Margery J. Doyle, Scott Higgins, Lockheed Martin, MS2, and John Winters, Basic Commerce and Industries

NIGHT OPERATIONS VISUAL ERGONOMICS:
A CASE STUDY

SPONSOR CLEARANCE
This document is currently under internal review by Lockheed Martin MS2 for approval to be released.

ABSTRACT
In an effort to modernize today’s Navy, Cathode Ray Tube (CRT) displays are being replaced by one or more Liquid Crystal Displays (LCDs) throughout the Pilot House and other spaces that have External Viewing Responsibility (EVRs). Since low cost commercial LCDs provide a cost effective solution for designers eager to satisfy display requirements, the number of LCDs used is seemingly constrained only by available space – without due consideration for the cumulative ambient light impact on night vision.

The engineering/acquisition problems that initiated this case study will be bounded. Parameters and methods that can be used for validation and verification of requirements that support night vision will be discussed.

INTRODUCTION
This article focuses on a case study of Pilot House operations and the research of key scientific and engineering parameters and methods that can be utilized to improve design and outfitting of EVR spaces to better support watchstander night vision.

Assumptions
In order to analyze the problem, an assessment and identification of the shipboard external viewing areas took into consideration space and equipment impacts on night vision. Based on this initial assessment using subject matter expertise and compartment layout drawings the following spaces to require the need to support night vision:

- Pilot House
- Flag Bridge
- Primary Flight Control (PRIFLY)
- Signal Bridge
- Helicopter Control Station (HCS)
- RAST Control Station (RCS)

During night operations, display brightness and placement (i.e., around the windows) create problems for watchstanders attempting to view a darkened horizon for detection, identification, and targeting of vessels or hazards. These and other issues have led to an increase in crew reports about excessive brightness and reflections coming from equipment during night operations.

Constraints
After a preliminary review of the literature it was apparent that no one document provided a whole system solution supporting dark adaptation during night operations for surface combatants.

Compounding the problem, methods for designing and testing the displays and other lighting aboard ships often supported the Industrial Engineering point of view rather than a Visual Ergonomic perspective. Measurements, standards and guidelines often did not take into consideration unaided night vision requirements and limitations.

Many available standards, articles, and handbooks violated the scientific parameters of
dark adaptation and visibility in EVR spaces. Additionally, many standards available took an Industrial Engineering (IE) approach measuring in watts per square meter (watts/m² i.e., radiance), rather than candela per square meter (cd/m²), a Visual Ergonomics (VE) approach which uses the average human sensitivity response to a stimulus (i.e., photometry). IE methods are physics based, while the VE approach is also based on physics the VE approach also takes psychophysics into account. The properties of luminaries are measured with psychophysics based human visual perception parameters. Vision-based psychophysics takes into consideration relationships between physical stimuli (light) and sensory response (vision and adaptation to stimuli). In other words, rather than considering only the magnitude (watts) of a light or display, the VE approach determines perceived brightness (cd/m²).

The effort to develop a whole system solution that would be generalizable to most EVR spaces also included a review of the literature and the creation of generalizable requirements that could be injected into the design phases without up-front validation and verification (V&V). With the professional communities’ consensus it was agreed that V&V of the requirements would occur during the design, test, and V&V phases of product development. This approach led to the understanding that verification and validation of the new requirements and guidelines would not fully be tested until either a full scale mock-up was created or the first ship based on the new requirements was built. However, it was acknowledged that many of the major issues potentially impacting night vision could be determined and measured in labs and through Computer Aided Design (CAD) type software modeling and analysis, directing changes needed; before full testing took place.

In this case, a scientific and military literature search and review for requirements that accommodate vision constraints, especially night vision was carried out. Based on this information, a hardware envelope was created, one; that goes just beyond the boundaries of visual requirements. Using a hardware envelope allows for minor requirements adjustments to be made; deterring any new extensive costs for completely new hardware prototypes. Additionally, this method allows for software and middleware fine tuning of requirements within the hardware envelope. For example if it is known from scientific parameters that night vision is supported best if dimming controls are able to dim a display down to .0001 lux than building a hardware envelope supporting dimming to .00001 lux or .000001 lux assures designers the level that will be useful to users is somewhere within that hardware envelope. For instance, readability with vary with environmental factors (day, dusk, or dark), character stroke height and width, and the Graphical User Interface GUI color palette used. If the hardware is built to support as many variables as possible, software modifications can be used for minor modifications: potentially avoiding cost incurred with redesign of hardware.

**Background**

In an attempt to preserve night vision, the Navy often used red and amber lighting and added red covers or filters to existing displays and indicators. This practice, however, supports color adaptation and not dark adaptation. The use of colored filters can also cause a loss of chart details that contain the same hue – a red symbol is negated by a red filter, often making navigation difficult.

A variety of low cost techniques, such as Plexiglass®, color filters, curtains, and tape have provided suboptimal temporary fixes in reducing illuminance, luminance, and reflective-light effects (see Figure 1). While these fixes reduce some equipment luminance affects on night vision, these fixes are not fully effective in solving the underlying causes that effect operator visibility in the critical operator Forward Field-of-View (FFOV).
Recently scientists, engineers, and Subject Matter Experts set out to determine the root case of these problems. A significant effort went into canvassing standards and scientific information for potential whole system solutions to this systemic problem. As a result a handbook for Navy equipment and space visual ergonomics guidance was drafted, covering all spaces requiring external viewing responsibilities.

The handbook provides a whole system solution by providing space and layout guidance to support a dark-adapted state sufficient to carry out most night operations. While the handbook was mainly created to establish space and layout guidance for Visual Ergonomics of night operations, it is also intended to establish responsibility within the Naval Sea Systems Command (NAVSEA) enterprise including Program Executive Offices (PEOs) associated with all Navy surface combatants. The main goal of this NAVSEA HDBK is to provide one universal guiding document to programs that develop and install equipment, and support the design of spaces requiring EVR spaces such as the Pilot House. More specifically, this document was developed to improve the tactical and night operations environment where dark adaptation/night vision of the unaided eye may be required.

This document covers equipment guidance including specific display luminance ranges, contrast ratio, color palette, and brightness/contrast settings. The color palette recommendations are based on the Raster Navigational Chart specification guidance (IHO Special Publication S-61; Product specification for Raster Navigational Charts and IHO s52 Appendix 2, Annex A. IHO ECDIS presentation Library User’s Manual. Special Publication No. 52) which provides the ability to switch between daytime, dusk, or night palette settings. Additionally, there is guidance provided regarding panels and indicators designed not only for dark adaption needs, but to also group them together in a location for watchstander ease of recognition and reaction. There is also a recommendation to consider an Enhanced Vision System (EVS) similar to the DDG-1000 Pilot House using eight surveillance cameras instead of lookouts. EVS utilize the zooming power and infrared capability of the camera to augment night vision and more accurately assess surface contact identification, military intentions, submarine periscope detection, etc.

Additionally, the handbook provides recommended changes to Ship Specifications (DDG-51 is used as an example) to procure equipment and design spaces conducive to dark adaptation as well as establish a testing program to verify/validate that the equipment and the space guidance in fact supports human visual performance and ease of navigation during night operations.

Also, internal visibility of key equipment, status, and alarm indicators within the FFOV were addressed and critical placement was considered. FFOV issues are key to layout and configuration decisions to address navigation mission needs to help avoid collisions at sea.

Night vision goggles (NVGs), night vision IR systems (NVIS), and other devices may also be used aboard ships. In most cases night vision devices are only used when patrolling the
exterior of the ship when a watchstander is outside the EVR space. In this case the luminance and chromaticity values of the space and its equipment should not typically be an issue for NVIS device use. If NVGs or NVIS devices are used then equipment in the space should use the proper luminance and chromaticity standards for such devices. Neither the handbook nor this document addresses the proper requirements to meet luminance and chromaticity for NVIS type devices.

In order to support the dynamics of human, visual perception and performance suggested specifications contained in the document were formulated to provide the proper procurement of dark-adapted state/night vision compatible equipment, lighting, and design layouts for future, naval EVR spaces. MIL-HDBK-87213A Electronically/Optically Generated Airborne Displays contained a majority of rationale and guidance on presenting instrument information in the avionic cockpit for the unaided eye under night vision conditions. Since the maritime EVR space conditions and operating environment from a visual performance perspective are similar, guidance from MIL-HDBK-87213A that could be applied to the EVR space visual situation was incorporated. Care was taken to make sure that the stated requirements to be used as guidance are valid based on the science of vision, the physics of light, and engineering guidelines of visual ergonomics as of 2008.

By remaining true to the scientific fundamentals of unaided night vision requirements, this guidance is germane to all Navy surface combatants and is being presented to reflect new scientific and engineering information which proposes a whole systems solution and results in a paradigm shift, particularly from a color usage perspective.

**APPROACH**

The overall approach was to determine if a common solution across surface platforms would be applicable. The following activities should be performed for verification and validation:

- Through research, literature review and analysis determine fundamental unaided eye night vision needs
- Determine validity and applicability of current standards as a whole and in part
- Determine night operations Concept of Operations (CONOPS); Conduct Task Analysis
- Determine validity of previous engineering approach by checking previous approach against known night vision parameters
- Exclude NVIS type requirements due to insufficient standards available and lack of NVIS use on surface combatants.
- Determine a valid set of hardware, software, and space requirements from similar EVR space specifications to support night vision and high sunlight conditions
- Conduct trade study on hardware capabilities to meet new requirements
- Design hardware envelope
- Fully develop new color palettes that support unaided night vision and readability under low luminance conditions
- Determine valid test procedures
- Test hardware envelope
- Test readability in low luminance conditions with new hardware
- Model and analyze numerous hardware components with CAD /Radiance type modeling software
- Conduct full testing and V&V analysis in ecologically valid setting
- Refine prototypes and space layout as needed
RESEARCH AND ANALYSIS

Dark Adaptation

Aboard ship, watchstanders and lookouts normally go through a brief period prior to watch turnover that allows their eyes to dark adapt to night conditions. Dark adaptation occurs when going from a well lit area to a very low-level lit area. Initially, blackness is seen because the eye cones temporarily decrease in activation.

To achieve dark adaptation, equipment and displays are typically set to low luminance levels. In this context, dark adaptation is achieved when the watchstander is able to view through the window out onto a darkened horizon visual targets. If any exterior or interior light source is too bright (e.g., full moon, Q-70 console), then interference with dark adaptation may prevent watchstanders from distinguishing objects on a dark horizon, and from being able to perform safe navigation. Refer to Figure 1, Dark Adaptation Scale in Lux.

Photopic – Scotopic Vision

When the eye is adapted for bright light, in luminance levels generally greater than ~3.19 cd/m² the cones dominate; this is called photopic vision. At luminance levels below ~0.0036 cd/m² (~.01 lux) the rods dominate in what is called scotopic vision. The physiological lower limit of the scotopic range is ~ 0.000000318 cd/m² (~.000001 lux) and the physiological upper limit of the photopic range is 317965.02 cd/m² (~1,000,000 lux). See Figure 2, Dark Adaptation Scale in Lux.

Brightness

Brightness is an attribute of visual perception in which a source appears to emit a given amount of light – the perception elicited by the luminance of a visual target, or the perceived brightness of an illuminated surface. At low levels of illumination, brightness discrimination is poor, but improves significantly as background illumination increases.
**Red vs. Low-level White Light**

Red lighting was instituted during World War II to facilitate dark adaptation (see figures 4 and 5; Submarine night operations: rigged for red and Raster Navigational Chart; rigged for red).

Figure 4. Submarine night operations: rigged for red.

Figure 5. Raster Navigational Chart (RNC); rigged for red

Some applications (e.g., aircraft, submarines, and naval ships) use chromatic (color) illuminants. Red light was often unpopular since it made it difficult to read charts, and also resulted in fatigue. It was originally thought that the relative sensitivity curve showed that the rods were not sensitive to red wavelengths >600 nm. The hypothesis was that if red were used at night operators could still read charts while preserving night vision. In actuality, the rods and cones are equally sensitive to the long wavelength (i.e., red) end of the spectrum. Therefore ships rigged for red effect both the cones and the rods and do not allow the operator to gain dark adaptation to begin with. Meaning the rods are no longer at their peak sensitivity, the operator is not dark adapted and becoming dark adapted could take several minutes in a completely darkened space (Rothblum and Wyatt, 2005).

It was also determined that a set of studies run starting around WW II determined that when luminance was near the levels needed for dark adaptation there was no significant difference between the amount of time it too become dark adapted after being exposed to red as being exposed to low level white light. Meaning as the intensity of light decreases, the visual response to red and white become virtually the same (Luria and Kobus, 1984).

Considering the disadvantages of red light, where many symbols and colors on displays of the same hue (i.e., red, pink, brown, any symbol that contains a ting of red) can be rendered near invisible, or negated by the use of red light. Therefore, for the purposes of this case study, it was concluded that low-level, blue-filtered white light should be used and is preferable to red light. The blue-filtered portion of the low-level blue-filtered white recommendation comes from the Naval Air Warfare Center (Aircraft Division requirements’ guidance; SAE-AS 7788, Panels, Information, Integrally Illuminated, 1999-07).

**Forward Field of View (FFOV)**

A measurement problem stood out in many of the standards for the design of EVR spaces. Some standards suggested the average luminance be considered from the average overall space. This premise did not seem to have a stable foundation as an argument. It is the case that light from various places within a space may affect the viewing space of an operator, but the FFOV would obviously serve as a more valid measure of ambient influence for EVRs. For instance if an operator were standing near the aft port and there were no extraneous light sources than the FFOV luminance level may be much less than if the operator were standing near the windows but
turned back to look aft to make eye contact with another operator. Why because there may be several light sources in the FFOV of the operator looking toward the aft to speak with another operator while the FFOV of the operator standing near the aft and looking at a wall with now extraneous sources of light would not have as much light impeding on their dark adaptation level.

Additionally, many measurement methods suggested the meter be pointed directly up to the ceiling where the light was placed (MIL-HDBK 289-SH, 1986 Lighting on Naval Ships; Metric). We questioned how often a human would actually look directly at the ceiling where lights are mounted. This type of measurement may be important to determine how well lit a desk surface is but not the ambient influence on FFOV viewing capabilities during night conditions when the overhead lights would be off anyway. When it comes to supporting a visual task such as locating targets on darkened horizon, the ecologically valid VE approach would be to consider the FFOV zone for the main measurements of interest, along with the viewability out onto the horizon, and the readability of any displays or indicators.

**Reflection and Glare**

Reflection and glare can make viewing a display or indicator light nearly impossible in high sunlight conditions. Additionally, reflectance and glare can make viewing low level luminance displays difficult as well. Therefore the space and layout guidance should address ambient light reflection and glare prevention and reduction methods regarding equipment and bulkhead paint colors, task lighting, paint texture, egress lighting, and dimming controls. The use of anti-reflective/glare film coatings or filter devices may be required to compensate for excessive luminance or reflections caused by improperly placed indicators.

**Light Measurement**

Photometry is the measurement of light, in terms of its perceived brightness to the human eye (i.e., Visual Ergonomics approach). Radiometry is the measurement of radiant energy (including light) in terms of absolute power (i.e., the typical Industrial Engineering approach). In photometry the radiant power at each wavelength is weighted by a luminosity function (a.k.a. visual sensitivity function) that models human brightness sensitivity.

The measurement of light is luminous flux, which is the rate (density) at which light energy is emitted from a source, and is expressed in lumens (lm). One lumen/meter$^2$ is equivalent to 1 lux. The corresponding radiometric unit measures for irradiance is watt/meter$^2$. Lux measures the intensity of light, with wavelengths weighted according to the average sensitivity of the human eye based on a standardized model of human brightness perception. There is no single conversion factor between lux and watt/meter$^2$ (the corresponding radiometric unit); there is a different conversion factor for every wavelength, and it is not possible to make a conversion unless one knows the spectral composition of the light.

Note: 1 foot candle (fc; lumen per square foot [not meter]) ≈ 10.764 lux. See Table 1 and 2.

Lumen per square foot (fc) and foot-lamberts (FL) are non-International System of Units [SI]. The cd/m$^2$ (candela per square meter) is the SI unit of luminance as is lumen for luminous flux. See Table 3, Conversion Factors for Photometric Units.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Radiometric</th>
<th>Photometric</th>
</tr>
</thead>
<tbody>
<tr>
<td>power</td>
<td>watt (W)</td>
<td>lumen (lm)</td>
</tr>
<tr>
<td>power per unit area</td>
<td>W/m$^2$</td>
<td>lm/m$^2$ = lux (lx)</td>
</tr>
<tr>
<td>power per unit solid angle</td>
<td>W/sr (steradian)</td>
<td>lm/sr = candela (cd)</td>
</tr>
<tr>
<td>power per area per solid angle</td>
<td>W/m$^2$-sr</td>
<td>lm/m$^2$-sr = cd/m$^2$ = nit</td>
</tr>
</tbody>
</table>

Table 1: Common Radiometric and Photometric Units
### Table 2. Standard International Units of Measure; modified from USAARL Guide for making Laboratory Light Measurements 1992.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>SI unit</th>
<th>Abbr.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminous flux</td>
<td>lumen</td>
<td>lm</td>
<td>also called luminous power</td>
</tr>
<tr>
<td>Luminous intensity</td>
<td>candela (= lm/sr)</td>
<td>cd</td>
<td>an SI base unit</td>
</tr>
<tr>
<td>Luminance</td>
<td>candela per square meter</td>
<td>cd/m²</td>
<td>sometimes called nits</td>
</tr>
<tr>
<td>Illuminance</td>
<td>lux (= lm/m²)</td>
<td>lx</td>
<td>Used for light incident on a surface</td>
</tr>
<tr>
<td>Luminous emittance</td>
<td>lux (= lm/m²)</td>
<td>lx</td>
<td>Used for light emitted from a source</td>
</tr>
<tr>
<td>Luminous efficacy</td>
<td>lumen per watt</td>
<td>lm/W</td>
<td>ratio of luminous flux to radiant flux</td>
</tr>
</tbody>
</table>

### Table 3. Conversion Factors for Photometric Units. Table 3 shows that 1 nit (nt) is equivalent to 0.2919 fL and 0.0929 cd/ft².

<table>
<thead>
<tr>
<th>Luminance</th>
<th>Illuminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>cd/m²</td>
<td>fL</td>
</tr>
<tr>
<td>lx</td>
<td>fc</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>cd/m²</td>
<td>1</td>
</tr>
<tr>
<td>fL</td>
<td>3.426</td>
</tr>
<tr>
<td>cd/ft²</td>
<td>10.76</td>
</tr>
<tr>
<td>lx</td>
<td>-</td>
</tr>
<tr>
<td>fc</td>
<td>-</td>
</tr>
</tbody>
</table>

### Key Findings

The primary areas of guidance identified through the case study and research were compartment layout, equipment selection, and performance requirements. Additional criteria were identified in the areas of surfaces, lighting, controls, and software characteristics.

**Compartment Layout.** The overall layout of equipment and items in the compartment will primarily impact the overall light level in the space or the FFOV and the visibility of the external environment (see Figure 3).

- The number and location of displays and the viewing angles should be based upon informational needs of the crew.
- Within the critical Dark-Adapted zone around windows there should be no more than two displays mounted ~1.5 feet below the level of the window for critical crew information.
- Displays should not be mounted on the aft bulkhead.
- All displays should face away from the forward windows towards the aft bulkhead.
- The recommended dark adapted FFOV ambient level should be from 0.0001 lux to 0.001 lux.

**Equipment Selection.** Proper placement can attenuate the negative impacts of inappropriate equipment, but it cannot fully account for equipment with characteristics that hinder development and sustainment of dark adapted vision.

- All displays should have an option to accommodate an upper/lower rounded corner hood.
- Displays should have sufficient resolution, uniformity, refresh and update rate.
- The dimming floor should be .0001lux (.0000318 cd/m²).
- To accommodate various organic and external solar lighting on/in the ship’s bridge, displays should produce a
contrast sufficient to support readability.

- The image source should provide high contrast >700:1.
- Where possible ships should be equipped with a dedicated Inferred Enhance Vision System (EVS; i.e., SEAFLIR) which is zoom capable and provides 360° view around the ship.

**Performance Requirements.** Specific performance requirements can be established to determine the cutoff for acceptability of individual equipment items. To provide a space that is effective overall, every equipment item must be held to the appropriate standards.

- Readability must be maintained.
- Displays shall be fully visible under ambient lighting conditions up to a maximum of 86,000 lux.
- The display should allow for the non-illuminated background to be perceived as black, not a glowing gray.

**Surfaces.** The surfaces of equipment, fixtures, bulkheads, and even windows must have particular characteristics to prevent reflections that may increase the overall light level within the FFOV or create the illusion of false external contacts.

- All bulkhead and overhead paint finishes should be matte texture and conform to colors Black (37038) and/or Gray (36231) FED-STD-595C.
- Reflectivity off the bulkhead should be < 10%.
- The display front surface and any other surfaces in the optical path should have a reflection reducing coating.
- Equipment display face design should include a matte black (37038) border.
- Specular reflection should be minimized to preclude distracting image reflections (e.g., navigator’s white shirt reflections). The photopic reflection should be <= 0.5%.
- If anti-reflective coatings must be used follow SAE AMS-2521-C Coating, Reflection-Reducing for Instruments Glass and MIL-C-675 Coating of Glass Optical Elements (Anti-Reflection) recommendation.

**Lighting.** Excessive lighting within the compartment or for individual panels or items will impair dark adapted vision.

- Low-level blue-filtered white color should be used for panel, display, task, backlit keyboard, and egress lighting.
- Recessed low-level blue-filtered white lights facing the floor should be used for egress; meeting 1-BW & 2-BW Blue-filtered White, type 1h chromaticity requirement as described in SAE AS25050-2006.

**Controls.** The capabilities of the equipment and lighting may not be able to be brought into conformance with EVR guidelines unless their controls possess certain characteristics.

- The dimming range of instruments should be continuously variable from full on to off.
- Each display should have both a button/membrane/knob based and software based brightness (dimming) and contrast control.
- Ganged brightness control should be provided for panel light dimming.

**Software Characteristics.** Hardware requirements alone are insufficient to ensure an overall space compatible with dark adapted vision. The software that drives the displays must also meet certain criteria (see figures 6, 7, and 8).
• Day, Dusk and Dark software related color palettes should be compliant with the Raster Navigational Chart (RNC) developed color palettes, character height and stroke width.

CONCLUSIONS

A review of the key findings permits several conclusions to be drawn. First, equipment for use in EVR spaces must be designed or selected to meet more stringent luminance and contrast requirements than displays in other spaces. Displays must be able to dim to a suitable level, and indicator lights need to either be dimmable or shielded from the operator’s view in some manner.

Even if display hardware meets the stringent EVR space requirements, its users will be unable to develop or sustain dark adapted vision if the color palette employed by the devices is not compatible with the darkened environment. The colors used must be dim to not impair night vision, but they must also possess sufficient contrast at low luminance levels to permit them to remain legible.

The overall layout of an EVR space must also be tightly controlled. Even if stringent luminance requirements are met, placing too many of these devices within the operator’s FFOV can degrade their night vision. Layout must be controlled in order to limit the number of light sources near personnel requiring external vision and to place other light sources in a location and orientation that their light output or its reflection from increasing the overall ambient light of the space.

The wide range of factors listed above illustrates the difficulty in ensuring a space can remain usable and effective and yet not interfere with the development and sustenance of dark adapted vision. To address all of these factors, personnel responsible for hardware selection, for software development, for equipment layout and installation, and for painting and finishing of the space all need to adhere to the appropriate requirements. Failure in any one area is likely to impair operator night vision and thereby negate advances in other areas.
REFERENCES

Standards, Specifications, and Handbooks

DDG 51 Class Ship Specification
FED-STD-595C 01-16-2008 Colors used in Government Procurement
JSSG-2010 Crew Systems
JSSG-2010-5 Crew Systems Ship Lighting
NAVSEA-HDBK
JSSG-2010-11 Crew Systems Emergency Egress
NAVSEA-HDBK
MIL-HDBK-87213A (USAF) 8 February 2005 Electronically/Optically Generated Airborne Displays
MIL-STD-411F 03-10-1997 Department of Defense Design Criteria Standard Aircrew Station Alerting Systems
MIL-DTL-13455E 08-28-1998 Filter, Light (For Blackout Secure)
MIL-L-85762 Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible
MIL-STD-411 Aircrew Station Alerting Systems
MIL-STD-461 Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-3009 Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible
MIL-C-675 Coating of Glass Optical Elements (Anti-Reflective)

Discretionary Practices

MIL-HDBK-46855A, Human Engineering Program Process and Procedures
DOD-HDBK 289 dated 26 November 1986
NAT-STD-3800 Night Vision Goggle Lighting Compatibility Design Criteria

Scientific Documents


Non-Government Standards and Other Publications

American Bureau of Shipping (ABS) Guidance Notes on Ergonomic Design of Navigation Bridges, October 2003, Houston, TX USA
SAE-AMS-2521C Coating, Reflection-Reducing for Instrument Glasses
C.I.E. Supplement No. 2 to Publication 15 (E-1.3.1), Recommendations on Uniform Color
Spaces-Color Difference Equations, and Psychometric Color Terms
Illumination Engineering Society; IES Approved Method for Total and Diffuse Reflectometry (1992)
International Hydrographic Organization (IHO) Special Publication (S-61) Raster Navigational Chart Product Specification (RNC) product specifications for Raster Navigational Charts
ISO 13406-1:1999 Ergonomic requirements for work with visual displays based on flat panels -- Part 1: Introduction
ISO 1346-02:2001 Ergonomic requirements for work with visual displays based on flat panels -- Part 2: Ergonomic requirements for flat panel displays
SAE-ARP-4260 1998-11 Photometric and Colorimetric Measurement Procedures for Airborne Flat Panel Displays
SAE AS7788 1999-07 Panels, Information, Integ rally Illuminated
SAE ARP4032 Reaffirmed 2007-02 Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays
SAE ARP4102 Flight Deck Panels, Controls, and Displays
SAE AS 25050 Reaffirmed 2006 Colors, Aeronautical Lights and Lighting Equipment, general Requirements For SAE ARP4256 Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft
SAE ARD50019 Human Engineering Issues for Enhanced Vision Systems
SMPTE-170 Television – Composite Analog Video Signal – NTSC for Studio Applications
VES A FPDM 2.0 Flat Panel Display Measurements Standard
Web Links
http://www.cg.tuwien.ac.at/courses/Seminar/WS2005/index.php/Optische_Taeuschungen#Contrast_illusions
http://www.visualexpert.com/Resources/nightvision.html
http://en.wikipedia.org/
http://en.wikipedia.org/wiki/Luminous_flux
http://www.optics.arizona.edu/Palmer/rpfaq/rpfaq.htm
http://www.maptechnavigation.com/water/Chart Navigator/gallery.cfm

AUTHORS
Margery J. Doyle
Ms. Doyle earned a Master’s, 2007 from the University of West Florida where she worked in collaboration with The Florida Institute for Human and Machine Cognition on the DARPA Augmented Cognition initiative. Ms. Doyle has contributed the scientific engineering realms of cognitive workload, situation awareness, situation understanding, decision making under uncertainty, automation, levels of autonomy, and unmanned systems. Ms. Doyle also completed work towards a PhD in Cognitive Science; leading to several contributions to the field of cognitive engineering and modeling. Her work

Scott A. Higgins

Scott Higgins served 26 years in the US Navy transferring to the Fleet Reserve in 2006 as an Operations Limited Duty Officer (LDO) Lieutenant Commander. During his career as an Operations Specialist and then LDO in 1994, he served 15 years of his experience at-sea during 5 deployments working in CIC and Pilot House operations. In 2006, he joined Lockheed Martin Maritime Systems and Sensors (MS2) in Mooresville, New Jersey supporting Aegis Modernization Human Systems Integration. In 2007, he supported PEO Ships sponsored studies on manpower optimization for Aegis Cruiser and Destroyer ships. He specifically analyzed tasks and workload for the SQQ-89 A(V)15 Acoustic Tracking Supervisor/Fire Control Operator, Sonar Supervisor, Sonar Log Keeper and ASW Evaluator.

John Winters

John Winters is a Senior Human Factors Engineer and program director with Basic Commerce and Industries (BCI) in Dahlgren, VA. Since 1998 he has worked on various projects through the Naval Surface Warfare Center and other Navy customers. His projects have included process integration and development and evaluation of a design environment for human engineering and systems engineering activities, concept development and testing for tactical symbology and watch turnover capabilities, definition of program certification criteria for human systems integration, development of a taxonomy and repository for human performance measures, and technical warrant liaison for multiple warfare systems programs.

COMMON TERMS

CONTRAST RATIO (CR) or luminance ratio: CR=Lt/Lb, numerically equal to (ΔL+Lb)/Lb, also = 1.0 + ΔL/Lb. This quantity ranges from 1.0 (no contrast) to approaching infinity. CR can be used to determine the contrast ratio of the foreground vs. background: Lt is the total luminance of the symbol or image, including any transmitted and reflected light as measured in the specified lighting conditions. Lb is the luminance of the background, or dimmer area, including any transmitted and reflected light and any stray display emissions measured in the specified lighting conditions.

CONTRAST (C) or luminance contrast: C=ΔL/Lb, numerically equal to (Lt-Lb)/Lb, 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 CI, which is the contrast of a lighted element against an unlighted element, and Cul, which is the contrast of an unlighted element against its background.

DIFFUSE REFLECTION: Scattered or broken up reflection of light.

GRAY SCALE: The incremental levels of display element light transmission which exists between fully off (dark) and fully on (bright). Gray scale refers to the number of luminance levels, or shades of gray, available in a display.

GRAY SHADE: One increment in luminance, generally assumed to be a ratio of 1.41 (square root of two) brighter than the adjacent shade.
GRAY LEVEL: One increment in luminance level. The size of the increment depends on the system. The number of levels is a measure of how finely a digitized image is quantified in luminance.

HIGH-AMBIENT LIGHTING CONDITIONS: The maximum ambient illumination the Pilot House would be exposed to, at least 86,000 lux (8000 ft-c). These numbers, of course, are mediated by such factors as sun altitude, transmittance of the window filters and angle of incidence of light to the display.

HUE: The quality of light that is characterized by the words green, red, blue, yellow, etc. Hue is independent of both saturation and brightness.

ILLUMINANCE: A measure of the amount of light incident on a surface. This can be measured by instrumentation. The SI units are lumens per square meter (lm), abbreviated as lx. The older, British units are footcandles, abbreviated as fc. One footcandle is equal to 10.76 lux.

LUMENS PER SQUARE METER (lm/m2): The lm/m2, or lux (light flux) is the SI unit for illuminance (commonly called illumination). Illuminance is used to measure light falling on a surface, such as a desk or display surface. One lux is approximately equal to 0.0929 footcandles (1 fc approx. = 10.76 lux).

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

LUMINANCE: The amount of light emitted, transmitted or reflected from a display, light source, or other object. It can be measured by instrumentation. The SI units are candelas per square meter (cd/m2) the older British units are footlamberts, abbreviated as fL. One footlambert is equal to 3.426 cd/m2 or nits.

NIT OR CANDELA PER SQUARE METER (cd/m2): The cd/m2 is the SI unit for luminance. Luminance is used to measure light radiating or reflecting from a surface, such as the face of a display. A cd/m2 is approximately 0.292 foot Lambert (1 fL approx. 3.43 cd/m2). The cd/m2 is also called “nit,” particularly in the United States. This may be a contraction for “normalized intensity,” or may be from Latin "nitere" = "to shine."

RASTER DISPLAY: A display in which the entire screen is scanned sequentially. This produces less luminance than stroke written images due to the higher writing rate of raster systems. This is not to suggest that the palette recommendations are executed on a Raster Display, only that the palette recommendations use the line, character stroke and width as the samples provided to enhance viewability under darkened ship conditions.

REFLECTANCE: is the fraction of incident radiation reflected by a surface. In full generality it must be treated as a directional property that is a function of the reflected direction, the incident direction, and the incident wavelength.

SPECULAR REFLECTIONS: Reflections from a finite, resolvable area of a surface which continuously, over that area, follow the law of reflection (angle of light incidence equals angle of light reflection). Such reflections are exemplified by