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Human Factors Criteria for Displays: A Human Factors Design Standard Update of Chapter 5

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16. Abstract

This document contains updates and expands the design criteria and information on displays from the Human Factors Design Standard. A research team of human factors experts evaluated the existing guidelines for relevancy, clarity, and usability. They drafted new guidelines as necessary based on relevant sources, and they reorganized the document to increase usability. This resulted in extensive changes to the original document including the addition of new guidelines, sources, and topic areas.

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1. INTRODUCTION

Today, computer displays have become commonplace in the Federal Aviation Administration (FAA) work environments. In the past, these computer displays consisted almost exclusively of Cathode Ray Tubes (CRTs). This is no longer the case. Due to recent advances in technology, the number and type of different displays has increased dramatically. Whereas, previously, the decision on which display to purchase may have depended on only one or two factors, now there are dozens of factors to take into consideration, particularly when choosing between different display technologies. This can lead to confusion on the part of the decision makers responsible for procuring new displays.

The FAA is in the process of modernizing the National Airspace System (NAS) (FAA, 2007b). New systems are being added to the NAS and older systems are being upgraded. Many of the new systems being added to the NAS include new displays. Other existing systems have a set schedule for technology refresh, which often includes the upgrade of displays (FAA, 2007a). As the number of displays and frequency of use has increased within the FAA, the need for good human factors display standards has also increased. Good quality displays that follow human factors principles can benefit user performance, safety, and user health. Thus, in order for the FAA to reach its modernization goals, decision makers will need to have access to current information such as that provided in this chapter.

This document summarizes the process followed by the research team in the development of an updated and revised set of display criteria. We explain the research and revision process used for creating this set of criteria in this document, followed by an appendix containing the design criteria. The material in the appendix is intended to replace the current material on *displays* in the Human Factors Design Standard (HFDS) (Ahlstrom & Longo, 2003).

Although Ahlstrom and Longo (2003) originally combined the material on displays with the material on printers in a single chapter in the HFDS, this revision effort addresses only the display information. We will address information on printers in a subsequent revision effort.

1.1 Purpose

The purpose of this document is to provide an updated set of criteria on displays that meets the need of the FAA missions and systems and to describe the process used to create these criteria.

1.2 Scope

This document is limited in scope to displays such as those used to interact with or view computer-generated information. It does not address criteria for mechanical display devices such as counters, flags, and moving pointers. It also does not include touch screen displays. Touch screen displays are addressed in another chapter.

The majority of the criteria offered in this chapter are sufficiently generic to apply across a range of FAA operating environments; however, certain paragraphs may not be applicable to all operating situations. We have provided additional information to assist the decision maker in determining the tradeoffs and suitability related to the design criteria, where relevant.

The purpose of a display is to support the user in accomplishing a specific function by conveying specific information. The characteristics of the hardware necessary to achieve this goal depend on a number of factors. These factors are related to the tasks that the user must perform in order to complete the overall objective and the information and operating characteristics involved in accomplishing the tasks. Some displays may be perfectly suitable for one purpose, but inadequate for another. For example, a display suitable in a normal office environment may not be satisfactory for a high brightness environment like an Airport Traffic Control Tower (ATCT). Therefore, the first step system designers should carry out when developing or procuring a visual display is to define the function of the display.

Some questions that may be relevant in understanding the function supported by the display include the following:

1. What are the specific tasks to be accomplished with the display?
2. What information should it display?
3. How critical is the information on the display?
4. How frequently does the user refer to or interact with the information on the display?
5. Is the information static or dynamic?
6. How critical is it for color to be accurately depicted?
7. From what angles and distances will the user view the display?
8. What are the ambient lighting conditions under which the display will be used?
9. What are the physical environmental conditions (e.g., vibration, temperature, dirt/environmental contaminants) under which the display will be used?
10. Are there space constraints for the display?
11. What is the level of detail and/or accuracy required for displayed information?
12. What are the time frames of display use (e.g., 8 hours a day, 24 hours a day)?
13. Is the information on the display used in isolation or in conjunction with other information?
14. What else (other tasks) does the user need to do while viewing the display?
15. How does the user interact with the display (e.g., does the user monitor the display constantly or periodically or does the display react to user input)?
16. How will the display be maintained?
17. What are the characteristics of the target user audience for the display (e.g., age, visual acuity, color perception, anthropometry)?
18. What are the users' experiences and expectations related to the display?

These questions are critical for defining the display requirements. An effective display optimizes the match between the user, tasks, conditions, and equipment. Although the criteria contained within the appendix can help the decision makers, each situation is in some way unique. Thus, the use of the information within this document alone will not guarantee the best display for the task. The design/procurement process should include formal assessment, prototyping, or simulation with users performing typical tasks under typical operating conditions, as appropriate. The appropriateness of the assessment technique will depend on the aspect of the display that is of interest. For example, a mock up of the physical work space may be necessary if the ergonomics of interaction is important, but not if the aspect of interest is resistance to environmental contaminants.

1.3 Shall and Should

Each specification is identified as a "shall" or "should" statement. A solid, black square (■) adjacent to the specification identifies the "shall" statements. These originate from or are comparable to statements from authoritative sources such as those associated with FAA orders, standards, military specifications, and valid peer-reviewed research.

Each "should" statement is identified by an open, white square (□). These represent best practices guidance that is applicable in most cases but may involve trade-offs or be influenced by domain or system-specific factors.

2. METHOD

Researchers organized the revision process in phases that included the review and verification of information from the HFDS; identification of new source material; systematic evaluation of literature, reorganization, addition, and revision of certain topic areas; addition of information to justify the design criteria and define tradeoffs associated with the design criteria; and creation of supplemental information. We distributed this document and the attached appendix with the design criteria to subject matter experts for review.

2.1 Review of the Human Factors Design Standard

In the first phase of this effort, researchers from the Human Factors Team-Atlantic City sought out guidelines and standards that pertained to computer display procurement and design. We took the information in displays from the existing HFDS chapter and placed it into a column of a spreadsheet, with one paragraph per cell. As we reviewed each standard, we created a new column in the spreadsheet, matching the new information with the existing information. Using this method, we were able to compare information from other sources against the current information from the HFDS and against each other. When there was new information beyond what was already present in the HFDS, we created a new row near other related information. We then updated the information from the HFDS, as appropriate. The researchers used the reference lists from the standards and guidelines to identify primary sources. When possible, we obtained primary sources to verify the information within the guidelines and standards.

The researchers then expanded their search to identify current research related to existing and emerging displays published in the literature. We used multiple keywords and acronyms, including terms such as CRT, Liquid Crystal Display (LCD), and Video Display Terminal (VDT). We searched databases available through the Internet such as Ingenta (www.ingenta.com), Association for Computing Machinery (ACM) (www.acm.org), and Google Scholar (www.google.com). These databases allowed us to review abstracts for relevancy. If the abstract appeared relevant, we would request the full article through interlibrary loan or by contacting the author directly. We added keywords from relevant articles to our list of search terms, as appropriate. Once we received and reviewed the full text articles, we added the relevant references to a table. We used the table to summarize important information from the article, with columns for the reference, purpose, experimental procedure, and experimental results. This is a technique that we used successfully before to help us review, compare, and analyze large quantities of information from the literature (Ahlstrom & Kudrick, 2004a, 2004b). We used the information from the literature as appropriate to supplement and justify the information from the other sources. Upon review of each source, researchers weighed the relevancy, adequacy, and validity of the material before including it in the document. We rewrote relevant information from the literature into shall or should statements that could be used in requirements documents. When warranted by the new information, we updated existing information or created a new specification. When new source material proved specifications in the current document were outdated or invalid, these specifications were revised or deleted as necessary.

In the process of our literature search, we discovered that there were limitations to the existing research literature. The operational environments and use of displays in the literature focused mainly on typical office or home use. FAA operating environments include not only office-type environments, but also many environments atypical to normal office use. We felt it was necessary not only to address issues typical to a normal office environment, but also those that are somewhat unique to the FAA. We were aware of several FAA studies that had addressed some of these issues. Thus, in addition to our Internet literature search, we sought out documents related to the acquisition and testing of monitors and displays for the FAA. These documents evaluated the suitability of monitors specifically for FAA environments. The majority of these documents focused on displays for ATCTs. ATCTs have specialized needs because controllers often view the information at an angle or distance different than the typical office environment, and the lighting conditions can vary from high brightness in the daylight hours to very dark at night (Crown Communications, Inc, 1998; FAA, 2002). Additionally, FAA displays are often used continuously as opposed to the 8-hour timeframe of most office displays.

In addition to reviewing documentation, we spoke to individuals who were involved in monitor acquisitions and solicited feedback on issues and concerns that arose during past FAA monitor acquisitions. Among other issues, these concerns included cleaning, aspect ratio and resolution, and off-axis color shift.

2.2 Reorganization

With the addition, deletion, and revision of many of the existing specifications and the creation of new specifications, we needed to reorganize the entire chapter. With the goal of enhancing document usability, researchers had volunteer HFDS users perform card sorts with the specifications (Ahlstrom & Allendoerfer, 2004). The researchers then used the results of the card sort to organize the chapter.

2.3 Additional Information

Users are often able to implement only some of the design specifications, but not all of them, due to budget constraints, time constraints, or other concerns. These users need to know what the consequences might be of violating design specifications or under which conditions violation of design specifications might be acceptable. Feedback from actual FAA users indicated that it was important to supply justification for the specifications within the standard (Ahlstrom, 2005). Thus, throughout the document, the researchers added paragraphs of information that provide the users with the basis they need to make informed decisions when faced with difficult design choices.

After review of the material and discussions with several human factors experts who had past experience in FAA display acquisitions, we became concerned that the users needed help in the interpretation and application of some of the material within the chapter. This need was further reinforced by requests that our team received from programs within the FAA asking for our help in determining aspect ratio, resolution, and visual angle for current procurement efforts. We decided to develop additional material as a supplement to the chapter on displays. The supplemental materials include interactive tools that will be available on our website (http://hf.tc.faa.gov). One tool will allow the user to apply the guidance on visual angle by calculating visual angle based on other inputs or calculating other inputs required to achieve a given visual angle (visual angle calculator). Another tool calculates character size based on aspect ratio and resolution (resolution and character size calculator). These tools are intended to help the user apply the material contained within the standard. We may add other tools as necessary.

2.4 Expert Review

We circulated a draft of the newly created chapter among a group of human factors professionals for review and comment. Reviewers included those individuals both inside and outside the FAA. We asked the reviewers to provide feedback on the chapter's organization, content, clarity, and relevance. We used the reviewers' comments to make improvements on the final document.

3. SUMMARY OF CHANGES

The revision of the HFDS information on displays (Chapter 5) created notable changes. The primary change in the chapter is the update of information to include newer technologies and the lessons learned from research. The earlier chapter was published when display technology was in its infancy. At that time, the primary display technology was the CRT. Changes in the chapter address newer technologies not previously addressed and also incorporate research that was not available when the earlier chapter was created.

The reorganization of the information in this document involved regrouping, separating, and removing certain redundant, obsolete, or unverifiable guidelines. New guidelines replaced outdated material, where warranted.

We created these standards to aid in uniformity and cohesion of the design, use, and procurement of displays. However, as with any set of standards, common sense and advice from human factors professionals should be sought for use in specific applications.

The *Human Factors Criteria for Displays: A Human Factors Design Standard Update of Chapter 5* should be considered a living document. It will be updated as necessary to keep abreast of emerging technology, additional research, technological advances, and user feedback.

The researchers attempted to create a useful, organized, and comprehensive document. This is evidenced throughout the document where the user will find that each standard has at least one valid source. The effort to supply the user with an organized, easy-to-use reference document is also evidenced in the arrangement of the report.

The researchers understand that there is always room for improvement and encourage comments and feedback. Comments and feedback should be sent to the first author (Vicki Ahlstrom) at the Human Factors Team – Atlantic City, FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405. The Document Improvement Proposal appears on the last page of this document.

An appendix presents the full set of display design criteria. A table of contents precedes the document. A list of references and a glossary containing key terms follows the standards.

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Appendix

Chapter 5: Updated Human Factors Criteria for Displays

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List of Exhibits

5 DISPLAYS

This chapter covers different types of displays used for computer information output; sometimes referred to as Video Display Terminals (VDTs) or Video Display Units (VDUs), including Cathode Ray Tubes (CRTs), Liquid Crystal Displays (LCDs), Plasma displays, projection displays, and stereoscopic displays. It does not address touch screen displays, visual indicators such as Light Emitting Diode (LED) displays, or lights accompanying switches and controls. Touch screen displays are addressed in the chapter on non-keyboard interaction devices (Chapter 9) and visual indicators are addressed in the chapter on controls and visual indicators (Chapter 6).

5.1 Visual Displays

5.1.1 General

▪ 5.1.1.1 **Make displays function under operational conditions.** Visual displays shall function under any circumstance corresponding with the operational and use philosophies of the system. [Source: Department of Defense (DOD), 1999]

▪ 5.1.1.2 **Make displays legible under all conditions.** Visual displays shall be legible under all anticipated viewing conditions. [Source: DOD, 1999]

> **Discussion.** Factors affecting the **legibility** of a display include the nature and characteristics of the display itself, ambient lighting, and viewing distance.

▪ 5.1.1.3 **Surface quality.** The display surface shall have no visible defects (i.e., bubbles or scratches), which could increase errors, reduce task speed, or cause visual discomfort. [Source: Hopper, Dolezal, Schur, & Liccione, 1994; International Organization for Standardization (ISO), 1992]

▫ 5.1.1.4 **Evaluate through prototyping.** The suitability and effectiveness of a display should be evaluated using representative tasks, users, and environmental settings before being incorporated in a new system. [Source: Avery & Bowser, 1992]

▫ 5.1.1.5 **Environmental impact.** Displays should be selected to minimize environmental impact during manufacturing, use (including storage and breakage), and final disposal (e.g., in a landfill). [Source: Hopper et al., 1994]

▫ 5.1.1.6 **Durability.** A display should be designed to minimize maintenance, and provide protection of components from environmental contaminants, abrasion, vibration, and maintenance-induced damage. [Source: Hopper et al., 1994]

▪ 5.1.1.7 **Reliability.** The mean-time-between failure goal of the display shall be more than 10,000 hours. [Source: Hopper et al., 1994]

▪ 5.1.1.8 **Health and safety.** The display shall be designed so as to preclude injury during operation and maintenance. [Source: Hopper et al., 1994]

▪ 5.1.1.9 **Surface temperature.** Displays shall not expose users or maintainers to surface temperatures that exceed 104 degrees F. [Source: National Aeronautics and Space Administration (NASA), 1995, 6.5.3]

▫ 5.1.1.10 **Acoustic noise from displays with fan.** Display fans should make as little noise as possible, not to exceed the A weighted sound pressure level of 44dB when operating and 39 dB when idling, to minimize user annoyance. [Source: TCO '05, 2005]

▪ 5.1.1.11 **Smooth edges.** Displays shall have no sharp edges or pinch points where the user or maintainer may come into contact with them. [Source: Nuclear Regulatory Commission, 2002]

▫ 5.1.1.12 **Easy to clean.** Displays should be easy to clean without requiring specialized cleaners or procedures. [Source: FAA, 2002]

Additional information. In many FAA environments, users write on the screens with grease pencils (also known as china markers). Displays are often exposed to dirt, fingerprints, and environmental contaminants. Users need to clean the displays while the displays are on and running. [Source: FAA, 2002]

▫ 5.1.1.13 **Aspect ratio.** The aspect ratio of a display should not adversely impact displayed data. [Source: Crown Communications, Inc, 1998]

Additional information. The aspect ratio of a display is the ratio between the horizontal and vertical dimensions of the display. Common aspect ratios include 4:3, 4:5, and 16:10. Some FAA displays even have a 1:1 aspect ratio.

▫ 5.1.1.14 **Controls should conform to Chapter 6.** Controls for displays should conform to the design criteria contained in Chapter 6, Controls and visual indicators.

5.1.2 Cords, cables, and plugs

▫ 5.1.2.1 **Prevention of insertion errors.** It should be obvious to the user where and in which direction to insert a plug into a display. [Source: DOD, 1992]

- 5.1.2.2 **Protect connectors from disconnect or damage.** Display cables and connectors shall be designed or protected so that they are not easily dislodged or damaged by the movement of people or objects in their vicinity. [Source: DOD, 1992]

  Additional information. One study found that some equipment outages in the FAA could be linked to cables or plugs that were disconnected when someone bumped into or tripped over them. [Source: Ahlstrom & Hartman, 2001]

5.1.3 Adjustability

- 5.1.3.1 **Tilt.** It shall be possible to tilt displays up or down between -5° and +20° in steps or continuously. [Source: TCO'03, 2005b]

- 5.1.3.2 **Height adjustment**. It should be possible to raise or lower the display by at least 110 mm in total in steps or continuously. [Source: TCO '03, 2005b]

- 5.1.3.3 **Safe adjustment.** There shall be no danger of pinching fingers when adjusting the monitor. [Source: Board of Standards Review/ Human Factors and Ergonomics Society (BSR/HFES), 2002; TCO '03, 2005b]

- 5.1.3.4 **Swivel.** It shall be possible to swivel the display by a minimum of 45 degrees to the left or right in steps or continuously. [Source: TCO '03, 2005b]

- 5.1.3.5 **Adjust to user comfort.** Users should be able to easily angle, tilt, and swivel a display to maintain a comfortable working position. [Source: ISO, 2006]

- 5.1.3.6 **Stability.** The display shall be stable in all adjustment positions. [Source: TCO '03, 2005b]

5.1.4 Location and arrangement

- 5.1.4.1 **Locate displays to be readable without assuming uncomfortable positions.** Displays shall be located so that a user can read them to the degree of accuracy required without having to assume an uncomfortable, awkward, or unsafe position. [Source: DOD, 1999]

- 5.1.4.2 **Viewing angle.** All areas of the display surface shall be legible from within at least 40 degrees of the axis centered on, and normal to, the screen. [Source: ISO, 1992]

- 5.1.4.3 **Parallax error.** Displays shall be located so that they can be read from the design eye point with no discernible parallax. [Source: NASA, 1995]

- **5.1.4.4 Make readable without special equipment.** A user should be able to read a visual display without the use of a ladder, a flashlight, or other special equipment. [Source: DOD, 1999]

- **5.1.4.5 Locate directly in front of user** The most frequently used screen should be directly in front of the user in his or her normal working position. [Source: Department of Energy (DOE), 1992]

  Discussion. Locating the screen off-center can cause the user to adopt uncomfortable or awkward positions, leading to pain. Exceptions to this rule are when the users look at the monitor infrequently.

- **5.1.4.6 Simultaneous use.** A visual display that must be monitored concurrently with manipulation of a related control shall be located so that it can be read to within required accuracy while adjusting the control. [Source: NASA, 1995]

- **5.1.4.7 Multiple displays.** When the manipulation of one control requires the reading of several displays, the control shall be placed as near as possible to the related displays, but not so as to obscure displays when manipulating the control. [Source: NASA, 1995]

- **5.1.4.8 Arrange displays consistently.** The arrangement of functionally similar displays shall be consistent across systems. [Source: DOD, 1999]

- **5.1.4.9 Make line of sight below horizontal.** For a typical work environment, the line of sight from the viewer's eyes to the center of a frequently used screen should be between 10° and 60° below horizontal, preferably allowing the user to set the angle most comfortable for him or her within this range. [Source: Balci & Aghazadeh, 1998; DOD, 1999; DOE, 1992; ISO, 1992]

  Discussion. The resting position of the eyes, considered to be the most comfortable position, is 15° below the horizontal. However, a lower monitor position improves the ability to accommodate and facilitates convergence (the turning in of eyes to focus on a nearby object), particularly for persons over 40 years old. Additionally, some research claims that a monitor location 40° below horizontal can reduce discomfort in the neck, shoulders, forearms, and wrists for users wearing bifocals. By placing the top of the screen below eye level, the user can view the information on the screen using a downward gaze. When people view the displays at eye level, they tend to blink less, and eyes can get dry and irritated. A slight downward gaze exposes less of the eye to the atmosphere, preventing dry eyes. It is important, however, not to position the monitor in such a way that the user is forced to adopt an uncomfortable position to view the monitor. [Source: Balci & Aghazadeh, 1998;

Krimsky, 1948; Morgan, Cook, Chapanis, & Lund, 1963; Ripple, 1952; Tsubota & Nakamori, 1993; Tyrrell & Leibowitz, 1990]

▫ 5.1.4.10 **Orient perpendicular to line of sight.** Display screens should be positioned so that the face is perpendicular to the user's line of sight whenever feasible. [Source: DOE, 1992; NASA, 1995]

> **Discussion.** Tilting the monitor downward can lead to increased discomfort both physically and visually, particularly in the neck area, versus a monitor tilted back a little. [Source: Ankrum, Hansen, & Nemeth, 1995; Ankrum & Nemeth, 1995]

▪ 5.1.4.11 **Avoid excessive tilt.** The display face shall not be tilted more than 45° from the normal line of sight. [Source: DOD, 1999]

▫ 5.1.4.12 **Group task-related displays together.** All displays necessary to support a user's activities or sequence of activities should be grouped together. [Source: DOD, 1999]

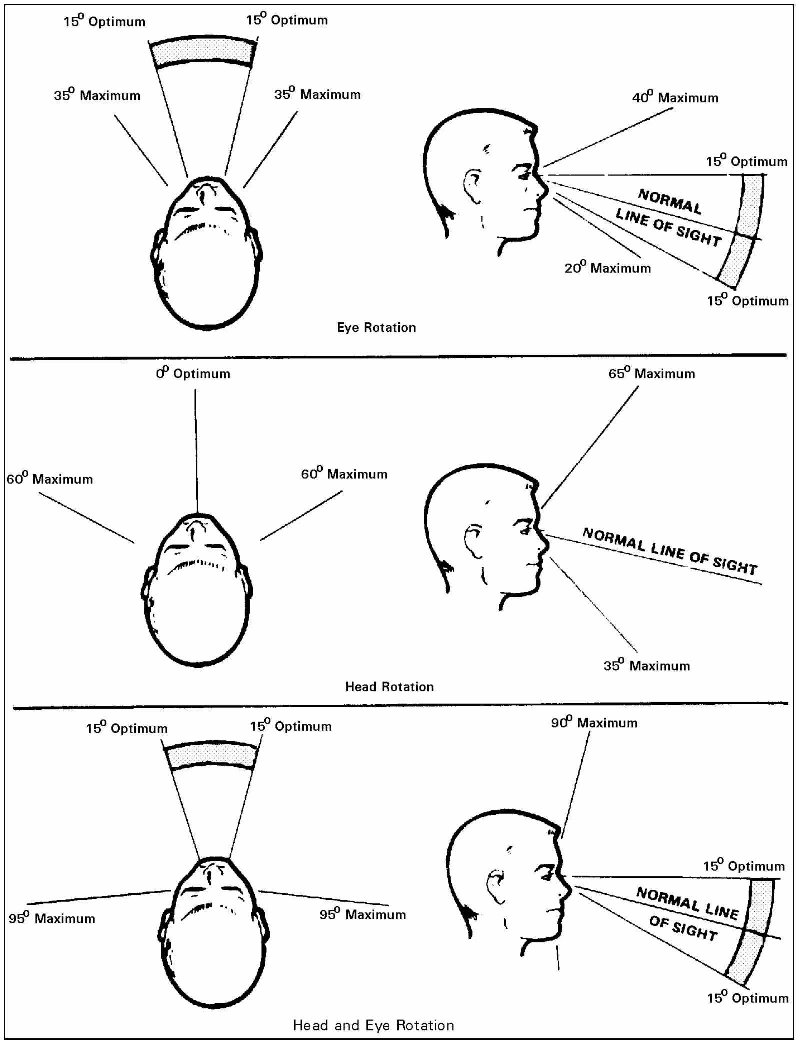
▪ 5.1.4.13 **Arrange according to function and sequence.** Displays shall be arranged in relation to one another according to their sequence of use or the functional relations of the components they represent. [Source: DOD, 1999]

> **Discussion.** In general, it is beneficial if displays are arranged sequentially within a functional group so that they provide a left-to-right or top-to-bottom information flow within the group because this is how people read.

▪ 5.1.4.14 **Locate critical displays in central visual field.** Critical or frequently used displays shall be located in the **central visual field**, as illustrated in Exhibit 5.1.4.14, and occupy a privileged position in that field (e.g., the top or left-most position). [Source: DOD, 1999]

> **Discussion.** Focal vision is the central 30° of the visual field, pictured as the shaded area in the top panel of the Exhibit 5.1.4.14 (along with the range of eye movements with the head stationary). This is the area that people use to look at objects in the world, moving their eyes as needed to bring images of the object on to the **fovea**, which is the area of highest acuity. When an object is outside of the focal area, a person will usually turn the head rather than simply move the eyes. The range of head rotation is illustrated in the second panel of Exhibit 5.1.4.14. The combined range of combined head and eye movement is illustrated in the third panel of Exhibit 5.1.4.14. By locating frequently used displays in the central 30° of visual field, the user is not required to move his or her head to bring the information into the focal area, presumably minimizing neck strain.

Exhibit 5.1.4.14 Optimum vertical and horizontal visual fields



- **5.1.4.15 Distance for monitors with controls.** If there is a frequently used control associated with a display, the display and control shall be within normal reach and vision of the user, not to exceed 635 mm (25 in.). [Source: DOD, 1999; Ministry of Defence, 2000]

  Discussion. The reach distance for a 5th percentile female is 26 inches, so setting the distance at 25 inches ensures that the 5th percentile female can reach the controls. The 5th percentile female measurements and reach ranges represent the customary minimal design criteria. Designing to accommodate the minimal reach range will increase the likelihood that the entire user population can reach the controls.

- **5.1.4.16 Maintain at least a minimum viewing distance.** The viewing distance from the eye to a display should not be less than 500 mm (20 in.), preferably 980-1000 mm (38-40 in.), unless the periods of viewing will be short or if dim signals must be detected, in which case the minimum can be 250 mm (10 in.). [Source: BSR/HFES, 2002; Jaschinski-Kruza, 1990; Owens & Wolf-Kelly, 1987]

  Discussion. In general, a further viewing distance is preferred. Earlier recommendations were to locate the monitor at the same viewing distance as the distance for reading hard copy 307-410 mm (12-16 in.). However, new research has found that eyestrain is not increased when the document and monitor were viewed at different distances. Less eyestrain is reported for 980 mm (38 in.) viewing distances than 660 mm (26 in.). Users judged 50 cm (20 in.) as too close for computer work and performance suffered at this distance over a 100 cm (40 in.) distance. Virtual keyboards and touch screens are an exception to this rule, and are addressed in another chapter. [Source: BSR/HFES, 2002; DOD, 1999; ISO, 1992; Jaschinski-Kruza, 1990; Owens & Wolf-Kelly, 1987]

- **5.1.4.17 Determine maximum viewing distance by legibility.** Maximum viewing distance for displays should be determined by the legibility of the displayed information. [Source: DOD, 1999]

  Discussion. The further the screen is from the viewer, the more difficult it is for the eyes to resolve fine detail. This can often be fixed by displaying screen items at larger resolution.

- **5.1.4.18 Modify displayed information when viewing distance exceeds 50 cm (20 in.).** Information on displays that are located at viewing distances greater than 50 cm (20 in.) should be appropriately modified in aspects such as display size, symbol size, brightness ranges, and resolution to ensure legibility of displayed information. [Source: DOD, 1999]

  Discussion. A general rule is that items viewed at twice the distance will appear half as large. As the preferred character size for readability is 20-22 min of arc and the preferred size for color discrimination is 30 min of arc, the size of the characters on the display will need to be larger to maintain the preferred character size at greater distances. [Source: BSR/HFES, 2002]

- **5.1.4.19 Allow users to adjust viewing distance where possible.** Although there may be a set normal viewing distance, workplace design should allow observers to view displays from other distances. [Source: DOD, 1999]

Example. The set distance between the viewer's eye and the display screen may be 50 cm (20 in.), but the viewer may occasionally want to lean forward to take a closer look at the information displayed on the screen.

Discussion. Users have individual differences in their preferred viewing distances. Particularly for workstations with a single user, it is preferable for users to adjust the viewing distance to their preferred distance. Users report more visual strain when they are forced to work at a distance shorter than their preferred distance. [Source: Jaschinski, Heuer, & Kylian, 1998]

5.1.5 Temporal characteristics

- **5.1.5.1 Refresh rate.** Non-interlaced CRT displays shall be refreshed at a rate of at least 80 Hz, preferably 100 Hz or higher, to avoid the perception of flicker for photosensitive users. [Source: Bauer & Cavonius, 1980; Cardosi & Murphy, 1995; DOE, 1992; NASA, 1995; Vanderheiden & Vanderheiden, 1991]

  Definition. **Refresh rate** is the rate in cycles per second (Hz) at which the displayed contents of a computer screen are periodically regenerated.

  Discussion. A vertical refresh rate of 100 Hz on a non-interlaced monitor is considered sufficient to ensure that flicker is well beyond the threshold of perception even in the peripheral vision where sensitivity is higher. (A 100 Hz refresh rate on an interlaced monitor refreshes a given line only 50 times a second, causing noticeable flicker.) Individual differences exist in flicker sensitivity. The perception of flicker increases in the peripheral vision, so the bigger the monitor is, the higher the refresh rate will need to be to ensure flicker is not a problem. [Source: Bauer & Cavonius, 1980; Cardosi & Murphy, 1995; DOE, 1992; NASA, 1995; Vanderheiden & Vanderheiden, 1991]

- **5.1.5.2 Flicker.** Displays shall have no apparent flicker to at least 90% of a sample of the user population when viewed under the expected conditions of use. [Source: BSR/HFES, 2002; DOE, 1992; ISO, 1992]

  Discussion. The refresh rate is one of several factors that can cause the user to perceive flicker. The perception of flicker increases in the peripheral vision, so the bigger the monitor is, the higher the refresh rate will need to be to ensure flicker is not a problem.

Ambient illumination, display contrast, interference from other equipment, colors used, and the phosphor persistence of the monitor also contribute to the perception of monitor flicker. One of the traditional ways of minimizing flicker for CRTs is by keeping the screen as dark as possible.

For CRTs, a longer decay rate on the phosphor (high persistence phosphor) decreases the flicker perception but can produce trails or after images behind moving elements. There are also individual differences and age differences in the ability to perceive flicker, with younger people generally being more sensitive.

▫ **5.1.5.3 Minimum image formation time.** If motion artifacts are not important, image formation time should not exceed 55 ms. [Source: Avery & Bowser, 1992; BSR/HFES, 2002]

Definition. Motion artifacts are the after images (made up of the previously drawn object that have not yet decayed enough to disappear) that one sees that appear to follow a moving display object. They often look like the tail of a comet following the object in motion.

▫ **5.1.5.4 Image formation time when motion artifacts are important.** If it is important to avoid motion artifacts, image formation time should not exceed 10 ms. [Source: Avery & Bowser, 1992]

5.1.6 Luminance and contrast

▪ **5.1.6.1 Illumination levels.** Critical visual displays shall be capable of providing clear indication of equipment condition within the following room illumination levels consistent with the area of intended use:

a. Control Room: 5 to 50 footcandles.
b. Equipment Room: 50 to 100 footcandles
c. Air Traffic Control Tower: 1 to 6,000 footcandles
d. TRACON: 1 to 50 footcandles
e. Typical office environment: 20 to 50 footcandles. [Source: FAA, 2005; OSHA, 2007]

▪ **5.1.6.2 Minimize luminance variation across the display.** Luminance shall not vary by more than 1.5:1 (L_{Max}:L_{Min}) from the center to the edge of the display. [Source: BSR/HFES, 2002; ISO, 2006]

Definition. Luminance is the physical measure of the amount of light emitted by or reflected in a given direction from the display. Luminance is expressed in candela per meter squared or footlamberts. **Footlamberts** is a measure that has been corrected for the visual system's differential sensitivity to different wavelengths, giving an approximation to perceived brightness. [Source: Murch, 1987]

- ▫ **5.1.6.3 Luminance degradation**. Luminance should not degrade by more than 3% of the original luminance for each 1000 hours of operation. [Source: Hopper et al., 1994]

- ▫ **5.1.6.4 Maximum luminance for a CRT.** The maximum luminance of a CRT should be ≥ 120 cd/m^2 (35 fL) for normal use. [Source: TCO '03, 2005a]

- ▫ **5.1.6.5 Maximum luminance for a flat panel display.** The maximum luminance of a flat panel display should be ≥ 150 cd/m^2 (43 fL) for normal use. [Source: TCO '03, 2005b]

- ■ **5.1.6.6 Character luminance.** Either characters or their background, whichever has higher luminance, shall have a luminance of at least 35 cd/m^2 (10 fL), with at least 100 cd/m^2 (30 fL) preferred. [Source: BSR/HFES, 2002; DOD, 1999; Nuclear Regulatory Commission, 2002]

  Discussion. Increasing luminance reduces pupil diameter, reducing distortions and improving speed of accommodation and depth of field, especially for users over 40 who tend to lose some of their ability to accommodate. However, higher luminance increases sensitivity to flicker. [Source: Bauer & Cavonius, 1980]

- ■ **5.1.6.7 Off-axis contrast**. The display contrast shall not change by more than 20% when viewed at +/- 30 degrees. [Source: TCO '03, 2005b]

- ■ **5.1.6.8 Screen luminance.** The screen illumination shall not contribute more than 25% of screen brightness through diffuse reflection and phosphor excitation. [Source: DOD, 1999]

- ■ **5.1.6.9 Provide adjustable contrast and brightness.** Easy-to-use controls shall be provided that are capable of providing multiple step or continuously variable contrast and brightness consistent with the ambient environment. [Source: DOD, 1999]

- ▫ **5.1.6.10 Luminance range.** A control should allow the user to vary the luminance from 10% luminance to 100% luminance. [Source: Nuclear Regulatory Commission, 2002]

- ■ **5.1.6.11 Detection of weakest target.** Adjustment of brightness, contrast, and other electronic parameters shall permit the detection of the weakest target that is simulated. [Source: Nuclear Regulatory Commission, 2002]

- **5.1.6.12 Dimming to off**. Displays shall not be capable of being dimmed to a level beyond which they cannot be differentiated from the OFF condition. [Source: DOD, 1999]

  Additional information. Failure to differentiate between ON/OFF conditions could lead to critical operator failures (i.e., failure to detect or perform a critical step in an operation). [Source: NASA, 1995]

- **5.1.6.13 Contrast adjustment.** A control shall be provided to adjust the foreground-background contrast ratio. [Source: DOD, 1999; NASA, 1995]

- **5.1.6.14 Contrast ratio.** The contrast ratio of the display foreground to background shall be greater than 3:1; a contrast ratio of 7:1 is preferred. [Source: BSR/HFES, 2002; ISO, 1992; Nuclear Regulatory Commission, 2002]

- **5.1.6.15 Minimum contrast ratio for high ambient light**. As the highest ambient light level is reached, the contrast ratio between the lowest intensity symbology and the background shall degrade to not less than 2:1 (unless a lower contrast has been manually selected). [Source: NASA, 1995]

- **5.1.6.16 Facilitate detection of faint signals.** When the detection of faint signals is required, and the ambient illumination may be above 2.7 lux (0.25 fc), displays shall be hooded, shielded, recessed, or employ a suitable filter system. [Source: DOD, 1999]

- □ **5.1.6.17 Display luminance relative to adjacent surfaces.** With the exception of emergency indicators, no light source in the immediate surrounding area should be of greater luminance than the display signal. [Source: DOD, 1999]

- **5.1.6.18 Provide adequate ambient illumination.** The ambient lighting levels in areas of the display shall not degrade the visibility of signals on the display. [Source: DOD, 1999]

- **5.1.6.19 Provide controls to modulate ambient lighting.** If ambient illumination in an area where a display is used is variable, controls shall be provided to dim all light sources, including illuminated panels, indicators, and switches in the immediate vicinity of the display where necessary to facilitate visibility of displayed information. [Source: DOD, 1999]

5.1.7 Glare control

Glare may be of two types, diffuse or specular. **Diffuse glare** is caused by the general environmental illuminance, which effectively reduces the display contrast. **Specular glare** is the appearance of unwanted images (reflections) on the display surface. The most effective method of glare control is to design the workplace so that neither type is produced. Other methods include screen meshes placed over the display surface, etched faceplates, anti-reflective coatings, and bonded quarterwave filters. All of these degrade both contrast and resolution to some degree.

▪ **5.1.7.1 Minimize or eliminate glare.** Glare shall be eliminated or minimized. [Source: DOD, 1999]

Discussion. Some of the methods that can be used to eliminate or minimize glare are as follows;

a. place displays properly relative to light sources,
b. use indirect lighting,
c. use many dim light sources rather than a few bright ones,
d. use hoods as long as they do not interfere with task performance,
e. use an anti-glare treatment, such as a diffusing surface or an optical coating (providing that it does not decrease contrast luminance or contrast so that it impacts performance), or
f. filter control of the light sources. [Source: BSR/HFES, 2002; DOD, 1999]

▪ **5.1.7.2 Anti-glare treatment.** The use of anti-glare treatments shall not cause the display to violate the requirements for luminance, contrast, and resolution that may impact task performance. [Source: BSR/HFES, 2002; DOD, 1999]

▪ **5.1.7.3 Hoods.** Hoods shall not be used to prevent or minimize glare if they restrict the viewing angle of screens in a way such as to interfere with tasks. [Source: BSR/HFES, 2002; DOD, 1999]

▪ **5.1.7.4 Display shielding.** Displays intended for use near windows shall be shielded from sunlight entering the window or be designed to be legible in sunlight. [Source: NASA, 1995]

▪ **5.1.7.5 Make adjacent surfaces matte.** Surfaces adjacent to the display shall have a dull, matte finish. [Source: DOD, 1999]

▪ **5.1.7.6 Use of glare reduction techniques.** If glare reduction techniques are used, they shall not noticeably degrade display quality. [Source: ISO, 2006]

▪ **5.1.7.7 Minimize reflections.** Displays shall be constructed, arranged, and mounted to minimize interference from reflections of illumination sources, windows, and other visual displays. [Source: DOD, 1999]

Discussion. If necessary, shields, filters, or other techniques may be used to ensure that system performance is not degraded. [Source: DOD, 1999]

- ▫ **5.1.7.8 Luminance of specular glare.** The luminance contrast of specular glare should be less than or equal to 1.25 [(L_{Min} + $L_{Specular\ Glare}$.)/ L_{Min}]. [Source: BSR/HFES, 2002]

5.1.8 Resolution

- ▪ **5.1.8.1 Allow discrimination of similar characters.** The display shall have adequate resolution to allow the discrimination of similar characters and codes from the expected operational viewing distance. [Source: DOD, 1999]

  Example. The letter "l" and the number "1", or the letter "Z" and the number "2" are easily confused.

- ▪ **5.1.8.2 Resolution for high reading speed.** When high reading speed is required, high resolution monitors with at least 90 pixels per inch (90 dpi) shall be used. [Source: DOE, 1992]

  Discussion. Higher resolution displays (greater than 90 dpi) are associated with increases in visual performance and decreases in visual fatigue in visual search tasks. [Source: Ziefle, 1998]

- ▫ **5.1.8.3 Resolution for complex symbols.** Displays used for displaying complex symbols and graphic detail should have at least 100 pixels per inch (100 dpi). [Source: DOE, 1992]

- ▫ **5.1.8.4 Character formation -- vertical orientation.** Characters in a vertical orientation should be formed from a matrix of at least 5 x 7 pixels minimum uppercase, 7 x 9 for continuous reading, 4 x 5 minimum for super/subscript or information not related to the task. [Source: Avery & Bowser, 1992; ISO, 1992]

- ▫ **5.1.8.5 Minimum character formation for nonvertical orientation.** Characters in a nonvertical orientation should be formed from a matrix of at least 8 by 11 pixels, preferably 15 by 21 pixels. [Source: Avery & Bowser, 1992]

- ▫ **5.1.8.6 Character stroke width.** Character stroke width should be between 1/12 and 1/6 the character height, with wider strokes preferred for positive polarity displays. [Source: Avery & Bowser, 1992; BSR/HFES, 2002; ISO, 1992]

  Definition: Stroke width is the thickness of the lines used to make up the number or letter.

- ▫ **5.1.8.7 Minimum spacing between characters.** For maximum readability, characters should be separated by at least one stroke width or pixel, with two pixels or stroke widths preferred. [Source: Helander, 1992; ISO, 1992]

- ▫ **5.1.8.8 Minimum spacing between lines of text.** For maximum readability, lines of text should be separated by at least two stroke widths or pixels, with 50-100% of character height separation preferred. [Source: Helander, 1992]

- ▫ **5.1.8.9 Character width-to-height relationship.** The width of characters should be 0.5:1 to 1:1, with 0.6:1 to 0.9:1 preferred for maximizing legibility. [Source: BSR/HFES, 2002]

- ▪ **5.1.8.10 Alphanumeric character and symbol size.** The height of alphanumeric characters and geometric or pictorial symbols shall subtend a visual angle of at least 10 min arc for information not critical to the task or not time critical and 16 min arc for information critical to the task or when readability is important as measured from the longest anticipated viewing distance, with 22-24 min of arc preferred. [Source: BSR/HFES, 2002; DOD, 1999; ISO, 1992]

  Definition. Visual angle is the angle subtended by objects measured in minutes of arc. It represents an apparent size of an object based on the relationship between an object's distance from the viewer and its size (perpendicular to the viewer's line of sight). For example, if an object that is size ***h*** is at a distance ***d*** from the retina, the visual angle subtended (***x***) is equal to arctan (***h***/***d***).

  Note! The visual angle subtended by a character may change if a monitor with one resolution is replaced by a monitor with another resolution. Character height may be defined in software by the number of pixels. A 10 pixel character on a high resolution display is smaller than a 10 pixel character on a lower resolution display.

- ▪ **5.1.8.11 Minimum display capability for producing characters.** Displays shall be capable of producing a character height of 20-22 min of arc as measured at a normal viewing distance. [Source: ISO, 2006]

5.1.9 Linearity

- ▫ **5.1.9.1 Avoid jitter.** When tested in the intended operational environment, deviations in the location of a displayed element should be less than 2 mm per cm of viewing distance at frequencies from 0.5 to 30 Hz. [Source: BSR/HFES, 2002; ISO, 1992]

Definition. Jitter is a departure from geometric stability. It occurs when pixels in displayed objects move instead of remaining in a fixed position.

Additional information. Jitter can be caused by interference such as magnetic fields generated by other equipment in the operational area such as fluorescent lamps or other equipment or displays. Thus, it is important to examine jitter in the operational environment or conditions that approximate the intended operational environment.

▫ 5.1.9.2 **Maintain uniform element size.** The size of a display element (e.g., an alphanumeric character or symbol) should not vary by more than 10% regardless of its location within the display. [Source: American National Standards Institute (ANSI), 1988]

Discussion. If you type the capital letter E such that it fills the screen, all of the Es, from the ones in the center to those on the outer edge, should appear to be the same size.

▪ 5.1.9.3 **Minimize element displacement.** The displacement of a single display element's position shall vary by less than 5% of the display element box height relative to those above and below, or right and left of it. [Source: ANSI, 1988; ISO, 1992]

▪ 5.1.9.4 **Maintain column and row linearity.** Rows and columns shall be parallel and orthogonal to each other with the linearity of any column or row not varying by more than 2% of the length of the column or row. [Source: ANSI, 1988]

5.1.10 Color characteristics

▪ 5.1.10.1 **Color temperature.** Each color shall have a color difference Δ u'v'≤ 0.01 when compared to Commission Internationale de l'Eclairage (CIE) u' and v' chromaticity coordinates for corresponding correlated color temperatures. [Source: CIE, 1976; TCO '03, 2005b]

▪ 5.1.10.2 **Color uniformity** Δ u'v' shall be ≤ 0.01 for the maximum color deviation between measured active areas on the screen that are intended to maintain the same color. [Source: CIE, 1976; TCO '03, 2005b]

▪ 5.1.10.3 **Off-axis color uniformity** Δ u'v' shall be ≤ 0.025 when it is measured at +/- 30 degrees from the center of the screen. [Source: CIE, 1976; TCO '03, 2005b]

▪ **5.1.10.4 RGB color settings.** The display shall be able to reproduce at minimum, CIE RGB color settings of:

Red		Green		Blue	
u'	v'	u'	v'	u'	v'
$\geq$ .411	$\geq$ .503	$\leq$ .140	$\geq$ .548	$\geq$ .150	$\leq$ .224

[Source: CIE, 1976; TCO '03, 2005a, 2005b]

▫ **5.1.10.5 Prevent color fringes.** Displays should not have noticeable color fringes or moiré patterns. [Source: DOD, 1999; ISO, 1992]

▪ **5.1.10.6 Chromaticity desaturation.** When exposed to ambient illumination conditions of up to 6000 fc, the display primary color chromaticity shall not exhibit more than a 20% reduction in their color saturation. [Source: Hopper et al., 1994; Crown Communications, Inc, 1998]

> **Additional information.** Of the three colors, red, green, and blue, red is often the most sensitive to desaturation (shift toward white) under high illumination. When color is desaturated, color coding becomes ineffective and text can become difficult to read. [Source: Crown Communications, Inc, 1998]

▪ **5.1.10.7 Black level.** The luminance of black shall be ≤ 2 cd/m^2 when the display luminance is set at the maximum brightness for critical displays and displays used in dark-adapted environments. [Source: TCO '06, 2006]

> **Additional information.** In order to produce satisfactory brightness in environments with high ambient lighting such as an Air Traffic Control Tower, some displays increase overall brightness of the display. This can have unintended negative consequences in an Air Traffic Control Tower environment if the display cannot be dimmed sufficiently at night. Displays that are bright enough by which to read a watch at night when the monitor is displaying black can cause disturbing reflections that are likely to be unacceptable by the user.

▫ **5.1.10.8 Color contrast.** Color contrast should be greater than 40 $\Delta E_{Yu'v'}$ if absolute color classification is necessary, 100 $\Delta E_{Yu'v'}$ if relative color classification is necessary. [Source: BSR/HFES, 2002; CIE, 1976; Helander, 1992]

5.2 Display Types

5.2.1 Flat-panel displays

In flat-panel displays, images are formed from discrete, non-overlapping, rectangular pixels. These images can differ from images on CRTs in character-to-character spacing, interline spacing, character and symbol design, the effect of ambient illumination, image polarity, and failure mode. [Source: Avery & Bowser, 1992]

□ 5.2.1.1 **Minimize pixel failure rate.** Displays should be selected and maintained so that the pixel failure rate does not exceed 1%. [Source: Avery & Bowser, 1992]

■ 5.2.1.2 **Full rows or columns of pixel defects.** There shall be no full rows or columns of defective subpixels. [Source: Hopper et al., 1994]

■ 5.2.1.3 **Acceptable ratio of cluster defects.** The ratio of display area in square centimeters (in square inches) to the number of cluster defects shall be not less than 16:1 (25:1). [Source: Hopper et al., 1994]

Additional information. A **cluster defect** is a group of two or more adjacent color pixels containing one or more defective subpixels.

■ 5.2.1.4 **Impact of filed pixels on legibility.** The presence of defective or failed pixels shall not affect the legibility of critical data, increase errors, reduce reading rate, or cause visual discomfort. [Source: Hopper et al., 1994; ISO, 2006]

■ 5.2.1.5 **Location of cluster defects.** Displays shall not have any cluster defects located in areas where critical information is to be displayed. [Source: Hopper et al., 1994]

■ 52.1.6 **Response time.** The rise and fall response times shall be less than 13 ms. [Source: TCO ’06, 2006]

5.2.2 Large-screen displays

The selection or design of a large-screen display, especially a projection display, may be more complex than that of other workstation displays. The effects of ambient illumination, observer location, type of data to be displayed, visual acuity for symbol size and contrast, screen size, screen format, symbol luminance, and screen gain are all important factors.

▫ 5.2.2.1 **When to use.** Large-screen displays should be used when

a. more than one user needs to refer to the same displayed information, but space or other constraints make the use of a single, common display preferable to many, individual displays;

b. one or more members of a team of users need to be able to move about, yet still need access to displayed information;

c. space or other constraints preclude the use of individual displays for each team member to call up commonly-used information; or

d. it may be desirable to have general information available to persons who should not interrupt on-going group operations by looking over the shoulder(s) of individual operator(s) to see individual displays. [Source: DOD, 1999]

▪ 5.2.2.2 **When not to use.** Large-screen displays shall not be used if the spatial and environmental conditions do not allow all users to have appropriate visual access in terms of viewing distance, angle, and lack of interference from intervening objects, personnel, and ambient lighting. [Source: DOD, 1999]

▪ 5.2.2.3 **Viewing distance.** The display shall be near enough that the most distant viewers can resolve the critical details presented, but not closer to any viewer than 1/2 the display width or height, whichever is greater. [Source: DOD, 1999]

> **Additional information.** The determination of the maximum viewing distance on a large-screen display will depend on an analysis of the information requirements of individuals and their locations in the work area. Application of this criterion must consider the types of information contained in the group-view display, the ways in which this information is used by individuals, the locations of these individuals relative to the display, and whether some or all or the large-screen display information is available on separate displays located closer to these individuals. For example, individuals may need to resolve all details or may only need to detect changes that require additional scrutiny. [Source: Nuclear Regulatory Commission, 2002]

▫ 5.2.2.4 **Off-centerline viewing angle.** Individual viewers in a fixed location should be no more than 10 degrees off the centerline and multiple viewers should be no more than 30 degrees off the centerline with a preferred limit of 20 degrees. [Source: Nuclear Regulatory Commission, 2002]

> **Additional Information**: The determination of the acceptability of off-centerline viewing should take into account both the spatial distortion of the image and the

effect of the viewing angle upon screen characteristics such as brightness and color rendition. This guideline addresses spatial distortion of the displayed image due to the viewing angle. However, off-centerline viewing of large-screen display devices may also result in (1) loss of general brightness for high-gain screens and (2) loss of color rendition in projection-type devices due to the angles of reflection of the separate projection elements. Loss of general brightness for high-gain screens is usually not a problem until off-centerline viewing exceeds 25 degrees for beaded screens and 30 degrees for high-gain metallic screens. These effects may further reduce perceived resolution by reducing the effectiveness of color codes and image contrast. Thus, the combined effects of off-centerline viewing upon image distortion and screen characteristics should be considered. [Source: Nuclear Regulatory Commission, 2002]

▫ 5.2.2.5 **Viewing of multiple display devices.** When multiple, large display devices are used, the normal work areas of each user should be within the acceptable off-centerline viewing area of each large display that each user must view. [Source: Nuclear Regulatory Commission, 2002]

▪ 5.2.2.6 **Locate so that view is not obscured.** A large-screen display shall be located so that its critical users do not have their view of it obscured by persons moving about in their normal traffic patterns. [Source: DOD, 1999]

Additional information. There are two methods for achieving this: (1) laterally staggering (off-setting) personnel and consoles to maintain an unobstructed view and (2) elevating the line of sight of personnel (e.g., supervisors) who are located farther from the display so they may see over the heads of personnel located closer to the display. The line of sight may be elevated by using raised or inclined floors or by raising the height of the screen. [Source: Nuclear Regulatory Commission, 2002]

▪ 5.2.2.7 **Ensure critical information cannot be deleted.** Control of large-screen group display systems shall ensure that critical information cannot be modified or deleted inadvertently or arbitrarily. [Source: DOD, 1999]

▪ 5.2.2.8 **Place display changes in control of users.** Changes in the group display shall be under the control of designated users who operate according to pre-established procedures, on command of a person in charge, or both. [Source: DOD, 1999]

▪ 5.2.2.9 **Separate display.** When a user must make changes that are of interest only to him or her, a separate, remote display shall be provided. [Source: DOD, 1999]

- ▫ **5.2.2.10 Character height.** The height of letters and numerals intended to be read should be not less than 16 min of arc, with 20-22 min of visual angle preferred at the typical viewing distance. [Source: DOD, 1999; ISO, 1992]

- ▪ **5.2.2.11 Character height at longest viewing distance.** The height of letters and numerals intended to be read shall not be less than 10 min of visual angle from the longest anticipated viewing distance. [Source: DOD, 1999]

5.2.3 Large-screen optical projection displays

- ▫ **5.2.3.1 When to use.** When ambient light can be properly controlled, optical projection displays should be used for applications requiring group presentation, pictorial and spatial information, past history versus real-time presentation, synthetically generated pictures, simulation of the external world, or superimposition of data from more than one source. [Source: DOD, 1999]

- ▪ **5.2.3.2 When to use rear projection.** Rear projection shall be used where physical obstructions to front projection result in poor visibility, or where work areas require high ambient illumination for other activities. [Source: DOD, 1999]

- ▪ **5.2.3.3 Viewing distance and screen size.** The ratio of viewing distance to screen size (measured diagonally) shall be more than 2:1 and less than 8:1. The optimum ratio is 4:1; the preferred range is more than 3:1 or less than 6:1. [Source: DOD, 1999]

- ▪ **5.2.3.4 Viewing angle for groups.** The angle off centerline for viewing a large-screen display shall not be greater than 30° for groups. The optimum viewing angle is 0°, and the preferred limit is 20°. [Source: DOD, 1999]

- ▪ **5.2.3.5 Viewing angle for individuals.** The angle off centerline for viewing a large-screen display shall not be greater than 10° for individuals. [Source: DOD, 1999]

- ▪ **5.2.3.6 Image luminance with no film in the projector.** The image luminance with no film in the operating projector shall be not less than 17 cd/m^2 (5 fL), and not more than 70 cd/m^2 (20 fL). [Source: DOD, 1999]

- ▪ **5.2.3.7 Luminance ratio across the screen.** The ratio of maximum to minimum luminance across the screen shall be not greater than 3:1, with the optimum ratio of maximum to minimum luminance across the screen of 1:1, and the preferred limit of 1.5:1. [Source: DOD, 1999]

- **5.2.3.8 Luminance ratio as a function of viewing location.** The ratio of maximum to minimum luminance as a function of viewing location shall be not greater than 4:1. The optimum ratio of maximum to minimum luminance as a function of viewing location is 1:1, and the preferred limit is 2:1. [Source: DOD, 1999]

- **5.2.3.9 Luminance ratio of ambient light to brightest image.** The ratio of ambient light to the brightest part of an image shall not be greater than 1:10 for black and white images and 2:10 for images with gray scale or color, while maintaining optimum image luminance. The optimum ratio of ambient light to the brightest part of the image is 0:1 and the preferred range is 1:100 to 1:500. [Source: DOD, 1999]

- **5.2.3.10 Average luminance.** The optimum image luminance should be in the range of 27 to 48 cd/m^2 (8 to 14 fL), with 35 cd/m^2 (10 fL) preferred. [Source: DOD, 1999]

- **5.2.3.11 Luminance of screen center at the maximum viewing angle.** The luminance of the screen center at the maximum viewing angle shall be at least half its maximum luminance when viewed at 0 degrees. [Source: DOD, 1999]

- **5.2.3.12 Luminance ratio.** Under optimal ambient lighting conditions, the luminance ratio for optically projected displays should be 500:1. [Source: DOD, 1999]

  Definition. Luminance ratio is the ratio of the luminance of an object to that of its surrounding field or background. [Source: DOD, 1999]

- **5.2.3.13 Minimum luminance ratio for viewing charts and text.** The minimum luminance ratio for viewing charts, printed text, and other line work shall be 5:1. [Source: DOD, 1999]

- **5.2.3.14 Minimum luminance ratio for images with limited range of detail.** The minimum luminance ratio for images that contain limited shadows and detail with a limited luminance range, such as animation or photographs, shall be 25:1. [Source: DOD, 1999]

- **5.2.3.15 Minimum luminance ratio for images with a full range.** The minimum luminance ratio for images that contain a full range of colors, or grays in black-and-white photographs, shall be 100:1. [Source: DOD, 1999]

- **5.2.3.16 Minimize distortion.** Distortion of the projected image shall be minimized by ensuring that the screen is as nearly as possible perpendicular to the light beam from the projector. [Source: DOD, 1999]

- ▪ **5.2.3.17 Facilitate maintenance and servicing.** Projectors shall be designed and mounted so as to facilitate servicing and maintenance**,** preferably without requiring the use of a ladder. [Source: DOD, 1999]

- ▫ **5.2.3.18 Ease of adjustment.** Projectors should allow users to easily adjust the focus and contrast of the image without requiring special tools or a ladder. [Source: DOD, 1999]

5.3 Displays for Selected Applications

5.3.1 Stereoscopic and binocular displays

Stereoscopic displays generate the sensation of three dimensions, height, width and depth, within the human visual system. Three-dimensional display technology may be "stereoscopic," which requires that users wear special glasses that provide different images to the two eyes, or "auto stereoscopic," which does not require any special viewing aids. There are situations in which three-dimensional images can enhance user performance or increase the "naturalness" of the presentation of complex spatial data. Disadvantages of this display type include limitations in the field of view, the number of viewers, and the nature of data that can be displayed. In some cases, large screen displays can provide a similar immersive experience as the heads-up display. [Source: Avery & Bowser, 1992; Patrick, Cosgrove, Slavkovic, Rode, Verratti, & Chiselko, 2000]

- ▪ **5.3.1.1 Use only if third dimension is meaningful.** Three-dimensional displays shall be used only if the third dimension conveys a real benefit to the user, the user population has normal stereoscopic vision, and the field-of-view is suitable for the number of viewers intended. [Source: Avery & Bowser, 1992; DOD, 1999]

- ▫ **5.3.1.2 Do not slow system performance.** The three-dimensional presentation of information should not slow information display, degrade image quality, or degrade other aspects of system performance. [Source: Avery & Bowser, 1992]

- ▫ **5.3.1.3 Avoid interocular crosstalk.** There should be no interocular crosstalk, that is, the left eye should not see the images intended for the right eye, and vice versa. [Source: Avery & Bowser, 1992]

- ▫ **5.3.1.4 Avoid saturated primary colors.** Saturated primary colors that can produce unwanted depth effects such as chromostereopsis should be avoided in stereoscopic displays. [Source: Avery & Bowser, 1992]

Discussion. Saturated primary colors can produce depth perceptions by themselves, which might interfere with the stereoscopically produced depth perceptions. **Primary colors** for light emitting displays such as CRTs are Red, Green, and Blue (RGB). [Source: Avery & Bowser, 1992]

- **5.3.1.5 Adjustable interpupillary distance.** Devices with adjustable interpupillary distances should adjust at minimum from 50 mm to 74 mm (2 in. to 3 in.). [Source: ISO, 2006]

- **5.3.1.6 Interpupillary distance mismatch.** Any mismatch between user interpupillary distance and the distance specified by the device should not cause greater than 8.6 arc min misalignment. [Source: ISO, 2006]

- **5.3.1.7 Vertical alignment of displays.** Misalignment of binocular displays should be less than 8.6 min of arc between the two displays. [Source: ISO, 2006]

- **5.3.1.8 Size difference between displays.** Differences in size between binocular displays should be less than 2 degrees. [Source: ISO, 2006]

- **5.3.1.9 Interocular focus difference.** Differences in focus between binocular displays should be less than 0.25 diopters. [Source: ISO, 2006]

- **5.3.1.10 Temporal asynchrony.** Temporal asynchrony between binocular displays should not exceed 100 ms. [Source: ISO, 2006]

- **5.3.1.11 Temporal modulation for dynamic displays.** If dynamic three-dimensional displays are used, the temporal modulation of stereopsis should be approximately 1 Hz to ensure the most accurate perception of stereo motion. [Source: Avery & Bowser, 1992]

  Definition. Stereopsis (also called stereoscopic vision) is three-dimensional depth perception based on retinal disparity. As the eyes are slightly separated, each eye sees a slightly different image, when these images are fused in the brain. The result is a perception of depth or stereoscopic vision.

- **5.3.1.12 Separate depth-coded objects.** Depth-coded objects should be separated spatially to eliminate disparity averaging, crowding, and repulsion. [Source: Avery & Bowser, 1992]

  Definition. Disparity is the computation of depth values based on the lateral distance between corresponding picture elements in both image planes of stereovision.

- 5.3.1.13 **Scale images according to disparity.** Image size should be scaled according to the disparity of the image. [Source: Avery & Bowser, 1992]

- 5.3.1.14 **Provide individual size scaling if critical to task performance.** If accurate size perception is critical to task performance, size scaling should be done for each observer. [Source: Avery & Bowser, 1992]

- 5.3.1.15 **Co-modulate luminance and stereopsis.** Luminance should be co-modulated with stereopsis. [Source: Avery & Bowser, 1992]

  Discussion. Brightness is also a depth cue, with brighter objects being perceived as nearer. [Source: Avery & Bowser, 1992]

- 5.3.1.16 **Focal distance.** The focal distance should not be less than 40 cm with 100 cm preferred. [Source: ISO, 2006]

- 5.31.17 **Eye relief.** Eye relief (the distance from the physical surface of the display optics to the pupil of the eye) should be at least 25 mm. [Source: ISO, 2006]

- 5.3.1.18 **Object angular displacement.** The angular displacement of objects viewed through the combining glass assembly should not be greater than 0.5 mrad (1.7 min) of visual angle. [Source: ISO, 2006]

5.3.2 Heads-up display

A **Heads-Up Display** (HUD) is any type of display that presents data without blocking the user's view. This technique was pioneered for military aviation and is now used in commercial aviation, motor vehicle, and other applications. Any binocular/stereo aspects of HUDs should comply with the previous section on binocular/stereo displays.

- 5.3.2.1 **Compatible with human visual system.** HUDs shall be compatible with the capabilities and limitations of the human visual system. [Source: DOD, 1999]

- 5.3.2.2 **Windshield transmission rate.** If a vehicle windshield is used as a HUD combiner, the total transmission through the windshield shall be not less than 70% as measured along the line of sight. [Source: DOD, 1999]

- 5.3.2.3 **Eye box size.** The eye box size should not be less than 11.5 cm (4.5 in.) wide 6.5 cm (2.5 in.) high, and 15 cm (6 in.) deep. [Source: DOD, 1999]

- **5.3.2.4 Exit pupil.** HUDs shall have a minimum exit pupil (that area within a collimated beam in which the entire image formed by an objective lens is capable of being seen) of 72 mm (2.8 in.). [Source: DOD, 1999]

- **5.3.2.5 Legibility.** Sufficient contrast shall be provided to ensure symbol legibility under all expected viewing conditions. [Source: DOD, 1999]

- **5.3.2.6 Character height.** The height for HUD alphanumeric characters should be not less than 8.1 mrad (28 min) of visual angle. The height for HUD non-alphanumeric characters should be not less than 9.9 mrad (34 min) of visual angle. [Source: DOD, 1999]

- **5.3.2.7 Raster lines/symbol height.** For head-up raster displays, alphanumeric characters should not use less than 16 raster lines/symbol height. Non-alphanumeric characters should use not less than 20 raster lines/symbol height. [Source: DOD, 1999]

- **5.3.2.8 Adjustable luminance.** Symbol luminance shall be adjustable. [Source: DOD, 1999]

- **5.3.2.9 Symbol line width.** The line width of symbols used in HUDs shall be not less than 0.5 mrad (1.7 min). For most applications, symbol line width should be 1.0 ± 0.2 mrad (3.4 ± 0.7 min). [Source: DOD, 1999]

5.3.3 See-through displays

- **5.3.3.1 See-through displays.** Display imagery on see-through displays should be visually distinctive from any anticipated background. [Source: DOD, 1999]

- **5.3.3.2 Symbol brightness.** Symbols shall be bright enough to be legible under all expected ambient lighting conditions. [Source: DOD, 1999]

- **5.3.3.3 Legibility in direct sunlight**. When legibility in direct sunlight or background luminance of 34,000 cd/m^2 (10,000 footlamberts) or greater is required, symbol brightness shall be not less than 5000 cd/m2 (15,000 footlamberts). [Source: DOD, 1999]

- **5.3.3.4 Symbol brightness in high ambient.** For most high ambient light applications, symbol brightness should be 6,900 - 10,300 cd/m2 (2,000-3,000 footlamberts). [Source: DOD, 1999]

5.3.4 Helmet-mounted displays

- **5.3.4.1 Adjustable.** All HMDs should be easily adjustable to fit the individual user's head. [Source: Neale, 1998]

- ▫ **5.3.4.2 Controls.** All HMDs should have controls placed so that they are easy to use and reach while wearing the device (without requiring the user to remove the device). [Source: Neale, 1998]

- ▫ **5.3.4.3 Weight distribution.** Weight distribution of helmet-mounted items should be balanced to avoid or minimize neck strain, fatigue, and helmet movement relative to the operator's head**.** [Source: DOD, 1999]

- ▫ **5.3.4.4 Weight transfer.** The number of weight transfer points and the size and location of those points should be such that they minimize user discomfort. [Source: Neale, 1998]

- ▫ **5.3.4.5 External attachments.** Any required external attachments should not restrict operator head or shoulder motion. [Source: Rash, Ledford, & Mora, 1996]

- ▫ **5.3.4.6 Accuracy of head tracking system for HMDs.** Head tracking systems used for HMDs should be able to resolve changes in head position of at least 1.5 mm. [Source: Rash et al., 1996]

- ▫ **5.3.4.7 Accuracy in intended environment.** Head tracking systems used for HMDs should be accurate in the intended environment (in proximity of systems and equipment normal to operations). [Source: Rash et al., 1996]

  Discussion. Some head tracking equipment can be affected by the presence of computers or monitors. It is important to ensure the accuracy of the system in the presence of equipment that will be present in the operational environment.

- ▪ **5.3.4.8 Minimize time lag.** Time lags between visually coupled systems and the display shall be minimized so as not to negatively impact task performance or cause motion sickness. [Source: Rash et al., 1996]

- ▫ **5.3.4.9 Attention distraction.** HMDs should minimize attention distraction and user cognitive load demand by providing only task-oriented, essential, integrated information with minimum memory requirements. [Source: DOD, 1999]

- ▫ **5.3.4.10 Salient cues.** HMDs should provide only salient cueing (e.g., directing attention to critical information). [Source: DOD, 1999]

- ▫ **5.3.4.11 Standardized graphics.** All information presented graphically (e.g., positional, topographic, and spatial information) should use standardized symbols. [Source: DOD, 1999]

- **5.3.4.12 Symbol location.** All displayed symbols should be presented within the central 25-degree area of the HMD to minimize required eye movements. [Source: DOD, 1999]

- **5.3.4.13 Gray shades.** Monochromatic HMDs should provide at least six shades of gray for alphanumeric and simple graphic information and nine shades of gray for complex graphic or sensor data**.** [Source: DOD, 1999]

- **5.3.4.14 Field of view.** The field of view should provide acceptable visual search performance, object recognition, and spatial orientation for the task. [Source: DOD, 1999]

- ■ **5.3.4.15 Unobstructed view of displays and controls**. Operators shall have an unrestricted view of all displays and controls. [Source: DOD, 1999]

- **5.3.4.16 Visual orientation.** All required mission symbology should be in the operator's instantaneous field of view, regardless of head position. [Source: DOD, 1999]

- **5.3.4.17 Mode selection.** As applicable, a user-selectable optional display mode should be provided to reduce display clutter. [Source: DOD, 1999]

5.4 Special Conditions

5.4.1 Vibration

- ■ **5.4.1.1 Do not allow vibration to interfere with tasks.** Vibration of visual displays shall not hinder users in the performance of their tasks. [Source: DOD, 1999]

- **5.4.1.2 Vibration.** Displays that must be read during projected periods of high vibration should be designed accordingly. [Source: NASA, 1995]

- **5.4.1.3 Character size during vibration.** Display characters that must be read during projected periods of vibration should be sufficiently large to be perceived even when blurred. [Source: NASA, 1995]

- **5.4.1.4 Sufficient illumination for vibration.** Sufficient illumination should be used to avoid scotopic vision, which results in a lower critical flicker fusion frequency during periods of vibration. [Source: NASA, 1995]

- **5.4.1.5 Avoid excessive vibration.** Displays should be stabilized to avoid vibrating at frequencies greater than 5 Hz. [Source ISO, 2006]

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Glossary

Cathode Ray Tube (CRT) - A vacuum tube of a computer monitor in which phosphors coat the inner surface. When excited with an electron beam, these phosphors glow and produce light.

Central visual field - The central 30° of the visual field, which is the area of highest acuity.

Color fringes - The pixels along the border of an object that contain a combination of the selection and background colors.

Color temperature - The display's ability to reproduce colors accurately as brightness levels change. Color temperature is a term used to describe the color of light from its source. Color temperature is measured in degrees Kelvin and is sometimes referred to as white balance.

Contrast ratio - The luminance of the foreground divided by the luminance of the background. The greater the contrast, the sharper the image will be.

CRT - See Cathode Ray Tube.

Diffuse glare - A type of glare caused by the general ambient illuminance, which effectively reduces the display contrast without producing significant specular reflection.

Disparity - The computation of difference of depth values based on the lateral distance between corresponding picture elements in both image planes of stereovision.

Eye relief - The distance from the physical surface of the display optics to the pupil of the eye.

Flicker - The appearance of flashing that occurs in a computer display when the display is not refreshed frequently enough, causing the phosphor to begin to decay prior to being refreshed.

Focal vision - The central 30° of the visual field. It is the area that people use to look at objects in the world, moving their eyes as needed to bring images of the object on to the fovea, which is the area of highest acuity.

Footcandle - A unit of measure of the intensity of light falling on a surface, which is equal to one lumen per square foot.

Footlambert (fl) - A unit to measure luminance, which is equal to $1/\pi$ candela per square foot. It is a measure that has been corrected for the visual system's differential sensitivity to different wavelengths, giving an approximation to perceived brightness.

Fovea - The small central region of the retina that exhibits the greatest sensitivity to detail and color and comprises the area of most acute vision.

Head-Mounted Display (HMD) - A helmet-shaped display device that is worn on the head to have video information directly displayed in front of the eyes.

Heads Up Display (HUD) - Any type of display that presents data without blocking the user's view of the outside world.

Interlaced - A display that produces a video image by displaying alternate scan lines.

Interocular crosstalk - When the left eye can see the images intended for the right eye, and vice versa.

Jitter - A departure from geometric stability, which occurs when pixels in displayed objects move instead of remaining in a fixed position.

Liquid Crystal Displays (LCDs) - a type of flat-panel display that has two polarized layers on top of each other.

LCD - See liquid crystal display.

Legibility - The extent to which the user can decipher or read alphanumeric characters or text.

Luminance - The physical measure of the amount of light emitted by or reflected in a given direction from the display. Luminance is expressed in candela per meter squared or footlamberts.

Luminance ratio - The luminance of the foreground divided by the luminance of the background. Luminance ratio indicates how much brighter a pure white output would be than a pure black output. The greater the contrast, the sharper the image will be. Luminance ratio can also be referred to as contrast ratio.

Moiré patterns - An undesired pattern on displays that appears as periodic intensity variations over the screen image.

Motion artifacts - The after images made up of the previously drawn object that have not yet decayed enough to disappear that appear to follow a moving display object. They often look like the tail of a comet following the object in motion.

Non-interlaced - A display that produces a video image by displaying all lines in a frame in one pass from top to bottom before the next frame appears.

Phosphor - A luminescent substance used to coat the inside of a CRT, which emits visible light when illuminated by electrons within an evacuated glass tube.

Pixels - picture elements arranged in horizontal rows and vertical columns, which create the picture element.

Polarity - The relationship between the brightness of the background and an image. A bright image on a dark background is negative polarity and a dark image on a bright background is positive polarity.

Primary colors - Primary colors for light emitting displays such as CRTs are Red, Green, and Blue (RGB).

Refresh rate - The rate (in cycles per second or Hz) at which the displayed contents of a computer screen are regenerated.

Resolution - The number of pixel elements per square inch. Each display is associated with a specific physical display resolution. The display resolution signifies the number of dots (pixels) on the entire screen. The higher the resolution, the more dots or pixels on the display device. Common resolutions include the following:

- **VGA** (video graphics array) = 640 x 480
- **SVGA** (super video graphics array) = 800 x 600
- **XGA** (extended graphics array) = 1024 x 768
- **WXGA** (wide extended graphics array) = 1280 x 800
- **SXGA** (super extended graphics array) = 1400 x 1050
- **UXGA** (ultra extended graphics array) = 1600 x 1200
- **WSXGA** (wide super extended graphics array) = 1680 x 1050
- **WUXGA** (wide ultra extended graphics array) = 1920 x 1200

Response time - an attribute that applies to LCD monitors. It is defined as the time required for a liquid crystal cell to go from active (black) to inactive (white) and back to active (black) again measured in milliseconds (ms). Lower numbers mean faster transitions and therefore less visible image artifacts.

Specular glare - The appearance of unwanted images (reflections) on the display surface.

Stereopsis (also called stereoscopic vision) - Three-dimensional depth perception based on retinal disparity. As the eyes are slightly separated, each eye sees a slightly different image when these images are fused in the brain. The result is a perception of depth or stereoscopic vision.

Stereoscopic display - A method used to generate the sensation of three dimensions within the human visual system. Three-dimensional display technology may be "stereoscopic," which requires that users wear special glasses that provide different images to the two eyes, or "auto stereoscopic," which does not require any special viewing aids.

Stereoscopic vision - See Stereopsis.

Stroke width - The thickness of the lines used to make up the number or letter.

Viewing angle - The angle off the centerline from which a display will be viewed.

Visual angle - The angle subtended by objects measured in minutes of arc. It represents an apparent size of an object based on the relationship between an object's distance from the viewer and its size (perpendicular to the viewer's line of sight). For example, if an object that is size h is at a distance d from the retina, the visual angle subtended x is: $x = \arctan(h/d)$.

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