircraft in which the front part of the canopy is removed prior to emergency ejection. The HUD must withstand the windloads in order to avoid breaking up and injuring the pilot.

REQUIREMENT GUIDANCE

The F-16 HUD was designed to withstand the windloads which were determined by analysis and wind tunnel tests and were described in a figure in the specification. Specific loading requirements depend on the maximum safe ejection speed for the aircraft. Consult with escape system and canopy engineers to establish appropriate requirements.

REQUIREMENT LESSONS LEARNED

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.

VERIFICATION RATIONALE (4.2.1.25.6)

Combiner strength must be verified to assure pilot safety.

VERIFICATION GUIDANCE

Static force tests or a dynamic wind-tunnel test should be performed.

VERIFICATION LESSONS LEARNED

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

REQUIREMENT RATIONALE (3.2.1.25.7)

For HUDs, the optical characteristics of the combiner glass are important to provide comfortable, accurate viewing.

REQUIREMENT GUIDANCE

This requirement applies only to HUDs. MIL-R-6771 provides optical characteristics guidance. Transmissibility of 70%, and outer surface reflectivity of 0.5% are appropriate.

REQUIREMENT LESSONS LEARNED

For aircraft where NVGs will be used, the transmission of the combiner in the near IR range should also be specified.

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

VERIFICATION RATIONALE (4.2.1.25.7)

Compliance must be verified to assure adequate performance and appearance of the combiner.

VERIFICATION GUIDANCE

Verification can be done by measurement or data evaluation.

VERIFICATION LESSONS LEARNED

3.2.1.26 Helmet mounted display (HMD)-specific requirements. A HMD system with the following characteristics shall be provided: __________.

REQUIREMENT RATIONALE

A HMD system could be valuable for air-to-air and air-to-ground attack, CAS/BAI, low level terrain following missions, night and in-weather missions, night rescue, and special operations. It can provide the pilot with an overlay of both video and graphics information from sensor-generated and computer-generated sources and maintain the pilot's temporal and spatial relationships to the tasks at hand. It can provide the pilot with an instantaneous presentation of the tactical and portions of the strategic situation to improve the pilot's situational awareness and reduce workload. Through the use of EO, FLIR, and LLTV sensors used separately or in combination through appropriate signal processing, the HMD presentation can permit the pilot to fly with improved safety and allow him to detect/acquire objects at long range.

REQUIREMENT GUIDANCE

Because of the lack of existing successful production HMD systems to provide a "baseline" of performance requirements, this section is necessarily vague.

Existing HMDs typically add excessive weight and volume to the helmet and did not have the proper CG or wind blast resistance for safe ejection, although some experimental units now are considered ejection-safe. Monocular, symbology-only systems can be made bright enough for use in sunshine, while current technology makes it very difficult to provide video in sunlight. Video, with its high spatial frequency information, can cause binocular rivalry, and is thus more compatible with a binocular viewing configuration.

It is common practice to refer to a head-mounted system that can display raster video and/or dynamic stroke symbology as a Helmet Mounted Display (HMD). Head-mounted systems that can only display fixed symbols are referred to as Helmet Mounted Sights (HMS).

Current HMD systems use a miniature CRT, about 0.75 to 1.0 inch in diameter, to provide a video image on the helmet. HMSs use a smaller device, such as a pattern of light-emitting diodes (LEDs) to form a reticle. Installing a 1-inch CRT on the helmet adds significant weight, due to the weight of the glass CRT bottle, high-voltage connections, etc., so attempts are being made to build smaller CRTs with adequate performance. Providing high resolution, high brightness, ruggedness, and producibility in a 1-inch CRT is already very difficult, so meeting the same requirements in a smaller tube will be even more difficult, and will almost certainly result in loss of performance in some areas. Alternatives are being investigated. For example, small liquid crystal displays (LCDs) could solve the size and weight problem but introduce new problems in resolution; addressability; producibility; the need for a powerful, uniform backlight; and the need for an extremely high-contrast-ratio image source if one is to see through the background. Systems have been tested which locate the CRT remote from the helmet; the image is then carried to the helmet with a fiber optic cable. This allows the use of a larger CRT, mounted in a box where its full performance can be realized, but requires the use of an image-carrying fiber optic cable, with serious size, stiffness, weight, and resolution problems, and the addition of another box in the cockpit. The fiber optic cable approach has been used in an "NVG HUD", a device which is added to existing NVGs and provides symbology overlaid on the NVG images, but does not have adequate resolution to display video and is not integrated into an ejection-safe design.

Additional guidance is available in laboratory reports (for example, Kocien, 1991).

REQUIREMENT LESSONS LEARNED

The difficulties and risks associated with HMD development are due to the severity of the performance requirements applied and the lack of a major development effort to resolve the remaining problems. Since operational systems are still rare, it is not clear which features are essential and which could be optional.

4.2.1.26 Verification of HMD-specific requirements. TBD.

3.2.1.26.1 Sunshine video capability. The HMD shall be capable of displaying video, with contrast, resolution, and brightness as specified herein, in a __________ ambient.

REQUIREMENT RATIONALE

If a sensor is available which can "see through" certain atmospheric conditions better than the human eye, it may be useful to provide a full video capability which is bright enough to be used in sunshine. Otherwise, video is only required at night.

REQUIREMENT GUIDANCE

It must be recognized that video sensors (such as FLIR) which are designed to allow vision at night will provide far less utility in sunshine. For example, the resolution of the human eye in daylight is approximately 3 times better than that of a 30 degree FOV FLIR, so most of the time if it is bright enough to have a sunshine legibility problem, it is bright enough to fly without the FLIR. Symbology, on the other hand, should be usable in sunshine, since this allows the HMD to be used as a HUD and HMS in daylight, just as it can at night. Viewability in sunshine is not so difficult to achieve if a dark visor is used. For example, the normal "sunglasses" visor has transmission of around 15%, which means that a HMD operating inside this visor would need to be visible against a 1500-fL background, rather than normal 10,000-fL sunshine.

The brightness, resolution, and contrast requirements in the HUD section of this spec can be used as a starting point.

REQUIREMENT LESSONS LEARNED

4.2.1.26.1 Verification of video in sunshine capability. TBD.

3.2.1.26.2 Image intensifier (I^2) capability. The HMD shall include I^2 capability with the following FOV, resolution, gain, __________.

REQUIREMENT RATIONALE

A capability to see in the dark can be achieved by integrating I^2 capability into the helmet. I^2s do not require use of a FLIR or helmet tracking system, therefore can result in a much less expensive system. The disadvantages are that they operate in the visible and near-IR range—therefore the crewstation lighting must be made NVG compatible—and they do not detect radiated thermal energy (as a FLIR does). They also add more weight to the helmet and complexity to the optics

REQUIREMENT GUIDANCE

Attempts have been made to design helmets with I^2 capability are being designed for use in high speed aircraft with ejection seats, with the low weight and proper center of gravity (CG) to avoid excessive stress on the pilot's neck during high-G maneuvers and the high accelerations of ejection. They must also be designed to withstand the windblast which occurs during ejection without disintegrating and injuring the pilot.

One possibility being considered is to convert the I^2 imagery to a video signal, then display it on the HMD CRT, eliminating the need to optically combine images. This approach solves the optics weight and complexity problem, but creates the need for a camera to scan the I^2 image. This additional hardware then must be mounted on the helmet or on a gimbal controlled by the helmet position signals.

REQUIREMENTS LESSONS LEARNED

4.2.1.26.2 Verification of I^2 capability. TBD.

3.2.1.26.3 Head supported weight and center of gravity (CG). Weight of the helmet including display hardware and ___________ feet of interconnecting cable shall not exceed ___________. CG shall be below ___________ and aft of ___________.

REQUIREMENT RATIONALE

The weight of any helmet mounted equipment is critical. Any helmet becomes uncomfortable after long use, contributing to pilot performance degradation, and pilots regularly complain that their present helmet is too heavy.

REQUIREMENT GUIDANCE

The actual weight which can be tolerated in a given aircraft mission must be established by human factors studies. Past studies do not provide a specific number that the display hardware can be designed to, but indicate that it depends heavily on how long it must be tolerated, in what environment, and the physical conditioning of the individuals wearing the helmet. Aircraft with a lower G requirement and no ejection seat represent a milder environment compared to a fighter. Applying the same weight and CG requirements to a HMD for these aircraft as would be applied to a fighter will most certainly drive the display hardware design to greater complexity and/or lower performance, and could only be justified on the basis of a much greater cost to support two systems in the field rather than one.

Without a firm cutoff on acceptable weight, reducing the weight to a minimum must be the goal, with the knowledge that systems such as IHADSS, at 3.9 lbs, are tolerable in helicopters. At least one study has shown that CG is at least as critical as total weight, finding that significantly more weight could be added if the CG was maintained very near or below the natural CG of the head. A high, forward CG is the worst; this fact greatly complicates the optical design of a HMD by forcing components to be mounted low and toward the back.

REQUIREMENT LESSONS LEARNED

4.2.1.26.3 Verification of weight and CG. TBD.

3.2.1.26.4 Personal equipment compatibility and interface. The HMD shall be compatible with ___________.

REQUIREMENT RATIONALE

Use of existing goggles, oxygen mask, communications gear, etc, will save substantial development effort and eliminate logistics problems associated with unique hardware being dedicated to the aircraft with the HMD. Unique personal equipment provides the possibility of improving weight and CG and optimizing interface with the display hardware.

REQUIREMENT GUIDANCE

The goal, as always, should be to use the existing oxygen mask, communications gear, helmet, and nuclear/chemical/biological protective equipment if possible. However, the best solution for the overall system may be to redesign one or several of these items to improve weight, CG, or compatibility with the HMD equipment. These requirements must be established by human factors and personal equipment specialists.

REQUIREMENT LESSONS LEARNED

4.2.1.26.4 Verification of compatibility with personal equipment. TBD.

3.2.1.26.5 Compatibility with ejection seat. TBD

4.2.1.26.5 Verification of compatibility with ejection seat. TBD.

3.2.1.26.6 Head tracking system. A head tracking system shall be provided which provides helmet look angle, roll angle, and position to the following accuracies: ___________. Lag time between motion of the helmet and output of angles and positions within the above tolerances shall not exceed ___________.

REQUIREMENT RATIONALE

The ability of the HMD or HMS to position symbols in space, or sense where the user is pointing a helmet-mounted symbol, as well as the ability to point a head-steered sensor, depends on precise knowledge of helmet angles. Helmet position (in addition to angles) may be needed to compensate symbol positions for canopy distortions and tracker errors, and is required if pointing at closeup objects (within the cockpit) is to be used.

REQUIREMENT GUIDANCE

A significant difference between early tracking systems and current systems is their ability to sense helmet roll, and therefore stabilize certain images (such as a FLIR) in roll. If an image is not "roll stabilized", the image will roll with the pilot's helmet, rather than roll with the outside scene. This can be very disorienting, giving conflicting clues as to which way is up. Without roll stabilization, if the pilot tilts his head, the FLIR scene tilts with him, rather than staying fixed in inertial space, as the outside scene does. The IHADSS system is not roll stabilized, and has been used successfully, but this appears to be more an attempt to work around equipment limitations than an actual choice. Some head position sensing systems (including the magnetic HMS) provide roll sensing with minimal increase in hardware. In the past, a complex third axis in the FLIR gimbal was required to roll-stabilize the video, but with the advent of processor-controlled scan converters and CRTs, it is now possible to electronically roll the image. If the real world scene or I^2 imagery is overlaid with FLIR video, the lack of roll stabilization of the FLIR would show up as gross misregistration between the two images. There seems to be no research showing that gross misregistration and a rotating horizon can be tolerated. Therefore head roll sensing and roll stabilization of the FLIR and symbology should be pursued.

A magnetically coupled head tracking system was developed several years ago and has demonstrated capability in several installations to provide sensing of the pilot's head orientation (in 3 axes) and position, *with minimal weight or other encumbrance on the helmet.*

Static accuracy of 2 mr CEP on axis, 4 mr CEP beyond 30° has been recommended on some systems. Good accuracy is generally dependent on boresighting each time the system is used, to compensate for things like helmet fit.

REQUIREMENT LESSONS LEARNED

4.2.1.26.6 Verification of head tracker system. TBD.

3.2.1.26.7 Eye relief and exit pupil. Sufficient eye relief for comfortable viewing and viewing with eyeglasses on shall be provided. Exit pupil shall be sufficient to prevent vignetting of the image with normal helmet shifting due to G loading, and shall be at least __________ mm.

REQUIREMENT RATIONALE

Adequate eye relief (distance between eyeball and optics) and exit pupil (diameter of area from which the image can be seen) are difficult to achieve in a compact, lightweight optical design, but are critical to operator performance and acceptance.

REQUIREMENT GUIDANCE

Fifteen mm exit pupil has been recommended for HMDs with instantaneous or apparent FOVs up to 40°. Seventeen mm has been recommended for a 45-60 degree FOV. Thirty mm of eye clearance may be needed to provide clearance for eyeglasses.

REQUIREMENT LESSONS LEARNED

HMDs require compact, lightweight optics, and efficient combiners, and some require unusual optical characteristics, such as asymmetric reflectors. This appears to be an excellent area to apply diffractive optics, sometimes called holographic optics. A diffractive optics element can be thought of as a "hologram of an optical element". Instead of storing the characteristics of some object for later viewing, as is done in regular holography, the characteristics of an optical element are stored, and preserved in a thin layer of gelatin sealed between two pieces of glass. They are very selective to both wavelength and angle, so they make an ideal combiner, efficiently reflecting the image from the HMD (of the right color and angle), while efficiently passing the outside scene (of random colors and angles). They are also tricky to make, with only 4 or 5 vendors in the world capable of production rates. Furthermore, their angle sensitivity can be a real problem, especially in wide field of view systems.

4.2.1.26.7 Verification of eye relief and exit pupil. TBD.

3.2.1.26.8 Monocular/Biocular/Binocular capability. The HMD shall provide __________ image(s), meeting the following requirements: __________.

REQUIREMENT RATIONALE

The issue of whether a single image is provided to one eye ("monocular"), a single image is split and provided to both eyes ("biocular"), or an independent image is provided to each eye ("binocular") has a major effect on the performance, cost, weight, etc. of the HMD. For very wide field of view, "panoramic binocular" designs have been attempted, where the two images only overlap partially.

REQUIREMENT GUIDANCE

It has been demonstrated that NVGs using two I^2 tubes ("binocular") provide better night vision than NVGs with only one tube ("monocular"). There has also been a problem with eye dominance with the IHADSS system, where the operator's brain seems to prefer to concentrate on what is seen by the unaided eye, rather than look at the FLIR image provided to one eye by the IHADSS. Viewing symbology can usually be accomplished successfully with only a monocular display. Viewing video comfortably on an HMD usually requires a biocular or binocular configuration., but the complexity of providing video to both eyes in a helmet display may be reason to reconsider. Adding a second video source, with the associated optics and alignment hardware, may increase the weight and cost of the system beyond what can be tolerated. Having two I^2 tubes can improve imagery, since the imagery reaching each eye is from an independent sensor, so the noise in the pictures is uncorrelated, and their separation provides the possibility of some depth perception due to natural parallax. On the other hand, there will only be one FLIR on board, so feeding it to both eyes provides no gain in noise cancellation or depth perception. The eye dominance problem associated with monocular systems may be the brain's natural response to receiving a dim, fuzzy, (not roll stabilized) image; it prefers to concentrate on the less confusing image from the unaided eye.

REQUIREMENT LESSONS LEARNED

4.2.1.26.8 Verification of monocular/biocular/binocular capability. TBD.

3.2.1.26.9 Peripheral vision. The operator's unaided peripheral vision shall cover at least __________% of the area available with the standard __________ helmet.

REQUIREMENT RATIONALE

As long as the HMD is used only as a supplement to unaided vision, the ability to see around optical structures, etc., is very important.

REQUIREMENT GUIDANCE

Peripheral vision should be maintained as near to that available with a standard helmet as practical; 90% has been specified on one system. This is a worthy goal, but it may be an excessive driver on the design of the optics. Integration of video and symbology into the helmet should reduce the pilot's reliance on outside vision for situation awareness, and allow us to tolerate some blockage of peripheral vision if it results in a significantly better HMD capability. A dezine with stowable optics (optics that fold out of the way when not in use) could tolerate more blockage during use.

REQUIREMENT LESSONS LEARNED

4.2.1.26.9 Verification of peripheral vision. Verification of peripheral vision shall be by __________.

VERIFICATION RATIONALE

Verification of peripheral vision is necessary to ensure the HMD system does not adversely affect situation awareness and compromise aircrew safety during flight.

VERIFICATION GUIDANCE

Consult with crew systems engineers when determining the appropriate verification procedures. Typically, verification should be accomplished by inspection of Aitoff drawings which includes a plot of the exterior vision available with the standard helmet versus the HMD helmet and by demonstration with actual hardware.

VERIFICATION LESSONS LEARNED

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

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

REQUIREMENT AND VERIFICATION GUIDANCE (3.2.2 and 4.2.2)

The requirement and verification rationale, guidance, and lessons learned for physical characteristics are included in the following individual subparagraphs. Since these subparagraphs tend to describe a design, rather than the performance required, they are included in this handbook for information and should be used in the basic specification only when they are specifically needed.

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

REQUIREMENT RATIONALE (3.2.2.1)

Weight of equipment should be specified to prevent adding excessive weight to the aircraft, and in many cases to meet critical aircraft weight and balance requirements.

REQUIREMENT GUIDANCE

Equipment designed for retrofit into existing aircraft may have to meet specific existing limits. For new aircraft, the manufacturer should allocate allowable weights to the various avionics or provide specific guidance on the severity of weight control measures to be taken. MIL-STD-1472 lists maximum weight for easy handling, which may constrain the weight in some cases.

REQUIREMENT LESSONS LEARNED

4.2.2.1 Verification of weight. The equipment shall be weighed.

VERIFICATION RATIONALE (4.2.2.1)

Weight must be measured to assure that excessive weight is not added to the aircraft.

VERIFICATION GUIDANCE

Equipment shall be weighed.

VERIFICATION LESSONS LEARNED

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

REQUIREMENT RATIONALE (3.2.2.2)

Volume must be constrained to fit in the available aircraft space.

REQUIREMENT GUIDANCE

Equipment designed for retrofit into existing aircraft must generally fit into an existing space, whose dimensions can be obtained from existing design data and put in the specification in the form of dimensions or a sketch (figure) showing the outline.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE (4.2.2.2)

Volume must be measured to assure that equipment will fit.

VERIFICATION GUIDANCE

Verification should be by measurement.

VERIFICATION LESSONS LEARNED

3.2.3 Reliability. See 3.2.5.

4.2.3 Reliability verification. See 4.2.5.

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

Intermediate level: ____________ hours

REQUIREMENT RATIONALE (3.2.4)

Design for maintainability is a critical driver of life cycle cost.

REQUIREMENT GUIDANCE

Maintenance times should be specified based on an analysis of equipment complexity, deployment concept, and maintenance time budget. This can be a very subjective area, and the actual requirement inserted in the specification may be based on the opinion of an engineer who has experience on recent maintainability demonstrations of similar equipment. The times specified should be short enough to require good design practice and encourage innovative approaches to easy maintenance, but long enough to allow reasonable performance, reliability, and cost.

REQUIREMENTS LESSONS LEARNED

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.

VERIFICATION RATIONALE (4.2.4)

For development programs where the designer has some control over the maintainability features of the equipment, a demonstration is needed to assure equipment availability and maintenance costs will be acceptable.

VERIFICATION GUIDANCE

A maintainability demonstration using the latest version of MIL-STD-471, may be done in the full scale development phase. Task selection is usually based on Appendix A of MIL-STD-471.

VERIFICATION LESSONS LEARNED

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

REQUIREMENT RATIONALE (3.2.4.1)

In many cases the maintenance concept for a piece of equipment should be specified to assure that it will be compatible with existing spares provisioning and maintenance procedures.

REQUIREMENT GUIDANCE

The three-level (organizational, intermediate, and depot) maintenance concept has been used in the past for most complex electronic units. such as CRT displays. This philosophy should be reevaluated for new technology and packaging schemes. For example, a small circuit card or a hermetically sealed module may be cheaper to maintain as a throw-away module (no depot repair) rather than buy spare parts, data, and support equipment to repair it. A description of planned basing and shop mobility requirements should also be included, if possible, to guide decisions on how each part should be maintained.

REQUIREMENT LESSONS LEARNED

The trend toward better built-in-test (BIT), and the high cost of providing intermediate support facilities at remote locations, have caused most programs to change to a two-level maintenance concept. Under this concept, problems are isolated to the failed module or assembly on the aircraft, based on BIT, and failed modules are shipped directly to a depot for repair.

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

VERIFICATION RATIONALE (4.2.4.1)

Use of appropriate design philosophy for the chosen maintenance concept must be verified to assure low maintenance cost.

VERIFICATION GUIDANCE

Analysis of documentation can be used to verify compliance.

VERIFICATION LESSONS LEARNED

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 wearout characteristic which results in a determinable life span with non-random life distribution characteristics.

REQUIREMENT RATIONALE (3.2.4.2)

Scheduled maintenance is generally prohibited for electronic display equipment because of the cost in time and paperwork required to plan and perform it and keep the corresponding records.

REQUIREMENT GUIDANCE

Scheduled preventive maintenance is normally not allowed.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE (4.2.4.2)

Compliance must be verified to assure that the equipment is easily maintainable.

VERIFICATION GUIDANCE

The fact that no scheduled maintenance is included in the maintenance manuals, or reliability analysis and test, must be verified to assure low cost field operation.

VERIFICATION LESSONS LEARNED

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 __________% of all faults. Self test false alarms shall not exceed __________% 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.

REQUIREMENT RATIONALE (3.2.4.3)

Equipment self test is easily implemented on digital equipment, and generally provides confidence that equipment is working properly. Analog circuitry (such as that driving a CRT) is harder to test.

REQUIREMENT GUIDANCE

For mission-essential equipment containing a digital processor, a high level of mission-essential fault detection and a low false alarm rate should be specified. A 95% detection and a 1% false alarm rate is not uncommon.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE (4.2.4.3)

Appropriate detection and false alarm rates must be verified to assure that the equipment user will have confidence in the equipment and insure that he does not unknowingly rely on degraded equipment.

VERIFICATION GUIDANCE

Data gathered during a maintainability demonstration is generally adequate to be used in an analysis to verify this requirement.

VERIFICATION LESSONS LEARNED

3.2.4.4 Built-in tests (BIT). Operator-initiated BIT, supplemented by self test, shall be capable of detecting at least ___________% of the malfunctions and out-of-tolerance conditions (at their predicted frequencies) with a false alarm rate of less than ___________%. BIT, supplemented as necessary by self test, shall be capable of isolating to the faulty LRU a minimum of ___________% of the detected malfunctions and out-of-tolerance conditions. The BIT shall isolate to the faulty SRU ___________% 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 lookups. Faults or out-of-tolerance conditions that are obvious by looking at the display are considered "detected" even if they are not electronically reported.

REQUIREMENT RATIONALE (3.2.4.4)

A BIT capability generally does away with organizational level (on-aircraft) test equipment and allows for the fastest possible correction of problems on the aircraft.

REQUIREMENT GUIDANCE

High levels of fault detection and isolation to the faulty LRU are important in reducing unnecessary LRU replacements and improving aircraft availability. A 95% detection, 90% isolation, and 5% false alarm rate can be achieved in new equipment which is mostly digital, and processor-controlled. Isolation to the faulty SRU is also required in some cases. The system specification for the KC-135 ICDU required the following SRU fault isolation performance:

90% to one SRU

95% to two SRUs

100% to three SRUs

Some display parameters are best evaluated by operator interpretation of an internally generated BIT pattern display. A flightline go/no-go evaluation of brightness, contrast, resolution, color convergence, and purity (on shadow mask CRTs), etc., based on an internally generated test image should be considered.

REQUIREMENT LESSONS LEARNED

A test pattern generated within the display system helps maintenance personnel quickly decide whether the display, or a system providing data to the display, is at fault.

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.

VERIFICATION RATIONALE (4.2.4.4)

BIT capability must be verified to assure low maintenance costs and high aircraft availability rates.

VERIFICATION GUIDANCE

Verification should be based on data collected during maintainability and flight test.

VERIFICATION LESSONS LEARNED

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 __________% of all failures of digital SRUs and __________% for analog SRUs.

b. Fault isolation to a single circuit element (component) in __________% of the detected failures for digital SRUs and __________% to 3 active components on analog SRUs.

REQUIREMENT RATIONALE (3.2.4.5)

Design for testability is needed to assure that maintenance work and support equipment is reasonably simple.

REQUIREMENT GUIDANCE

These requirements are dependent upon the type of equipment and the maintenance concept chosen and should be established by a thorough analysis of these factors. Fault detection rates of 90% (sometimes 95% or 99%) for digital SRUs and 90% for analog SRUs have been used. Isolation to a single component in 90% of failures on digital SRUs, and to 3 components on 90% of analog failures, has been used.

REQUIREMENT LESSONS LEARNED

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.

VERIFICATION RATIONALE (4.2.4.5)

Testability must be verified to assure that equipment is easily repairable.

VERIFICATION GUIDANCE

Verification is normally done by analysis.

VERIFICATION LESSONS LEARNED

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

REQUIREMENT RATIONALE (3.2.4.6)

For aircraft having a central computer capable of storing maintenance data, self test- and BIT-detected failures should be reported in order to allow rapid maintenance. This is particularly important in finding faults which are intermittent or only occur in certain flight conditions.

REQUIREMENT GUIDANCE

This requirement should be applied wherever a computer capable of storing fault data is available. In a system with no central fault reporting system, the display subsystem should record a history of its fault reports. This data should be retained in a non-volatile memory until it is intentionally cleared by a maintenance person.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE (4.2.4.6)

Verification is needed to assure that faults reported to the computer are consistent with what the operator saw.

VERIFICATION GUIDANCE

Data can be taken during the maintainability demonstration to analyze compliance.

VERIFICATION LESSONS LEARNED

3.2.5 Product integrity. The equipment shall perform within specifications for a service life of __________ years when subjected to the environments which are expected to occur during the intended usage. The equipment shall perform within specifications after exposure to the expected transportation, manufacture, storage, and maintenance environments. Other product integrity requirements shall be established in accordance with *MIL-A-87244*.

REQUIREMENT RATIONALE (3.2.5)

A formal AVIP reduces development and life cycle problems with electronic systems which must withstand the often severe environment within aircraft and perform under adverse conditions. It integrates the numerous plans, analyses, and tests and ensures that the required activities are completed at the correct time to influence the design and manufacture of the product. The length of time the equipment will be used will affect many aspects of the design.

REQUIREMENT GUIDANCE

The actual environment will depend on the aircraft type and mission. Environments for transportation, storage, maintenance, etc., must be assessed to determine if they are less severe than the operational environments and considered in the design if they consume a significant part of the life. Refer to *MIL-A-87244* for further guidance.

AVIP is a structured and disciplined engineering approach with the goal of ensuring electronics will perform their function reliably for their intended service life. Early in the design phase, engineers should develop a thorough understanding of how the electronics will be used (design usage) as well as the environments the electronics will be exposed to and operated in. This understanding helps designers/engineers determine various stresses the electronics will experience during the service life cycle. It is also necessary to understand the properties, characteristics, and variabilities of materials, parts, and processes used in the equipment. This knowledge and data are then used to analyze and evaluate the durability and damage tolerance of the equipment. These analyses are supported and supplemented by appropriate engineering/development tests. Incremental verification of the durability and service life requirements takes place via analyses, lower level engineering tests, and finally a Durability Life Test (DLT). Appropriate life management and quality assurance provisions are established.

Environments will typically be much different for cockpit-mounted units than for equipment-bay-mounted units. For example, temperatures over 100°C have been measured in a closed, non-operating cockpit under desert conditions.

A Sunshine and Ultraviolet Radiation requirement applies to cockpit equipment which will be exposed to sunshine, either while operating or non-operating. An intensity of 950 W/m^2 (88 W/ft^2) has been used to represent a closed cockpit in the desert. Radiation of 1076 W/m^2 (100 W/ft^2) is appropriate for a canopy-open condition, but should not be used with the maximum closed cockpit temperature. Most long term damage is due to ultraviolet radiation; a test using 5000 hours of UV radiation at 100 W/m^2 has been used to simulate a lifetime of UV exposure. Organic dyes and materials tend to be most susceptible.

Display equipment must be designed to prevent entrapment of fluids, such as rain, and must not be damaged by contact with oil, fuel, or de-icing fluid. Optical filters are generally affected by oil (including oily fingerprints), and must return to full performance when washed with alcohol or window washing detergent.

Requirements for resistance to contact with fluids should not be applied to items where meeting them is impractical or of little value. For example, the tape used in the Airborne Video Tape Recorder is generally not usable after contact with these fluids, but it is expendable and it is not practical to make cassettes watertight.

Full performance in some extreme environments is sometimes not required, for example:

a. Flicker, jitter, noise, resolution, etc. of a display may be allowed to deviate from specifications during gunfire, provided the picture remains usable, since the vibration is severe and the duration is short.

b. A magnetic field environment of up to 5 Gauss, with a gradient of up to 6 Gauss per m (20 Gauss per foot) is sometimes applied. High resolution color CRTs may lose color purity under these conditions. A deviation should be allowed in this case, since these are short-term, worst-case conditions, normal operating conditions are much less severe, the image remains usable, and preventing the purity loss would require other design compromises.

c. Most avionics displays require a 2-minute startup time at cold temperatures. Displays required for engine starting and emergency taxiing in aircraft that must start quickly on alert will have shorter startup times. It may be appropriate to allow deviations from full performance (minor distortion, smearing, image lag) for the first five or ten minutes, since such cold starts should be rare, the displays would still be usable, and meeting full performance may require other compromises, such as use of excessive heater power.

The traditional documents on standard environmental requirements (MIL-E-5400) and environmental test methods (MIL-STD-810, RTCA-DO-160) may provide additional guidance on general levels and test methods that are in common use, but the specific environments of the equipment in question should be the overriding factor.

A CRT life requirement is often included for high brightness CRT displays such as a HUD, where the CRT is typically driven very hard in order to meet brightness requirements. A duration and brightness which represents the normal amount of operation at full brightness should be used. One thousand hours at 6,800 cd/m2 (2,000 fL) measured off the combiner was specified for the LANTIRN HUD CRT. ENASI tested a similar CRT at 38,000 cd/m2 (11,000 fL) measured at the CRT (no filters) and found that its life was significantly shortened.

Electromechanical elapsed time indicators were used in most display units, but they added cost and failure modes to the equipment. Modern equipment with a processor and non-volatile memory can electronically record operating time, on/off cycles, flying time, etc., with very little additional hardware.

REQUIREMENT LESSONS LEARNED

The rain, high humidity and high temperature environment has been observed at Eglin AFB, where F-4 canopies left open during maintenance were closed as quickly as practical during a sudden summer thunderstorm. After the storm, maintenance operation continued, with sunshine heating up the closed, wet cockpit.

The antireflective coating on the F-16 radar display experienced excessive spotting after only 25 hours of a severe humidity test. The requirement for this filter was changed to MIL-C-675, since it could meet this requirement and the filter is in a position where it will dry quickly.

4.2.5 Verification of product integrity. Verification shall be by ___________.

VERIFICATION RATIONALE

Compliance must be verified to assure that the equipment withstands the environment and has adequate service life and durability characteristics.

VERIFICATION GUIDANCE

Appropriate tests, analyses, demonstrations, and inspections, as outlined in MIL-I-87244, should be used.

Equipment using forced-air cooling should be subjected to a "sand and dust in the cooling air" test if small or complex air passages are used, or if the cooling air passes over components or connectors.

Verification of fungus resistance is often done by analysis on avionics, since modern electronic equipment usually contains very little fungus nutrient material.

VERIFICATION LESSONS LEARNED

Significant degradation of display optical filters in sunshine has been experienced. As a result of field degradation of filters on F-4 Wild Weasel aircraft, filter tests were performed and certain laminated filters were found to degrade. Holographic optical elements from the LANTIRN HUD program were also tested for approximately 900 hours at 150 W/m^2, which was intended to represent three years of sunshine. These elements contain a layer of dichromated gelatin, and the test result showed minimal degradation.

3.3 Design and construction.

3.3.1 (Reserved).

3.3.2 Electromagnetic compatibility.. See *MIL-A-87244*.

4.3 Verification of design and construction.

4.3.1 (Reserved).

4.3.2 (Reserved).

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 __________.

REQUIREMENT RATIONALE (3.3.3)

Marking, nameplates and nomenclature must be clear and be consistent with current DoD marking practices to allow efficient distribution, spare parts handling, and maintenance.

REQUIREMENT GUIDANCE

MIL-E-5400 provides guidance for marking. Nameplates should be installed per MIL-P-15025. Nomenclature should be obtained in accordance with MIL-N-7513.

REQUIREMENT LESSONS LEARNED

Most avionics development contracts require the contractor to submit requests for nomenclature (DD Form 61). However, the paperwork involved in getting this in the contract, approving it, and modifying it is often more work then actually filling out the form, since it is only a two page form. Nameplates are generally required to be riveted on, but for many units, such as optical modules, this is not practical and bonded-on nameplates should be allowed.

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

VERIFICATION RATIONALE (4.3.3)

Compliance must be verified to assure that efficient distribution, spare parts handling, and maintenance is possible.

VERIFICATION GUIDANCE

Not required.

VERIFICATION LESSONS LEARNED

3.3.4 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 __________.

REQUIREMENT RATIONALE (3.2.5.13)

Crewstation equipment should survive a sudden decompression caused by battle damage, canopy removal, etc.

REQUIREMENT GUIDANCE

Equipment located in the crewstation may be exposed to explosive decompression and should continue to operate. An appropriate air pressure change rate and limits must be inserted. Condition (a) of MIL-C-6781 has been used for F-16 equipment.

REQUIREMENT LESSONS LEARNED

This requirement is not applied to all crewstation equipment but should be applied to any equipment in a pressurized area which is critical to safety.

4.3.4 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 __________.

VERIFICATION RATIONALE (4.2.5.13)

Compliance must be verified to assure operation of equipment after decompression.

VERIFICATION GUIDANCE

The cabin altitude and flight altitude corresponding to the greatest pressure change should be inserted.

VERIFICATION LESSONS LEARNED

3.3.5 Interchangeability. (Reserved)

4.3.5 Verification of 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.

REQUIREMENT RATIONALE (3.3.6)

Safety requirements and features are needed to protect personnel and equipment.

REQUIREMENT GUIDANCE

The safety requirements of MIL-STD-882 and MIL-STD-454 are often applied.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE (4.3.6)

Compliance must be verified to assure that personnel are not exposed to unnecessary hazards.

VERIFICATION GUIDANCE

Verification should be done by inspection.

VERIFICATION LESSONS LEARNED

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.

REQUIREMENT RATIONALE (3.3.6.1)

For equipment located near the ejection envelope of an aircraft with ejection seats, clearance must be provided for safety.

REQUIREMENT GUIDANCE

Drawings or other data showing required clearance for cockpit equipment should be provided, usually as a figure in the specification.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE

Escape clearance must be verified to assure safety.

VERIFICATION GUIDANCE

Drawing analysis or a cockpit/crewstation demonstration should be used, depending on the equipment's position in the cockpit. MIL-E-87235 covers additional escape system requirements.

VERIFICATION LESSONS LEARNED

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

REQUIREMENT RATIONALE (3.3.6.2)

Cockpit noise level must not be high enough to interfere with pilot or maintenance personnel performance.

REQUIREMENT GUIDANCE

Noise levels should not exceed 75 dB where this can be easily achieved. Acceptable levels of equipment noise will depend on the duration of exposure and sound attenuation characteristics of helmets and other personal equipment. Specific requirements are contained in MIL-STD-1789.

REQUIREMENT LESSONS LEARNED

Noise from avionics is generally caused by high speed cooling fans. In some cases, noise created by equipment bay units is also a problem since maintenance personnel must be able to converse while performing bench checkout.

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.

VERIFICATION RATIONALE (4.3.6.2)

Compliance must be verified to assure noise is not objectionable.

VERIFICATION GUIDANCE

Compliance should be verified by test unless the equipment does not produce significant noise. The equivalent A-weighted sound level may be determined from AFR 151-35.

VERIFICATION LESSONS LEARNED

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

REQUIREMENT GUIDANCE

The high voltage accelerated electron beam of a CRT can produce dangerous x rays, especially in high-brightness color designs with anode voltage over 30kV. A limit of one milliroentgen per hour has been used. Reference OSHA, Code of Federal Regulations, part 1910.

REQUIREMENT LESSONS LEARNED

4.3.6.3 Verification of x-ray emissions. TBD

3.3.6.4 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.

REQUIREMENT RATIONALE (3.2.5.5.2)

Equipment must not create a hazard to the crew in case of a crash landing.

REQUIREMENT GUIDANCE

MIL-STD-810, method 516, provides appropriate crash safety shock levels. The requirement should be applied to crewstation equipment only.

REQUIREMENT LESSONS LEARNED

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

VERIFICATION RATIONALE (4.2.5.5.2)

Compliance must be verified by test or analysis for safety.

VERIFICATION GUIDANCE

A test on a structural mockup or an analysis of design data is often an appropriate alternative to a test of actual equipment, since the g levels are very high and can damage valuable equipment. If a test is performed, it should be based on MIL-STD-810, method 516, procedure III.

VERIFICATION LESSONS LEARNED

3.3.6.5 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.

REQUIREMENT RATIONALE (3.2.5.15)

For a HUD in an aircraft with a flexible canopy, the HUD should withstand the shock of a birdstrike on the canopy without injuring the pilot.

REQUIREMENT GUIDANCE

This paragraph should be deleted, except for a HUD in an aircraft with a flexible canopy. Data on aircraft type, airspeed, and canopy configuration should be inserted.

REQUIREMENT LESSONS LEARNED

4.3.6.5 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 ___________.

VERIFICATION RATIONALE (4.2.5.15)

Compliance must be verified to assure pilot safety.

VERIFICATION GUIDANCE

A birdstrike test, such as the one performed by General Dynamics on the F-16 and F-16 LANTIRN HUDs, is generally appropriate.

VERIFICATION LESSONS LEARNED

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 ___________.

REQUIREMENT RATIONALE (3.3.7.1)

Equipment must be designed for compatibility with human operators to be useful.

REQUIREMENT GUIDANCE

Extensive guidance is contained in MIL-STD-1472 and MIL-STD-1800.

REQUIREMENT LESSONS LEARNED

4.3.7 **Human engineering verification**

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

VERIFICATION RATIONALE (5.6.1)

Verification is required to assure comfortable and safe equipment handling.

VERIFICATION GUIDANCE

Verification shall be done by inspection.

VERIFICATION LESSONS LEARNED

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.

REQUIREMENT RATIONALE (3.3.7.2)

For equipment with a keyboard, the characteristics of the keyboard must be specified to assure that comfortable, accurate operation in the airborne environment is possible. These requirements will also apply to push buttons, such as might be located on the periphery of an MFD.

REQUIREMENT GUIDANCE

Guidance is contained in MIL-STD-1472, MIL-STD-1801, and MIL-STD-1800.

The operator should receive positive tactile feedback that a key has indeed been activated; however, it is important that the operating pressure be such that keys are not easily accidentally activated. The KC-135 ICU key operating pressure was originally specified at 16 ± 4 ounces but was later changed to 20 ± 4 ounces. The operating travel was specified to be 0.13 to 0.51 cm (0.05 to 0.20 inch) with clear tactile feedback.

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

VERIFICATION RATIONALE (4.3.7.2)

Keyboard characteristics must be verified to assure usability.

VERIFICATION GUIDANCE

These characteristics are normally verified by measurement and inspection.

VERIFICATION LESSONS LEARNED

40. ABBREVIATIONS AND ACRONYMS

ABC	automatic brightness control
AFR	Air Force regulation
AGC	automatic gain control
ARINC	Aeronautical Radio, Inc.
ASC	Aeronautical Systems Center
AVIP	avionics/electronics integrity program
BIT	built-in test
C	contrast
cd	candela
CD	color difference
CIE	Commission Internationale de l'Eclairage
CIELUV	a system of equations defined in CIE publication 15 supplement 2.
C_l	contrast of a lighted element against an unlighted element
C_m	contrast as modulation
CNI-CDU	communication/navigation/identification control/display unit
CR	contrast ratio
CRT	cathode ray tube
CTF	contrast transfer function
CTVS	cockpit TV system
C_{ul}	contrast of an unlighted element against its background
DEU	display electronics unit
EIA	Electronics Industries Association
EMD	electronic engine monitor display
EMI	electromagnetic interference
fc	footcandle
fL	foot Lambert
FLIR	forward-looking infra-red
FOV	field of view
FSA/CAS	fuel savings advisory/cockpit avionics system
h	hours, height
HDD	head-down display
HOL	higher order language
HUD	head-up display
HVPS	high voltage power supply
I^2	image intensification
IC	integrated circuit
ICD	interface control document

ICDU	integrated control and display unit
IFOV	instantaneous field of view
IR	infra-red
KIAS	knots indicated air speed
Δ L	difference luminance
L	luminance
L_b	luminance of the background
LCD	liquid crystal display
lm	lumen
LRU	line replaceable unit
L_t	total luminance of the image
L_{ul}	luminance of an unlighted element
MFD	multifunction display
MPD	multipurpose display (=MFD)
MTBF	mean time between failures
MTF	modulation transfer function
NR	NVIS radiance
NTSC	National Television Standardization Committee
NVG	night vision goggles
NVIS	night vision imaging system
OSHA	Occupational Health and Safety Administration
PID	prime item development
PROM	programmable read-only memory
RFP	request for proposal
RGB	red-green-blue
rms	root mean square
SIL	system integration laboratory
SRU	shop-replaceable unit
STANAG	NATO standard
SW	stroke width
TFOV	total field of view
TISEO	target identification set, electro-optical
TV	television
UCS	uniform chromaticity scale
VCR	video cassette recorder
WFOV	wide field of view

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(Project 6610-F302)

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4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

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