Ministry of Defence

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HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT

PART 7: VISUAL DISPLAYS

This Part of Def Stan 00-25
Supersedes
Def Stan 00-25 (Part 7)/Issue 1
Dated 27 October 1986

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Revision Note

This Defence Standard has been revised to promote its status from an Interim to a full Defence Standard; also to provide up-to-date technical advice, guidance and data which reflects recent advances in the subject including helmet mounted sighting systems.

Historical Record

This Defence Standard has its origins in “Human Factors for Designers of Naval Equipment” (a naval handbook in two volumes) published in 1971.

Arrangement of Defence Standard 00-25

The arrangement of the Parts comprising Def Stan 00-25 is shown below.

PART 1 - Introduction
PART 2 - Body Size
PART 3 - Body Strength and Stamina
PART 4 - Design of Workspace
PART 5 - The Physical Environment: Stresses and Hazards
PART 6 - Vision and Lighting
PART 7 - Visual Displays
PART 8 - Auditory Information
PART 9 - Voice Communication
PART 10 - Controls
PART 11 - Design for Maintainability
PART 12 - Systems
PART 13 - Human Computer Interaction
PART 14 - Training and Instruction (not yet published)

Two or more Parts may apply to any one equipment and it is, therefore, essential that all Parts be read and used where appropriate.

HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT

PART 7: VISUAL DISPLAYS

PREFACE

This Part of Def Stan 00-25 supersedes Def Stan 00-25 (Part 7)/Issue 1 Dated 27 October 1986

i This Part of the Defence Standard presents descriptive detail, technical data and diagrams relating to some of the important factors concerned with visibility comprehension and presentation of Visual Displays.

ii This Part of the Defence Standard is published under the authority of the Human Factors Subcommittee of the Defence Engineering and Equipment Standardization Committee (DEESC).

iii This Standard should be viewed as a permissive guideline, rather than as a mandatory piece of technological law. Where safety and health is concerned, particular attention is drawn to this Standard as a source of advice on safe working limits, stresses and hazards etc. Use of this Standard in no way absolves either the supplier or the user from statutory obligations relating to health and safety at any stage of manufacture or use.

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vii Any enquiries regarding this Standard in relation to an invitation to tender or a contract in which it is incorporated are to be addressed to the responsible technical or supervising authority named in the invitation to tender or contract.

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HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT

VISUAL DISPLAYS

Section One. General

0 Introduction

0.1 The aim of this Part of the Standard is to help designers produce effective visual displays by providing guidance on characteristics of the human visual system and physical design that influence perceptual performance. This aim is supported by offering the designer practical techniques for establishing design criteria during the early stages of the design.

0.2 The design principles are intended to be sufficiently generic to be applicable to most display types, from hand-produced signs to three-dimensional interfaces. The general guidance is supported by technology-specific recommendations, where appropriate. certain clauses may not be applicable or relevant for particular display media or operational tasks. Consequently, the designer should always adhere to the general principles and ethos of the Standard ahead of the specific detail. For these reasons it will be necessary for the designer to consult other sources of information for guidance on specific technologies and topics, such as Head-Up Display optics or strategic symbols used in active radar. Annex A provides a list of related documents.

1 Scope

1.1 The principles described in this Part of the Standard have been designed to be applicable to the vast majority of displays used for military purposes, irrespective of display technology, as far as is realistic given the rapid advance of display technology. Consequently, the emphasis of this Part of the Standard is on providing guidance rather than limited prescriptive specification. Nonetheless, principles expressed usinq the term ‘should’ have the strongest emphasis and the designer ought to be clear in his/her justification for departures from such recommendations.

1.2 This Part of the Standard is divided into four Sections, a General introduction, followed by three Sections reflecting conceptual stages in a design process to produce effective displays.

1.2 (Contd)

	General	**Section One:** General introduction including combined definition and glossary of terms used in sections two to four.
First decide **who** the design is for, **how** it will be used and in **what** circumstances	↓	
↓	Practical Techniques for Display Specification	**Section Two:** helps the designer establish design criteria based on the context in which the display is to be used, including the physical and operational environments, and relevant characteristics of the operators.
Next, consider how to portray the **meaning** of the information clearly and efficiently	↓	**Section Three.** provides guidance on designing displays to meet human perceptual capabilities and limitations.
↓	Perception of Information from Displays	**Section Four:** provides guidance on the physical characteristics of displays that influence human performance.
Then consider how it can be **achieved,** given the possibilities and constraints of the display media	↓ Physical Characteristics of Displays	

2 Related Documents

2.1 Related documents can be obtained from:

DOCUMENT	SOURCE
British Standards (BS) (BSEN) (IEC) and ISO	BSI Sales Office Linford Wood MILTON KEYNES MK14 6LE
North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) (NATO Publication APP6)	NMST Room 202 Archway Block (South) Old Admiralty Building Spring Gardens LONDON SW1A 2BE

2.1 (Contd)

DOCUMENT	SOURCE
Health and Safety at Work Regulations MOD MANPRINT Handbook PULHHEEM's Administrative Pamphlet	HMSO South Gyle Crescent EDINBURGH EH12 9EB
Defence Standards	Directorate of Standardization (Stan 1) Kentigern House 65 Brown Street GLASGOW G2 8EX

2.2 Reference in this Standard to any related documents means in any invitation to tender or contract the edition and all amendments current at the date of such tender or contract unless a specific edition is indicated.

2.3 The documents referred to in this Part of the Standard, together with additional publications providing greater coverage on specific aspects of the subject, are listed at annex A.

3 Definitions

For the purpose of this Part of the Standard the definitions described below apply.

Achromatic (displays): Displays generating colours that are perceived to be without hue. The colour names grey, black and white are commonly used.

Adaptation: The process that takes place as the visual system adjusts itself to the brightness or the colour (chromatic adaptation) of the visual field. The term is also used, usually qualified, to denote the final state of this process. For example 'dark adaptation' denotes the state of the visual system when it has become adapted to a very low luminance.

Advisors: A type of status indicator used to inform the operator of a condition or state that requires general awareness of a marginal or predicted imminent condition.

Alarm: A type of status indicator used to inform the operator of a hazardous condition or state.

Ambient illumination: General level of illumination at the workstation.

Anisotropic (display surface): A display surface for which radiation deviates from that of a Lambertian surface (see IEC 845-04-57) by more than 10% at any inclination angle $0 < 45°$.

3 (Contd)

Anthropometry: The measurement of human body dimensions. See Def Stan 00-25 (Part 2).

Attenson: A sound used to or inform.

Auditory cue: A sound designed to prompt the operator for a specific action.

BARB: British Army Recruitment Battery pre-selection test.

Brightness: The subjective response to luminance in the field of view dependent upon the adaptation of the eye.

Candela (cd): The SI unit of luminous intensity, equal to one lumen per steradian.

Caution: A type of status indictor used to inform the operator of a condition or state that requires immediate attention and a rapid remedial action. See also Advisors; Warnings.

CLOS (operation): A type of tracking system, ‘command-to-line of sight’, in which the controlled device (eg missile path) follows the operator’s command.

Code (visual): A systematic technique for representing information used aid comprehension. Codes can be used to speed interpretation, or to make presentation of the information more efficient (eg by reducing the size). Codes can also be used to add to, or modify the meaning of the information.

Contrast: (see also Def Stan 00-25 (Part 6)) A term that is used subjectively and objectively. Subjectively it describes the difference in appearance of two parts of a visual field seen simultaneously or successively. The difference may be one of brightness or colour or both. Objectively, the term expresses the luminance difference between the two parts of the field by such relationships as the difference between the luminance of the target and background, eg expressed as a ratio:

$$\text{Contrast Ratio, } C_R = \frac{L_{max}}{L_{min}}$$

Where L_{max} and L_{min} luminance represent the maximum and minimum luminance in cd/m^2, respectively - ie the luminance of the target and background.

Contrast sensitivity: The ability to perceive a lightness or brightness difference between two areas. See also Def Stan 00-25 (Part 6).

Control display dynamics: The spatial relationship between the control input and the display output.

CRT: Cathode ray tube.

3 (Contd)

'Dark quiet' (design philosophy): Status indicator design philosophy in which the displayed information is not visible or audible until directly relevant.

Descenders (in text): Elements of lowercase letters that extend below the baseline, eg on the letters g, p, j, y.

Diacritic: A modifying mark near or through a letter indicating a phonetic value different from that given the unmarked letter, eg a cedilla in 'façade'.

Diffuse reflection: Reflection in which the reflected light is diffused and there is no significant specular reflection, as from a matt paint.

Direct lighting: Lighting in which the greater part of the luminous flux from the luminaires reaches the surface (usually the working plane) directly, ie without reflection from surrounding surfaces. Luminaires with a flux fraction ratio less than 0.1 are usually regarded as direct.

Disability glare: Glare produced directly or by reflection that impairs the vision of objects without necessarily causing discomfort.

Discomfort glare: Glare which causes visual discomfort.

Display (visual): The type of information medium that is relevant to, and observed by, the human sense of sight.

Display modality: The human perceptual sense through which the display stimulus is perceived, eg visual, auditory, tactile, olfactory.

Dot matrix: A system of displaying characters within a given matrix of dots , often 7 x 9 or 5 x 7.

Duty cycle: The ratio of the active display interval compared versus the flashing interval, of a flashing stimulus, expressed as a percentage. See also Flash Coding.

Effective reflectance: Estimated reflectance of a surface, based on the relative areas and the reflectance of the materials forming the surface. Thus ,'effective wall reflectance' takes account of the reflectance of the wall surface, the windows, the filing cabinets etc, that comprise the sides of the room.

Emissive (displays): Displays that contain their own light source(s). The light is either produced by the transducer itself or provided by one or more internal light sources modulated by the transducer.

Flash coding: Information presented by temporal luminance variations, sometimes referred to as blink coding. See also Duty Cycle.

Flat panel displays (FPDs): Various types of electronic displays presenting information on a thin panel, eg Liquid Crystal Display (LCD), Electroluminescent Display (ELD), Gas Plasma Display (GPD), Vacuum Fluorescent Display (VFD).

3 (Contd)

Flicker: Visible modulation of luminous flux. Also referred to as temporal instability.

Frankfort Plane: An imaginary plane through the head established by the lateral extensions of a line between the tragion (centre of the ear, in profile) and the lowest point of the orbit (bottom of the eye in profile).

Glare: The discomfort on impairment of vision experienced when parts of the visual field are excessively bright in relation to the general surroundings.

Head/Helmet - Mounted Display (HMD): A type of display, often mounted upon or within the operator's protective helmet, incorporating a miniature FPD or HUD.

Head-Up Display (HUD): A type of display incorporating a part-reflective panel ('combiner') upon which the displayed image is projected, allowing the operator to view the image and background together.

Hierarchical Task Analysis (HTA): A method of hierarchically decomposing operator goals into tasks and sub-tasks for analysing design and training requirements.

Hue: The term that most closely resembles our notion of 'colour', for example, red, green and blue. It is that quality of a colour that cannot be accounted for by brightness or saturation differences. An objective measure of hue is provided by the dominant wavelength of that colour's spectral power distribution.

Illuminance (E, units: 1 m/m^2, lux): The luminous flux density at a surface, ie the luminous flux incident per unit area. This quantity was formerly known as the illumination value or illumination level.

Immersive (display): A type of display through which the operator is presented with a virtual visual environment - either generated or a remote real environment - that responds appropriately to head movements, using display devices close to each eye.

Infra Red (IR) display: A display of the content of a visual image that is comprised from the infra-red area of the electromagnetic spectrum.

Lumen (lm): The SI unit of luminous flux, used in describing a quantity of light emitted by a source or received by a surface. A small source which has a luminous intensity of one candela emits a total of 4π lumens in all directions and emits one lumen within a unit solid angle, ie 1 steradian.

Luminance (L, unit: cd/m^2) : The physical measure of the stimulus which produces the sensation of brightness measured by the luminous intensity of the light emitted or reflected in a given direction from a surface element, divided by the projected area of the element in the same direction. The SI unit of luminance is the candela per square metre. The relationship between luminance and illuminance is given by the equation:

3 (Contd)

$$\frac{\text{Illuminance x Reflectance factor}}{\pi}$$

This equation applies to a matt surface. For a non-matt surface, the reflectance is replaced by the luminance factor. The luminance of the sky (and other sources that cannot be visualized as surfaces) may be described in terms of the illuminance produced on a surface.

$$\text{Luminance of a small zone of sky} = \frac{\text{Illuminance on a surface directly facing sky zone}}{\pi \text{ x Angular size of zone}}$$

Lux: The SI unit of illuminance, equal to one lumen per square metre (lm/m^2).

Mnemonics: Letter-based code, eg acronym - a word comprising the initial letter of a sequence of other words.

Monochrome (displays): Displays perceived as having hue but that use luminance alone to differentiate between pixel states.

NBC: Nuclear, Biological and/or Chemical (hazard, protection state or event).

Operator: Person qualified to use the visual display and employed in the target role.

Phonetics: Aural components of speech. domain.

Pictogram: Simplified representational depiction of concrete visual objects.

Pitch Ladder: Display symbology used to indicate pitch and roll attitude of aircraft. Lines or bars are used to represent pitch angles, hence the appearent similarity to ladder rungs.

Pixel: The smallest addressable display element that is capable of generating the full colour and/or luminance ranges of the display.

Polarity: The relationship between the background brightness and image brightness. The presentation of brighter images on a darker background is designated negative polarity, and darker images on a brighter background is designated positive polarity.

PULHHEEMS: Scoring system for classifying the medical capacity of military personnel. See PULHHEEMS Administrative Pamphlet.

Pursuit reflex: A physiological mechanism that provokes the eyes to track moving images.

Redundant coding: Additional coding, used to enhance the salience of the coded information.

3 (Contd)

Referent ('real world'): The reference object or concept depicted by a symbol, pictogram or metaphorical construct.

Reflectance (factor (R, ρ): The ratio of the luminous flux reflected from a surface to the luminous flux incident on it. Except for matt surfaces, reflectance depends on how the surface is illuminated but especially on the direction of the incident light and its spectral distribution. It is expressed as either a decimal or as a percentage.

Representational display: A display that presents a representation of 'real-world' objects or concepts, often using pictograms and symbols.

Scotopic vision: The performance of the dark-adapted visual system.

Soft-key: A key for which the function may be changed according to software control. Sometimes, but not always associated with a software-controlled indicator of current function.

Specular reflection: Reflection without diffusion in accordance with the laws of optical reflection as in a mirror.

Status indicator: A display of discrete, separate, qualitative information.

Subject matter expert (SME): Person with task knowledge and accepted qualification in the target domain.

Target Audience Description (TAD): A descriptive profile of the characteristics, skills and abilities of the 'end-user' of the visual display.

Task analysis: A structured method for analysing the design and training requirements of an item of equipment based upon the operator's goals and tasks that the equipment is intended to support.

Task area: The area containing those details and objects that must be seen for the performance of a given activity, and includes the immediate background of the details or objects. In the absence of precise dimensions the task area is assumed to be a 0.5 m square, which is placed within a 1 m square surround.

Three Letter Abbreviation (TLA): A common form of coding for military terminology, eg 'AAM': Air-to Air Missile. Not all TLAs are acronyms, eg 'AWX': All Weather Fighter, and the same TLAs can have different meanings for different Units and in different contexts, eg 'TOT' which means 'Time On Target' to Artillery and 'Time Over Target' to Aircraft.

Transient adaptation: The repeated response of the visual system when the operator is alternately exposed to variation in the brightness or colour in the visual field.

Typographical cue: A method of highlighting displayed text, such as underlining.

3 (Contd)

Uniformity (illuminance (U_E) luminance (U_L)): The ratio of the minimum illuminance (or luminance) to the average illuminance (or luminance) over a specified surface. The ratio usually applies to values on the task area over the working plane.

Vestibulo-ocular reflex: The tendency of the visual system to stabilise based upon inertial movement of the head.

Veiling reflection: See Diffuse reflection.

Visual acuity: The capacity for discriminating between objects which are very close together. Quantitatively, it can be expressed by the reciprocal of the angular separation in minutes of arc between two lines or points which are just separable by the eye. The expression more commonly used for an individual's visual acuity is the ratio of the distance at which the individual can read a line on a standard optician's chart to the standard distance at which a person of normal sight can read that line (eg 6/12 means that the individual can just read at 6 m the line which a normally sighted person can just read at 12 m).

Visual disability: A disability is any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being.

Visual environment: The environment either indoors or outdoors as seen by an observer.

Visual field: The full extent in space of what can be seen when looking in a given direction.

Visual impairment: A loss or abnormality of psychological, physiological, or anatomical structure or function of the visual system.

Visual task: The visual element of the work being done.

Virtual environment: The notional environment generated by an immersive display which presents information in such a way as is appropriate to give the operator the perception of viewing and interacting with objects in three-dimensional surroundings.

Warning: A type of status indicator used to inform the operator *in advance* of a condition or state that requires immediate attention and immediate action. See also: Advisor; Alarm; Caution.

Section Two. Practical Techniques for Display Specification

4 Task requirements

The purpose of a display is to support a human operator in pursuance of an operational or other objective by conveying useful information. The degree to which the information helps the operator is influenced by its availability, timeliness, precision, comprehensiveness, validity, reliability and the degree to which it can be understood. These characteristics are related to the tasks which the operator must perform to complete the objective.

4.1 Understanding the tasks the display must support. Therefore the first steps for the designer should address the following:

(a) What is the overall objective?

(b) What information is required to support the objective?

(c) What part of the overall information requirements must the display provide?

(d) What is important about the information?

(e) Is the information used directly or with other information?

(f) Are further mental operations required for the information to be meaningful?

(g) What levels of detail and/or accuracy are required?

(h) How significantly and how often can the information change?

(i) Does the information need to be continuously monitored?

(j) Is the output of the display directly influenced by input from the operator?

(k) Under what environmental conditions does the display need to be viewed?

(l) What else does the operator have to do while viewing the information?

(m) What are the characteristics of the viewers?

5 Context of Use

The questions in **4.1** are essentially questions about the context of use. The context will include the physical and psychological and psychosocial environments in which the display is used. For example, a low ambient illuminance, high gravitational force and the wearing of nuclear chemical and biological (NBC) clothing and equipment may give rise to adverse viewing conditions. Similarly, high mental workload, sleep deprivation and fear-induced stress also affect visual performance, and should be taken into account in the display design. Thus, the extent to which performance is affected will differ within and between individuals. Therefore, and

5 (Contd)

understanding of the users' characteristics and their requirements is fundamentally important. Methods for identifying these are described in clause **6.**

5.1 Physical environmental conditions. Conditions which affect visual perception and extraneous factors which influence the design of the display should both be considered. These are discussed in detail below:

5.1.1 Visual conditions is enough light to read the display. The visual conditions include the level of ambient illumination (whether there is enough light to read the display, or too much) whether there are 'hot spots' (that cause glare and reflections - see Def Stan 00-25 (Part 6)) and the spectral content of the ambient light. For example, operators wearing Night Vision Goggles (NVGs) in a cockpit often suffer from problems of transient adaptation between the low level of illumination in the 'outside world' and the high level within cockpit, influenced by the luminance of the displays.

5.1.1.1 The spectral content of the ambient illumination is important as it affects the operator's ability to distinguish display detail. For example, red illumination is often designed into systems in an attempt to preserve scotopic (dark adapted) vision. However, this can render colour coding on displays ineffective, eg brown map contour lines on many maps (see Def Stan 00-25 (Part 6)). Similarly, NVGs are more sensitive to red wavelengths than blue, and hence blue images on darkened displays require greater luminance.

5.1.2 Cleanliness. Sometimes overlooked is the performance impairment that can be caused by displays that have become dirty in use. Glass-fronted displays usually provide two surfaces - external and internal - upon which substances can accumulate. The internal surface is often inaccessible and dust gathers worsening veiling reflections (see **18.5).** Finger marks (eg on touch screens or filtered screens), scratches, mud, and other substances (eg NBC decontamination powder) can obscure information, while water droplets can cause localized magnification.

5.1.3 Vibration. Vibration can impair visual performance by producing an image that moves on the retina. The environmental characteristics that are most likely to produce image motion are:

(a) frequencies in the range 1-20 Hz;

(b) displays mounted on the head;

(c) images not collimated (image not focused at infinity);

(d) retinal image motion of approximately 1 min of arc or greater;

(e) part of the visual task involves operator control (under vibration), eg holding a map;

(f) sinusoidal vibration components (single frequency);

(g) if the display is viewed through (optical) magnification device; or

5.1.3 (Contd)

(h) demanding visual tasks such as target identification or reading text or symbols in a short time.

5.1.3.1 The pursuit eye reflex allows eyes to follow images that move on the retina. Consequently, image motion that is produced by vibration has little effect on visual performance when this reflex is operating - ie up to about 1 Hz. Above about 20 Hz vibration encountered in military environments rarely produces sufficient image motion to impair visual performance.

5.1.3.2 Guidance on exposure limits to whole body vibration in terms of the affects on performance and health is given by BS 2631 Guide to Measurement and Evaluation of Human Exposure to Whole-body Vibration and repeated shock.

5.1.4 Auditory. Auditory stimuli are sometimes difficult to perceive in noisy environments and can therefore be enhanced with visual reinforcement (eg parachutists are signalled to jump in noisy aircraft cabins using lights). In such cases, redundant visual coding may be suitable.

5.1.5 Thermal. Electronic display media differ in respect of both heat emission and performance at temperature extremes (see clause **19).** The equipment or vehicle design and the operational environment may influence the choice of display technology.

5.1.6 Operational space. There may be physical limitations of the size of the display which have implications for the choice of display medium. For example, the smaller size of Flat Panel Displays (FPDs) might make them more suitable in restricted space such as a cockpit, armoured fighting vehicle (AFV) or for portability in the field, whereas where very large displays are required, Cathode Ray Tubes (CRTs) may be more suitable.

5.2 Operational security and soldier survivability. The nature of the display may be influenced by the procedural requirements necessary to avoid compromise. For example, it may be necessary to switch off display illumination when vehicle or command post doors are opened in the field. Similarly, the use of permanent illuminated status indicators (eg 'power-on' lights) should be avoided in the design of field equipment.

5.3 Mental workload. The intensity of the operator's mental workload caused by the overall task environment can have a significant effect on his/her capacity to perceive information from displays and the accuracy with which it is comprehended. The display designer should discuss all visual tasks with the crew station designer in which the operator is involved with particular attention in clause **15.2, 15.3.** Most importantly, the design should minimise the potential for conflicts both in terms of contradictory information and in the attentional demands of the operator, including stress.

5.4 Impact of regulations. Certain legal regulations cover the design of visual displays. For example, the Health and Safety (Display Screen Equipment) Regulations, require the following of display screens:

5.4 (Contd)

(a) The characters on the screen shall be well-defined and clearly formed, of adequate size and with adequate spacing between the characters and lines;

(b) The image on the screen should be stable, with no flickering or other forms of instability;

(c) The brightness and the contrast between the characters and the background shall be easily adjustable by the user, and also be easily adjustable to ambient conditions.

(d) The screen shall be free of reflective glare and reflections liable to cause discomfort to the user.

(e) The screen must swivel, tilt easily and freely to suit the needs of the user.

(f) It shall be possible to use a separate base for the screen or an adjustable table.

5.4.1 Guidance to compliance with these Regulations is published by the Health and Safety Executive in their guide L26. Though the Guidance indicates that most displays on board a means of transportation are exempt from the Regulations, designers should still endeavour to produce displays that will allow the Ministry of Defence (MOD) to comply with the terms of the Regulations, and strong justification is required for failing to do so. For displays in static operation, compliance to the terms of the Regulations is mandatory.

5.4.2 Most of the display obligations can be met by complying to the European standard EN 29241, Ergonomics requirements for office work with visual display terminals (VDTs), Part 3 Visual Display Requirements. Compliance with this standard will in most cases meet or go beyond these requirements.

5.5 Context of use Design Checklist. Consider the:

(a) operational objective;

(b) legal requirements, design standards and MANPRINT obligations;

(c) level of operational security required;

(d) visual conditions;

5.5 (Contd)

(e) levels of:

(i) illumination, luminance;

(ii) vibration;

(iii) noise; and

(iv) heat;

(f) space restrictions;

(g) likely cleanliness; and

(h) operator’s mental workload and stress when using the display.

6 Identifying Users and User Requirements

6.1 For the display to be effective, it must be compatible with the capabilities and limitations of its users. The designer should therefore pay close attention to the prescribed target audience description (TAD) for the equipment contained in the requirements/specification, which deals specifically with visual perceptual characteristics. Such a TAD may include characteristics of the operators, illustrated in Table 1. Specific information for TADs may come from various sources and Subject Matter Experts (SMEs). Some characteristics could be assumed on the basis of basic UK military screening such as the PULHHEEMS scoring system for classifying medical capacity and the British Army Recruit Battery (BARB) which provides a General Trainability Index (GTI).

6.2 The designer should, nevertheless, take care that the assumptions made on these basis are valid. For example, although the BARB includes a series of tests for various aptitudes (eg mental rotation, semantic identify, etc) the GTI provides a single ‘t-score’ for comparative purposes which may present an unreliable indication of aptitude in any individual dimension. In general, more situation-specific characteristics may have to be ascertained by performance trials or experiments (see **7.3).** A summary of the characteristics that should be taken into consideration in visual display design is given in table 1. The visual effects are described in Def Stan 00-25 (Part 6).

Table 1

Examples of Visual Perceptual Characteristics from Target Audience

Descriptions to be Taken into Consideration in Display Design

CHARACTERISTIC	VISUAL EFFECT	ISSUE
Age	increasing presbyopia, decreasing visual acuity, lens coloration and hardening	Affects size of displayed information, viewing distance, colour, required illuminance and contrast and focusing.
Visual acuity	range of visual accommodation	Affects size of displayed information, viewing distance.
Visual deficiencies	eg myopia, hypermetropia, astigmatism, phoria, amblyopia (no depth perception)	Affects size of displayed information, viewing distance, position in visual field.
Flicker sensitivity	variation between individuals of critical fusion frequency	Affects display medium, size of displayed information, luminance, position in visual field, lighting.
Colour perception	proportion of population with colour vision deficiencies (NB more common in males)	Affects display medium, size of displayed information, contrast, position in visual field, use of coding and status indication
Susceptibility to motion sickness	variation between individuals of visually induced motion sickness	Affects use of immersive displays, movement of displayed information, use of perspective.
Body anthropometry	clearance, proximity (eg reach to combined display/controls), postural eye position	Affects position in visual field, viewing distance

Continued on page 19

Table 1 - Continued

CHARACTERISTIC	VISUAL EFFECT	ISSUE
Facial anthropometry	size and calibration of equipment	Affects positioning of head/helmet mounted displays, use of special vision aids (eg NVGs) and corrective appliances.
Clothing/Uniform/ Helmet	restriction, obstruction,enhancement	Affects normal visual field, functional visual field (with head movement).
Cognitive attributes	eg spatial awareness, field dependence	Affects grouping, integration, use of symbols/pictograms.
Linguistic ability	comprehension, dyslexia	Affects use of text, coding.
Level of training/ experience	skill, familiarity, awareness	Affects use of esoteric terms/symbols, abbreviations, acceptance of technology.

7 Modelling User Tasks

Modelling user tasks to yield design specifications requires a certain amount of trial and error, but structured analysis can help the designer understand specific requirements of the display. Most modelling methods begin by decomposing the overall objective into sub-goals and identifying the component tasks required to achieve the sub-goals. Further general information is given in Def Stan 00-25 (Part 12).

7.1 Defining the tasks. A description of structured task analysis methods is given in Kirwan & Ainsworth (1992). An example of an Hierarchical Task Analysis (HTA) is given in figure 1 for a hypothetical command-to-line of sight (CLOS) missile system. HTA breaks-down tasks hierarchically into their sub-components and uses a plan to provide the logical rules that govern the execution of each task.

7.1 (Contd)

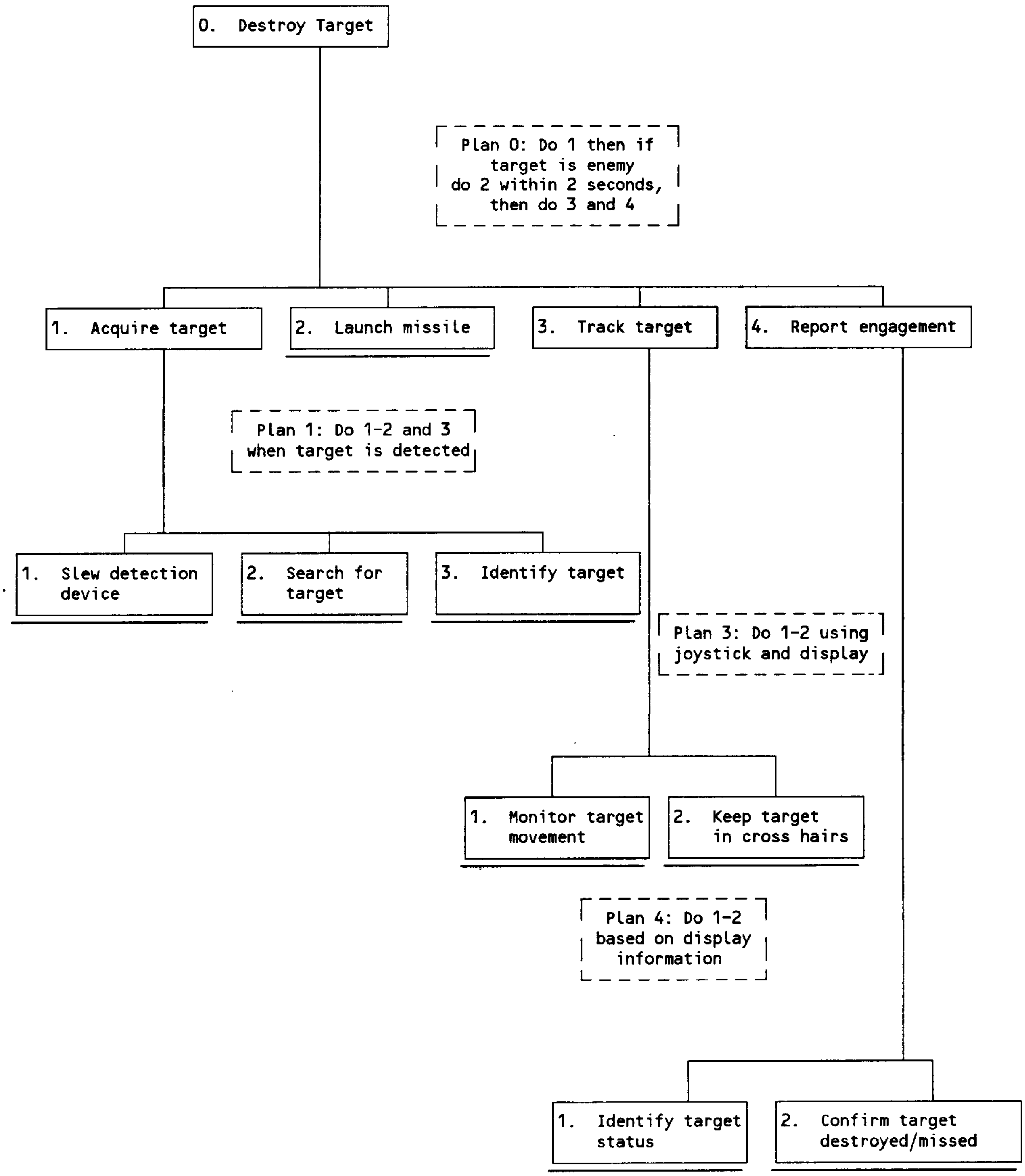

Figure 1 Task Description of a Hypothetical Missile System, Using HTA

In the example in figure 1 the designer can use the breakdown of individual tasks to identify design requirements of the display. For example analysis of the acquisition sub-tasks raises issues concerning the rate of presentation of information (during slewing), the size and contrast of the target image (for search purposes) and the distinctiveness of the image (for recognition and identification). The designer can use this

7.1 (Contd)

information, coupled with the operational requirements of the system to help decide upon the display characteristics, eg whether to use thermal/IR images or a representational or virtual display with arbitrary symbols.

As illustrated in the Plan for task 0, the system or operational requirements frequently impose time constraints upon the operator - in this example the missile must be launched within 2 seconds of acquiring the target. The designer should decide whether indication of the time to fire should be provided in the visual display or whether another medium (eg auditory cue) should be used to help the operator simultaneously maintain tracking performance. Similarly, how will the display show if the target has been destroyed or lost?

The operator's performance of tracking the target (task 3 in the example) will depend on the relative size and contrast of the cross hairs and target image, but will be most influenced by the joystick control law. Hence the display designer must take into consideration the control-display dynamics - for example, does a forward demand on the joystick cause the display to pan up (and the image down) or the image up (and the display down)? The task description should be used in conjunction with the statement of the context of use to model the operator - display interaction.

Note the directional relationship between input demand and system response should meet expectations of the operator (see Def Stan 00-25 Part 10 page 34, clause **16.8b.**

7.2 Modelling. By considering the task description in the context of use, a theoretical model can be constructed of the interaction between system and operator. the most appropriate method of depicting the model varies but commonly takes on the form of an annotated task description or a flow diagram. Computerised models are also used. The display designer should use the model to identify and resolve the combination of the task and contextual requirements of the display. For example, the task in the example in figure 1 may have to be conducted under high amplitude, low frequency vibration (eg whilst moving on a land vehicle over rough ground), and against a high background luminance (eg sunny sky). This may eliminate the use of a helmet-mounted display for gross acquisition of the target in favour of a semi-automated acquisition system. The model should take account of the dynamics of the interaction

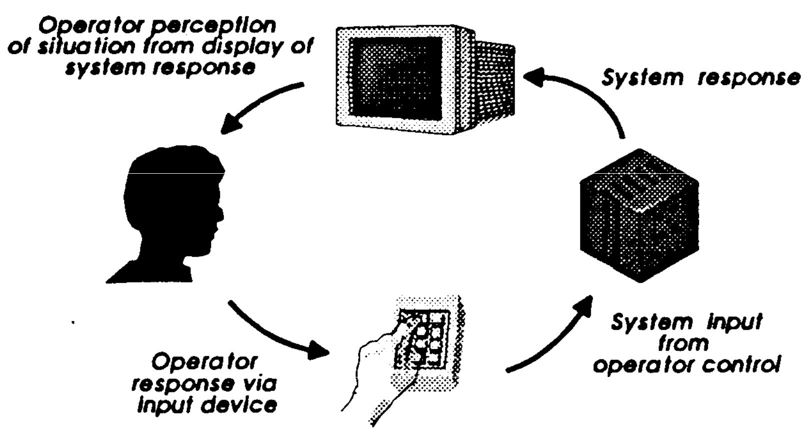

Fig 2 Control Loop Between Operator and Display

7.2 (Contd)

between operator and equipment, in particular the relationship between the operator's control input to the system and the way the resulting output is displayed. Figure 2 illustrates this 'control loop'; absent from the illustration are contextual influence upon both operator (eg training, orders, expectation) and system (eg external events, environmental conditions).

NOTE: The operator's perception of the situation affects his/her control response. the system performs as controlled and the result of the control is displayed. The presentation of the results (via the display) is critical in maintaining accurate situational awareness.

7.3 Design assessment. The design process should include iterative formal assessment of the display using performance trials and user evaluations. Prototypes, simulations and mock-ups of various constructions may be appropriate depending on the aspect of design under review. For example, if the meaningfulness of symbols is being tested, then paper display mock-ups may suffice, whereas if the clarity of the symbols is of interest, a working prototype, viewed under realistic conditions may be required. Similarly, some trials may not require representative operators (eg trials of absolute visual performance), though in general, the more the trial conditions and subjects match the real conditions and target operators, the more confidence there can be in the results (and hence in the resultant design decisions).

7.4 Analysing the display requirements: design checklist. By working through the task description, TAD and task model, the designer should be able to devise a statement of desired characteristics for the display. Before assigning appropriate display media and designing the display, however, it is useful to verify the statement using the following check:

Can	*this*	person,
with	*these*	characteristics,
and	*this*	training,
carry out	*these*	tasks,
to	*this*	specification,
under	*these*	conditions,
with	*this*	display?

8 Providing User Support and Training for the Display

8.1 Where possible, interactive display designs should be based around operator's existing experiences and expectations (see clause **6).** This will assist in ensuring that systems are intuitive to use without requiring further training. Where this is not possible, for example where a new design concept is being employed or as a result of a change in technology, additional user support may be necessary. This support may take two forms.

8.1 (Contd)

Firstly, the system itself may be designed with additional on-line/embedded support. The operator should have control over whether such support is displayed. Secondly, more comprehensive off-line user training in the system can be given.

8.2 In military applications, where speed and accuracy of performance are often critical, operator training will undoubtedly take place. This, however, should not be provided at the expense of providing a display design that is intuitive to understand and use. Generally, the provision of on-line support benefits new systems' implementation by:

(a) reducing training time and training costs;

(b) improving man-machine system efficiency;

(c) reducing errors;

(d) reducing the need for external system support.

8.3 Further general guidance is given in Def Stan 00-25 (Part 14).

Section Three. Perception of Information from Displays

The effectiveness of a display can be expressed as the completeness and accuracy with which the viewer can perceive the displayed information in a given time. Clearly, effectiveness relies on meeting the necessary physical requirements to be readable (see section four). Equally important however, is the requirement that having read the display, the information is correctly understood. In this respect the effectiveness depends on the degree to which the design of the information in the displays and the display integration and grouping meets the perceptual capabilities of the operators. This section gives guidance on general perceptual characteristics of displays. Guidance on physical characteristics is given in section four, except on the physical aspects of scales, which is included in this section for completeness.

9 Quantitative displays

Quantitative displays provide information about the value - ie the quantity - of a variable along a dimension. The variable is either static (eg speed limit) or dynamic (eg altitude). Three types of mechanical dynamic quantitative displays are shown in figure 3 and their advantages and disadvantages are described below.

9.1 Counters

9.1.1 Counters are best for tasks requiring accurate perception of precise numerical values (eg when setting a bearing or recording a distance).

9.1.2 The number of digits should be kept to a minimum. (Compared with designs of up to 3 digits, 4-6 digit displays take about 50% longer to read accurately and displays with more than 7 digits take 100% longer.)

9.1.3 Where including a decimal point is unavoidable, a clear distinction should be made between the digits separated by the point, with the use of a code (eg size or colour) or preferably by the counter drums.

9.1.4 Counters become difficult to read when moving quickly (where each numeral is presented for less than about 0.75 sec), especially for rate and direction of change.

9.1.5 For operators to read the information accurately, continuously rotating counter units need to be displayed for about 10% longer than those that move in discrete jumps.

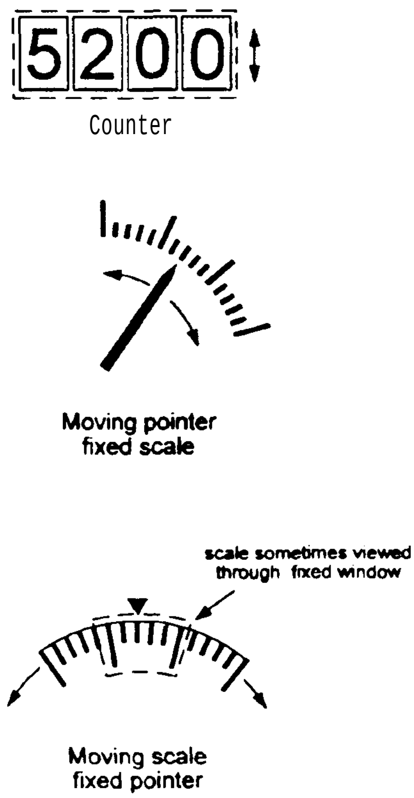

Fig 3 Types of Mechanical Dynamic Quantitative Display

9.2 Moving pointer. Operators perform best using fixed scale moving pointer displays in tasks where the direction or rate of change information is important, or where there is slight oscillation around a value.

9.2.1 Moving pointer displays are most limited in the absolute number of units that can be presented without compromising accurate quick reading. Performance is best with between about 20-100 units, more than 100 takes twice as long and more than 600 can take nearly five times as long to read accurately (depending on the degree of change etc).

9.3 Moving scale. In general, larger scales (diameter above about 215 mins of arc) are read slightly faster but less accurately than smaller scales. Where it is necessary to display a very large range of values, requiring a large display scale, fixed pointer moving scale displays have the advantage that the reading point is constant. Such displays typically present information in a window to minimise the amount of surface space they occupy on the display panel.

9.4 Numerical progression and scale interval

(a) Operators perform best where the conventional progression 0, 1, 2, 3, . . . etc is followed.

(b) Where space is limited or the designer needs to declutter a display, some numbers can be eliminated using the convention, 1, 2, 5, 10, 20, 50, ... etc.

(c) Care should be taken using logarithmic scales since they are notoriously difficult to read.

(d) Progression should, where possible match the orientation of any related control, bearing in mind that values increasing left-to-right or clockwise are read accurately about twice as quickly as the reverse.

(e) Straight horizontal scales are read quicker than vertical scales but both are inferior to part circular scales.

(f) The larger the scale interval (within a given physical size - see **9.5)**, the fewer errors and the quicker the scale is read.

9.4.1 Start and end points on circular and part circular scales. It is often appropriate in assigning the start and end points of scales (or controls - see Def Stan 00-25 (Part 10)) to exploit the 12 positions of a conventional clock face, since all operators will be familiar with the relative spacing and numerical values associated with clocks. For example, a circular display presenting the values 0, 1, 2, 3, 1 and 4 in their relative positions on a clock face - ie at 30° intervals with 0 at the top - will be read quicker than one in which they are arbitrarily arranged or equi-spaced.

9.4.1.1 In general, where values do not conveniently correspond to those on a clock face, the minimum value should be at the 7:30, 8, 9 or 12 o’clock position and the maximum value should be at the 3, 4, 4:30 or 5 o’clock position.

9.5 Scale markers. Recommended sizes and proportions for scale markers are given in table 2 for the dimensions given in figure 4. The recommended widths of all marks may be reduced to 2 mins of arc in good viewing conditions or where accuracy is not critical.

Table 2

Recommended Sizes of Scale Markers

	Size min arc	Approx size for viewing distance mm		
		700	900	1500
A Major mark width	4.3	0.88	1.13	1.88
B Minor mark width	3.1	0.64	0.80	1.34
C Intermediate mark width	3.7	0.76	.097	1.60
D Major mark height	27.1	5.55	7.10	11.81
E Minor mark height	12.2	2.50	3.21	5.36
F Intermediate mark height	19.6	4.00	5.14	8.57
G Minor mark gap	8.6	1.75	2.25	3.75
H Major mark gap	85.9	17.5	22.50	37.50

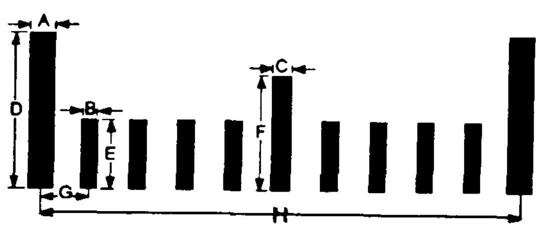

Fig 4 Recommended Sizes of Scale Markers

9.6 Pointer design

(a) The pointer should have a high contrast to the display background.

(b) The colour of the pointer should extend from the centre of the display dial to its radial end only in the direction of the pointer tip (see **14.1.1** and clause **18).**

(c) Numerals and labels accompanying scales should be positioned outside the scale markers so as to avoid being obscured by the pointer.

(d) The inside edges of major and minor scale markers should be aligned on the circumference swept by the pointer tip.

(e) The width of the pointer tip should be the same as the width of the narrowest scale mark. So as to enhance the readability for check-reading (see **14.1.1** and clause **18),** it may be necessary to increase the width of the main body of the pointer, in which case the angle from the pointer tip should be about 20°.

(f) The tip should meet the scale markers but not overlap them.

9.7 Quantitative display design checklist

(a) Moving pointer, fixed scale displays are preferred, especially if there is continuous small variation, or rapid change.

(b) Use counters or windowed moving scale fixed pointer display where precise numerical values must be read quickly.

(c) Counters should move in jumps.

(d) Use conventional progression (eg 0, 1, 2, 3, ... etc).

(e) Scale progression should increase in the same direction as the input associated controls.

(f) Indicate which units (preferably SI units) the display shows. For UK land vehicle applications, speedometers have dual scales in Km/hr and mph as road distances are indicated in miles.

(g) Use the clock face convention where appropriate for positioning of start and end points and for positioning values.

(h) Place numbers outside scale markers.

(i) Pointers should meet but not overlap scale markers and the tips should be the same width as the narrowest marker.

10 Qualitative Displays

Where specific or approximate values have special significance to the operator’s task, qualitative displays should be considered. The information in qualitative displays usually has a basic quantitative element but the operator is often more concerned with the thresholds or ranges of values that are significant to the task. A quantitative temperature display, for example, presents a numerical value for the

10 (Contd)

temperature from which the operator has to decide what the value means in relation to the task. The operator may not need to know the precise temperature, but may instead be concerned with whether the temperature is too hot or too cold for operational purposes. A qualitative display, however, could be used to present the information in such a way that it is immediately relevant, without requiring the operator to make an extra decision (eg by indicating that the temperature is 'too hot' or 'too cold'). Thus, qualitative information in displays can be useful to:

(a) enhance quantitative information;

(b) provide indication of the status of a particular variable (including alarms and warnings);

(c) provide information concerning relationships between entities.

10.1 Using qualitative information to enhance quantitative displays

10.1.1 Many quantitative displays are used for quantitative and qualitative purposes, for example, a pointer moving quickly, anti-clockwise on an altimeter indicates a rapid descent ie it conveys trend information concerning the direction and rate of change as well as numerical values for height of the aircraft.

10.1.2 There are many situations where qualitative information can be added to quantitative displays to enhance the significance of particular values or ranges of values. Some examples are given in figure 5 (a) and (b). Redundant coding is particularly useful to help the operator identify the status of information (eg shaded areas on a pressure level gauge may be used to indicate the boundaries of a safe operational level).

10.1.3 Similarly, if the predominant use of the display is for check reading, coding or labels can be used to highlight the 'normal' value (see also **14.1.1).** Typically in check reading the actual values are not required because it is the condition or status of the information that is important. In these circumstances the designer should consider whether the operator needs numerical values at all, or whether the display would be easier to read as depicted in figure 4 (c), with merely a pointer and zones indicating the alternative conditions or states.

10.1.4 An advantage of pointer displays over discrete status indicators is the ability to detect the rate and direction of change within each state, eg the pointer in figure 4 (c) is within the acceptable 'normal' range but may be moving towards the 'too low' zone.

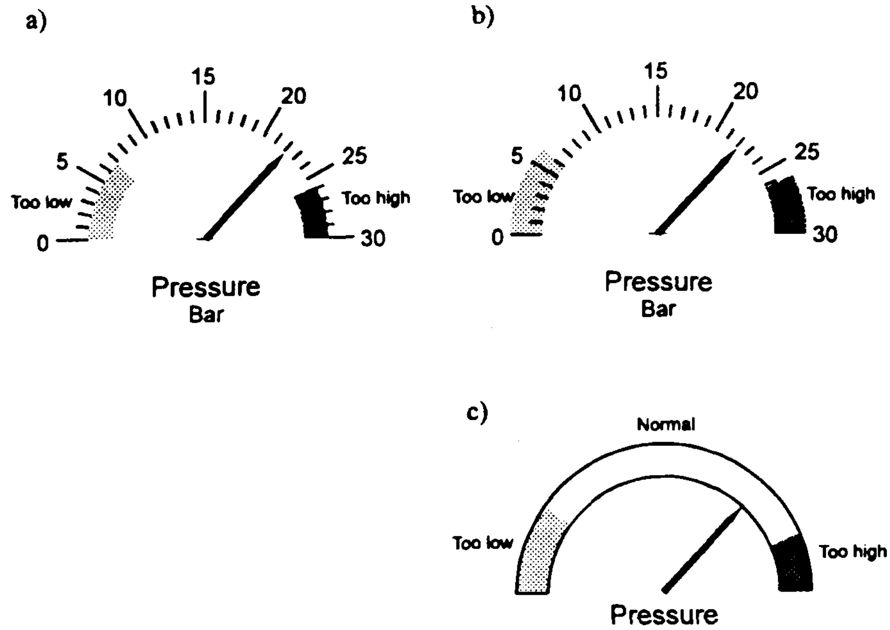

Fig 5 Methods of Adding qualitative Coding to Quantitative Displays

NOTE: The method shown above (in a) is preferred since it does not reduce the contrast of the scale markers. If numerical values are not required then the method c is preferred, making the display move qualitative.

10.2 Status indicators. Although qualitative information on quantitative displays is used to associate status with values along a continuum, status indicators are more commonly thought of as displays of discrete, separate, qualitative information. Status indicators typically have 2 states, ‘on’/’off’, though use of codes adds to the information content, especially where used for alarms and warnings (see **10.3).** When designing status indicators the following general rules should be followed:

(a) apply indicators consistently to related information;

(b) hide indicators until they become active (to avoid difficulties in discriminating the status);

(c) Avoid depicting more than 3 states per indicator (2 is preferred);

(d) Do not use status indicators for ‘normal’ states, eg ‘power on’, unless there may be reason for the operator to believe otherwise;

(e) Do not use colour alone to indicate status (combine with text, labels or symbols);

10.2 (Contd)

(f) Do not use red or yellow at all unless the status is associated with danger or caution;

(g) Ensure associated labels and codes are clear and meaningful so that the operator can easily understand the significance of the indicator (see clause **11** and **13).**

(h) Provide a facility for displaying all indicators to show the operator all the items of information that could be presented and to check that the indicators are functional.

(i) Follow a 'dark quiet' philosophy for 'normal' states, to increase the salience of alarms and warnings, whereby status indicators are not visible during 'normal' conditions.

10.3 Alarms, warnings and attentional directors. Alarms and warnings are status indicators designed to convey a special message to the operator, usually requiring some action or indicating an imminent event. Most alarms must serve two purposes: to direct attention to the message and to convey the meaning of the message. Visual attention directors should be designed as part of an integrated philosophy for alarms and warnings that encompasses effective use of other display modalities as required (eg auditory attensons, vocal warnings, vibration displays - see Def Stan 00-25 (Parts 5, 8 and 9)). For example, although reaction times in noisy environments are similar for both visual and auditory media, at low sound intensity levels, reaction to auditory stimuli is about 25 msecs quicker. In these circumstances, therefore, visual attentional directors should be augmented with attensons.

10.3.1 Classification

10.3.1.1 Prioritizing attentional directors should be central to the overall alarm philosophy and related to the operator's workload. The level of priority should be based on the following classification:

Advisors - require general awareness of a marginal or predicted imminent condition

Cautions - require immediate attention and a rapid response.

Warnings - require immediate attention and an immediate response.

NOTE: Some sources make the distinction between warnings as predictors of a future hazardous state and alarms as informers of a current hazardous state. In practical terms, assigning the above classifications to events means first having to determine all the potential system failures or external situations that may occur (eg using a task analysis - see clause **7** Modelling User Tasks) and then categorizing their implications for operator's safety and performance. In doing so it is worth considering the following:

10.3.1.1 (Contd)

(a) What are the consequences of the event to

(i) the operator?

(ii) the operational objective?

(iii) the system and equipment?

(b) Can the system respond to the event?

(c) Can the operator respond to the event?

(d) How quickly is it imperative the system or operator respond?

(e) How quickly can the system and/or operator respond?

(f) How adequately can the system or operator respond?

(g) What remedial actions are required?

(h) Under what conditions will the alarm be displayed?

(i) What are the consequences of ignoring the alarm?

10.3.1.2 The designer should be aware of situations in which it may be best not to present alarm or warning information. In general, alarm and warning information should only be presented if:

(a) All the criteria for presenting the alarm are satisfied (eg present 'canopy unlocked' alarm if both the canopy is unlocked and the aircraft is airborne);

(b) there is confidence in the veracity of the information;

(c) the operator is able to respond;

(d) the operator's response can be effective; and

(e) the system will not respond sufficiently.

10.3.2 Factors affecting detection

10.3.2.1 Detection of an attentional director is influenced by a combination of its size, colour, luminance contrast, shape, its position in the visual field and is also affected by ambient illumination and whether it flashes. General guidance on these aspects and other forms of information coding is given in clause **11.**

10.3.2.2 Clearly, high priority information requires maximum performance enhancement. The ability to detect stimuli is related to background 'noise'. Up to certain levels, the higher the ratio between signal and noise, the higher the likelihood of detection. Text characters larger than about 60 mins of arc in height, for example, offer no significant benefit

10.3.2.2 (Contd)

for presenting alarm and warning information. For maximum discriminability the luminance of alarm and warning information should be at least twice that of other displays in the visual environment. Where the effect on contrast is insignificant combining the information with other forms of coding may be appropriate. For example, detection and colour identification are more difficult under high ambient illumination due to contrast effects.

10.3.2.3 The position in the visual field also determines the likelihood and nature of the perception of the alarm (see section four, **15.1).** Perception of red information, for example, is about 75% slower than other information in peripheral vision. Signals presented in the bottom of the visual field (about 60 mins below the line of sight) are detected slightly faster than those at the top.

10.3.2.4 The shape of attentional directors, however, has not been found to be significant though an equilateral triangle inverted on its apex, ▼, has been preferred by some users, followed by a square on an apex, ◆.

10.3.3 Flashing and apparent motion

10.3.3.1 Guidance on flash coding is given in **11.3.** Flashing signals are detected quicker than steady displays but the effect is diminished if the background includes flashing stimuli. The frequency should be between 3 and 10 Hz, though 4 is preferred with a duty cycle of 50%. Text should flash at a maximum of 2 Hz and the duty cycle should be skewed so that the text is visible for 70% of the time, to increase ease of reading.

10.3.3.2 Depending on size and contrast, close alternately flashing stimuli in peripheral vision can appear as one moving stimulus, caused by an effect sometimes referred to as stroboscopic apparent motion. This has several implications for attentional directors. Firstly, two alarms may be perceived as only one, hence all flashing indicators should be synchronized. Though some studies have indicated that apparent motion may be a good attentional director, it is not appropriate in most situations since its effect is inconsistent ie the effect is not apparent in towards the centre of the visual field and it disappears once the operator has fixated upon its source.

10.3.4 False alarms. Though superficially obvious, eliminating false alarms should be given the highest priority. If a signal has been shown to be unreliable it will be ignored. Even if the operator only suspects the signal to be unreliable, it is possible that he/she will take no action until the signal is reinforced with supporting information. Similarly, 'normal' alarms or warning should not exist ie if an alarm is assigned the wrong status - or has a historical change in status such that it does not require immediate action - and is consequently ignored, its future effectiveness and the effectiveness of other warnings are undermined. The designer should, therefore, be aware of deviations from original design and event criteria that may influence the alarm and warning philosophy, as part of the evolutionary design process.

10.3.5 Alarms and warnings: design checklist

(a) Eliminate the possibility of confusing alarms with any other type of display.

(b) Present attentional directors close to the operator's line of sight: within a maximum 15° for high priority alarms and 30° for all other warnings.

(c) Use a master signal within 15° of the line of sight if attentional directors cannot be placed within 30°.

(d) Use negative polarity for high priority alarm text and symbols and positive polarity for low priority alarm text and symbols.

(e) Where possible, reduce workload from other tasks when presenting alarms.

(f) Ensure alarms are presented until the operator has responded or until the alarm state is no longer active.

(g) Provide a confidence test facility for displaying the alarms, to show the operator all the items of information that could be presented and to check that the alarms are functional.

(h) Use larger characters for alarm text (up to about 60 mins of arc), especially under adverse viewing conditions.

(i) Ensure alarms have at least twice the luminance of other displays in the working environment.

(j) Use flash coding sparingly for directing attention.

(k) Where flash coding is used, ensure:

(i) the background is free of flashing stimuli;

(ii) all flashing alarms are synchronized at between 2 and 10 Hz (4 Hz is preferred) with a duty cycle of 50%;

(iii) text flashes at no more than 2 Hz, with a duty cycle of 70%.

(l) Add auditory or voice signals to high priority alarms.

(m) Whilst directing attention, alarms and warning should not be so intense that they interfere with task performance.

10.4 Representational displays

10.4.1 The purpose of a representational display is to integrate qualitative information into a pictorial or symbolic form to make it easier for the operator to conceptualize relationships between objects. For example, a map combines, in a graphical presentation, information concerning both the relative position and separation of two objects. Presenting information in this way is useful because it can reduce the complexity of the operator's mental operations in transforming the displayed output into

10.4.1 (Contd)

meaningful information (see clause **14** for guidance of information integration). In this example the operator does not have to mentally convert numerical information (eg bearing, distance) into a spatial format before understanding the significance of the information the map offers the spatial information.

10.4.2 Conversely, representational displays allow the designer to add useful information that does not exist in the real world. Some nautical active radar displays, for example, can show the predicted path and position of a vessel after a given time (usually represented by a straight line in front of the vessel).

10.4.3 Increasingly common is a representational display that depicts a ‘virtual environment’ (commonly referred to as ‘virtual reality’). Such displays present the operator with either a true three-dimensional image of a space and objects (if the display is ‘immersive’), or a two-dimensional representation of a three-dimensional space and objects. The effectiveness of virtual and other representational displays is in portraying relationships between objects. The most significant aspects of the relationship and the important design implications are described below.

10.5 Schematic and symbolic respresentations.

10.5.1 Representational displays are most effective when they are kept simple, partly because of the variety and relative unpredictability of search methods used to perceived visual information in complex displays. Simplification also means the real-world information is reduced in some way - usually some detail is lost and hence the operator has less information to process (eg maps do not present every leaf on every tree, they merely indicate the wooded area). One of the most important aspects in designing effective representational displays is ensuring the information is task-relative ie reducing the information to its critical elements whilst still providing adequate detail to complete the task. The reduction in the level of detail means that the display becomes symbolic or schematic (see clause **12** for guidance on symbol design).

10.5.2 The adequacy of the information depends on the task. For example, if the purpose of the display is to provide route guidance, then some contextual information (eg landmarks) and information regarding the operator’s orientation may be required. If, however, the purpose is to show the movements of naval vessels in an area, information regarding the orientation of each vessel relative to the others is more important, whereas depicting individual waves is unnecessary. the task information should dictate how pictorial or abstract that representation should be. For example, the difference in appearance between enemy and friendly aircraft can be too subtle to discriminate quickly and accurately, and hence an abstract, symbolic representation using different geometric shapes may be the best method. Schematic wiring diagrams are useful for understanding the connections between electrical components but do not give reliable information about their relative positions (eg distances apart, etc). Where such information is required a less abstract, more pictorial representation should be used.

10.6 Orientation

10.6.1 The relative orientation of the real objects represented in the display, with respect to each other and to the operator, should always be clear. Studies have shown various affects on operator’s perception of the vertical plane with respect to the ground. For example, accurate perception of orientation is affected by head tilt, both sideways and backwards (related to the position of sensors in the inner ear), body tilt, displacement of gravitational force (eg in a steeply banking aircraft), and upon abrupt cessation of head or body rotation (eg when tracking an airborne target from the ground). Therefore, representational displays should normally present an orientation reference, either to the vertical, or to a horizontal direction (eg ‘magnetic North’ or ‘straight ahead’) . The effectiveness of displays designed specifically to aid orientation (such as a pitch ladder or an artificial horizon) relies on understanding of what is fixed relative to the operator, eg the aircraft or the ground.

10.6.2 Depicting orientation of objects relative to each other can be more difficult since details of the nature (or behaviour) of each object need to be displayed and identified by the operator, eg front and back, top and bottom, direction of motion, size, etc. The front (bow) of a ship, for example, may be represented symbolically with an apex.

10.7 Scale

10.7.1 There is a trade-off within a given display size between providing sufficient detail to recognise or identify objects and providing sufficient coverage to display all the objects in an area. A large scale can show more detail for each object but present fewer of them, potentially presenting a misleading representation of the situation ie the operator may not have the ‘full picture’. Conversely, a small scale allows presentation of many objects but in less detail, making recognition and identification of each object difficult. Where possible, the operator should be able to adjust the overall scale.

10.7.2 There is also a scale trade-off between the size of displayed objects (relative to each other and to the background environment) versus the accuracy and precision of the display. For objects to be easily discriminated, they may have to be presented larger than their true relative size (eg relatively large symbols for buildings in remote areas on maps, vs built-up areas where only boundaries are indicated). This should always be made clear, otherwise the operator may assume a false relationship, eg that one object is larger or nearer than another.

10.8 Two-dimensional representation of depth

10.8.1 Some displays require two-dimensional representation of three-dimensional images. An important mechanism for depth perception is binocular vision, where combining the two slightly different views received at each eye is used as a perceptual cue. Unless using a binocular immersive display that presents a laterally disparate image to each eye, two-dimensional displays cannot exploit this cue. There are, nonetheless, a number of static and dynamic monocular cues which can be used:

10.8.1.1 Static cues:

(a) Overlaid objects. Partially obscuring one object with another gives a powerful impression of depth. This is particularly significant where the overlaid object interrupts the contours of another object because it becomes clear which object is the ‘figure’ and which is the ‘ground’, so reducing the possibility of visual illusion.

(b) Texture graduation. By graduating the density of texture an effective visual gradient can be established that makes objects appear to have depth.

(c) Linear perspective. Using lines that converge towards a point creates a depth impression (like railway lines) because as a consistent width between parallel lines is viewed from farther away it subtends a smaller visual angle at the eye.

(d) Shadow. Using shading can give objects apparent depth, highlighted areas appear nearer than shaded areas.

(e) Detail resolution. The operator’s visual acuity limits the ability to resolve details on distant objects, thus, the designer can remove details from objects intended to appear distant.

(f) Familiarity with relative size. The operator’s knowledge of the size of familiar objects (especially those which are quite small) means that, if they occupy a large area, they can be perceived as near.

(g) Luminance variations. An object of higher luminance than another can appear closer than the other.

(h) Chromostereopsis. Spectrally extreme colours (eg blue and red) appear at different depths, but which appears in front of the other depends on pupil size, hence this cue does not produce constant affects if there is variation in luminance and illumination.

(j) Atmospheric attention. During daylight the colour of objects are paler and shift towards the “blue” end of the visible spectrum the further they are from the observer.

10.8.1.2 Dynamic cues:

(a) Motion parallax. When an operator moves, objects farther than the point of fixation move in the same direction as the operator, whereas nearer objects move in the opposite direction. The speed of the movement also increases with the distance from the fixation point. Incorporating these two effects into displays depicting a moving viewpoint provides a depth cue.

(b) Changes in perspective. The change in perspective when moving past an object is less for distant objects. Changing the perspective less in objects intended to appear distant produces a depth effect.

10.9 Metaphorical representations

10.9.1 The use of design metaphors can help operators understand displayed information by relating the information to a familiar concept. For example, much research effort has been invested in presenting information

10.9.1 (Contd)

to military pilots concerning safe flight routes (both to avoid physical obstacles and strategic threats). The resultant displays present a 'flight corridor', within which pilots should fly to stay safe. The flight corridor is essentially a metaphorical representation of a 'real world' corridor, insofar as its appearance resembles a real corridor (usually two walls, ceiling and floor or tunnel-like, depicted by a series of rectangles or ellipses) and the display responds in such a way that flying 'through' it gives the impression of traveling along a corridor (the rectangles become larger as if the aircraft is moving through them).

10.9.2 Metaphorical representations are not merely forms of visual cue, they also allow the designer to exploit operators' conceptualizations of how things work. In other words, metaphors can cause assumption about the behaviour of the displayed information, and it is for this reason that they should be used with extreme caution. All the while the metaphor accurately represents the 'real-world referent', it can provide a powerful conceptual 'short-cut', which facilitates rapid interpretation of the displayed information and aids the learning process. However, metaphors rarely 'map' completely from one domain to another ie the information portrayed in the display and the referent almost invariably differ in some respect. If the limitations of the metaphor as applied to the design are not clear to the operator, he/she may have a false assumption about the displayed information. For example, if a pilot perceives the flight corridor as if it were tunnel-like he/she may consequently formulate the potentially false impression that the hazards are predominantly above the flight path (since most tunnels allow people travel under obstacles).

10.10 Representational displays: design checklist

(a) Keep it simple.

(b) Provide only task-relevant information.

(c) Base the level of abstraction on the representativeness required for the operator's tasks.

(d) Consider symbols where pictograms would be too similar (see clause **12** Symbols).

(e) Provide 'global' and local orientation references (eg '↑ North', '↑ Forward', '↑ This way up').

(f) Provide object-specific orientation cues (eg sloped wings on aircraft symbol ✈).

(g) Use scale appropriate to the task - larger scale for more detail, smaller scale for greater coverage.

(h) Where possible, provide a facility for the operator to adjust scale.

(j) Indicate where schematic representations are not to scale.

(k) Indicate where objects differ in scale.

(l) Use monocular depth cures where appropriate.

11 Coding

Alphanumeric or graphical 'short forms' used to represent information can be effective in reducing clutter where there are space limitations (eg symbols on maps). By reducing the information, codes can also speed user response times, provided that the mental translation from code to information is simple (eg traffic signs).

The correct interpretation of codes depends on the context in which they re used. For example, a cross within a circle, , denotes an overcast state as a meteorological reference, whereas in military maps it indicates the presence of a medical unit. Wherever possible, codes should exploit and follow conventions with which the operators may be familiar both in the operational context and elsewhere. A means of reinforcing coding is to use redundancy whereby more than one coding technique is used to distinguish the coded information, eg by adding colour to symbols. This can provide beneficial reinforcement of a conceptual distinction provided it does not clash with or contradict other coding. Guidance on colour coding is given in **11.4** and Def Stan 00-25 (Part 6). If a type of coding is used for alerting the operator (eg flashing) it should not be used for any other purpose - in any of the displays that form the operators workstation.

11.1 Alphanumeric codes

General guidance on the use of text is given in clause **13.** All alphanumeric codes should be designed for the least skilled operator and should be both visually and auditorily distinct. Codes are more meaningful if clear associations exist between coded information and the intended meaning, such as the use of mnemonics. Special attention should be paid to existing conventions and specific terminology (eg common three-letter-abbreviations, or 'TLAs'). Codes should be applied consistently to all instances of the displayed information. Nonetheless the coding need not be arbitrarily applied to all information in a conceptual set. Priority should be given to preserving the meaningfulness and clarity of the information, by reducing the need for, and degree of translation required, to understand the code. For example, where the design has limited space (eg on a soft-key), no benefit is derived if, in pursuit of consistency with codes for other (longer) words, **'Fuel'** is abbreviated to **'FL'.**

Alphabetic codes are easier to learn and recall than numeric codes and should be used in preference unless the task requires rapid simple transfer of the displayed code (eg repeating a grid reference) , or entering codes into a system, in which case numeric codes may be easier for the user to reproduce and require simpler input devices (less keys, simpler display, etc). Alphabetic codes can represent more unique values in a given number of digits than numeric codes. Combining letters and numerals has the advantage of allowing shorter codes, than is possible with either single system, because the number of unique values per digit is extended (from 10 to 36). However, care should be taken to avoid use of frequently used pairs, eg S&5, 1&1, O&0, Z&2 (see clause **13).** Unless the code may need to be transferred (eg input into a flight system), codes combining letters and numerals should contain appropriate spaces between groups of letters or numerals rather than any other delimiting character, for example, use; 'VIN 50 NK 008 772' instead of 'VIN50-KN00-8772'.

11.1.1 Abbreviation and truncation. Abbreviations should be as short as possible (maximum 6 letters) whilst remaining unique. Truncation may be used as an alternative but methods of coding should not be mixed within a display ie do not use a combination of abbreviation and truncation for different items of information within a display.

A common method for developing abbreviations for military aircraft displays is to first eliminate all vowels from the word to be abbreviated, then remove one of any adjacent pair of identical letters. This will result in the word being shortened. If further abbreviation is required, eg to enable presentation on a 4-character ‘soft-key’, then an operator trial to test comprehension of the proposed abbreviation should be conducted.

In many application areas, such as in the cockpit environment, glossaries of commonly used abbreviations exist (eg STANAG 3647), however these are often aircraft-dependent. Great care should be taken when defining abbreviations that differ to those already known by the target audience, eg pilots, to ensure there is minimum potential for misunderstanding when transferring between aircraft.

11.1.2 Character highlighting. The use of intensity (bright characters), stroke width (bold characters) or underlining characters as a means of coding for text should be limited to applications that only require discriminations between 2 categories of displayed information. Using alternative typefaces or slanting the text (italics) should be avoided since the effect varies depending on the characters to which it is applied.

11.2 Graphical coding. Coding using different sizes and pattern shapes is useful for applications that require language independence and fast discrimination of information (see clause **11).** The disadvantage is that the meaning of the coding requires explanation and may require learning.

11.2.1 Size. The maximum number of discernible size code levels for efficient interpretation should be three, though two levels are preferred for easier discrimination. Size is best used where the overall density of information is low. The proportional size of larger levels in the code should be a minimum of 1.5 times the size of the level below.

11.2.2 Pattern shape. The maximum number of discernible levels for lines (eg dashed, dotted, bold) should be eight, though six is preferred. For the purposes of maximum discrimination, symbols should be designed for maximum dissimilarity, eg geometric shapes used in advanced radar displays where O and ♦, respectively, indicate friendly and hostile responses following interrogation (see clause **12).** Symbolic pictograms are usually easier to comprehend than abstract shapes provided they have conceptually simple referents (see **10.4).**

11.3 Flash coding. Flashing or blinking is effective to draw attention to information if used sparingly (see **10.3).** Since coded information must still be recognized and understood, flashing characteristics are not necessarily the same as those for attentional directors (see **10.3).** Performance is best if flash coding has only 2 levels, steady state and flashing, though up to four levels can be reliably distinguished if the information is displayed near the centre of the visual field. The flash rate should be between 1 and 3 Hz (l-5 Hz for FPDs), with a 50% duty cycle. Text should flash at a maximum of 2 Hz and should have minimum duty cycle

11.3 (Contd)

of 70% for ease of reading. In all cases it should be possible to switch off flash coding, and where possible, all flashing displays should be synchronized so as to avoid stroboscopic apparent motion (see **10.3.3).**

11.4 Colour coding. Guidance on displayed colours is given in clause **18.** Guidance of perception of colour is given in Def Stan 00-25 (Part 6). Colour may be used as a form of redundant coding, but its benefit is highly situation-specific. Redundant colour coding can significantly reduce search times, both for location and counting of displayed objects, especially if combined with shape or alphanumerics. In such tasks, the benefit increases with the density of the information (clutter). Little benefit is gained in monitoring tasks or where the significance of information is related to the position in the visual field. Similarly, using arbitrary colours or more than 6-7 colours has been shown to reduce performance, especially in computer displays. When selecting colours, functional meaning must always take priority over aesthetics. The significance of the colour should be clear and unambiguous to the operators. Where relevant, the conventions in table 3 should be observed.

Table 3

Common Associations for Colours

COLOUR	GENERAL CONVENTIONS	OTHER ASSOCIATIONS	TASK-SPECIFIC ASSOCIATIONS EG TACTICAL MAP DISPLAYS
Red	danger emergency failure	stop no go fire/hot	enemy/hostile
Blue	mandatory	water/sky off cold	friendly
Green	safe condition, proceed	safe passage, exit healthy	human made obstacle
Yellow	caution	ambient delay warm	NBC events
White	operational	pure cold new	none

Where the above conventions cannot be applied (eg in dark adapted conditions, or use of Night Vision Goggles - NVGs) trials should be conducted to ensure the operators are able to understand what the colours mean.

11.4.1 Colour coding: design checklist

(a) Use colour as a redundant form of coding only.

(b) Design for monochrome first.

(c) Observe task-specific conventions and be aware of other associations.

(d) Use colour *either* to help:

(i) locate;

(ii) classify;

(iii) associate; or

(iv) highlight importance.

(e) Do not use colour coding in the periphery of the visual field.

(f) Do not use saturated adjacent reds and blues.

(g) Do not use saturated blue for fine detail.

(h) Where identification or recognition of colours is required use a dark or dim background.

(j) Refer to Def Stan 00-25 (Part 6).

12 Symbols

Symbols can be useful in transmitting information quickly. In practical terms symbols can occupy less space than text messages conveying the same information, but there is also perceptual justification for using symbols:

(a) The meaning of familiar objects is perceived quicker from a symbol than from printed words, especially if the concept includes a negative (eg No smoking).

(b) Symbols can generally be understood irrespective of language, although accurate perception is not always culturally independent.

(c) Using symbols can also avoid the need for complex or highly specific vocabulary and grammar (eg NATO Standard Map Marking Symbology).

(d) Conversely, symbols can be used to generalize the meaning of information (eg ticks ✓ and crosses **x).**

(e) Symbols can add information to increase differentiation between similar visual structures that would otherwise be difficult to discriminate (eg adding dashes to differentiate canals, and rivers in maps).

A basic issue in designing or selecting symbols is how abstract or concrete - ie pictorial - to make the symbol. In this respect, it is useful to distinguish three types of symbol:

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(i) Representational; fairly accurate, simplified pictograms, silhouettes or outlines of familiar objects, eg  for tank.

(ii) Abstract; symbols that reduce the essential elements of a message to graphic terms, retaining only faint resemblance to the original concept, eg using a schematic representation of a propeller to indicate an Air Force  Unit.

(iii) Arbitrary; invented symbols (often geometric shapes) that have arbitrarily assigned associations, eg ♦ to indicate a hostile aircraft.

12.1 Symbols: design checklist

12.1.1 Consider the visual context:

(a) the size and contrast of the symbols

- large values help discrimination and identification;

(b) the viewing conditions, eg high ambient illumination may reduce contrast;

(c) the amount of other visual information that may be distracting;

(d) the consequences of the symbol being unnoticed.

12.1.2 Consider the task context:

(a) the overall goal, eg requirement for accuracy vs speed;

(b) the specific visual task;

(i) search requires distinctive symbols;

(ii) recognition requires discriminable symbols;

(iii) identification requires meaningful symbols;

(c) whether interpretation or naming of the symbol are necessary - it may be appropriate to add text to the symbol to alter the meaning or simply to use text instead;

(d) whether presentation of the symbol is predictable by the operator - highly predictable symbols are recognized more quickly but with more identification errors;

(e) the number and similarity of symbols within the set - a small number of highly distinctive symbols within a related set produces fewest errors;

(f) the number of identical symbols displayed simultaneously - the more symbols, the harder the search task;

12.1.2 (Contd)

(g) whether the symbols are moving - speed, size and graphical form influence the probability of detection;

(h) the consequences of misinterpretation.

12.1.3 Consider the target audience

(a) the operator's level of training, eg learning the symbol set

(b) operator's level of familiarity with the graphical form (eg specific thermal signatures of various tanks);

(c) cultural associations (eg interpretation by operators from hot climates of a snow hazard warning symbol may be unreliable).

12.1.4 Consider the purpose of the symbol

(a) Is the referent an object, system, function, or state?

- (i) Concrete objects are most suitable for pictorial representations.
- (ii) Systems may involve conceptual groups of related objects and are therefore more difficult to represent.
- (iii) Functions and states are abstract and often require additional text.

(b) Does the symbol require portrayal of negative or restrictive concepts?

- (i) Graphical representation of concepts can unintentionally reinforce the concept if the negative or restrictive indicator is not clear (eg speed limit signs do not indicate whether the driver must keep below, above or exactly at the speed shown).

12.1.5 Design new symbols according to the following general principles:

(a) Involve operators in the design - especially at the early conceptual stage - eg ask representative operators to draw suitable symbols).

(b) Keep the design as simple as possible.

(c) Use solid shapes in preference to lines.

(d) Use a closed figure, as it will often be easier to understand unless there is reason for the outline to be discontinuous.

(e) Incorporate all parts of the symbol within a single boundary.

(f) Use standard symbols where possible (see **12.2).**

(g) Test new symbols with operator trials (see **7.3** and **12.3).**

12.2 Existing standards and conversations. Many civilian standards and conventions exist concerning the design of symbols for different domains, such as ISO 2575 for displays in road vehicles and ISO 7000 for symbols for use on general equipment. Similarly, specific standards already exist for symbols (and text) used in signs where consistency and clarity of presentation is vital to understanding, eg BS 5499-1 and BS 5378-1 for safety signs. Standards are also in preparation for symbols or 'icons' used to represent control actions in software GUIs (see **14.3** and Def Stan 00-25 (Part 13)). The designer should follow these standards where applicable but also be aware of contradictory information that may be specific to military applications or between forces.

12.2.1 Symbols for maps and charts. Within NATO, a substantial degree of standardization has been achieved and agreements relating to maps and charts have been ratified by the United Kingdom. Any agency concerned with the design of maps and charts or of equipment which utilises maps and charts should first consult the Hydrographer of the Navy on Admiralty chart requirements or the Director of Military Survey on Land and Air map, chart and data requirements. Other symbol sets are prescribed in specific publications, eg Staff Officers Handbook.

12.2.2 Signs. The following conventions outlined in BS 5378 Part 1 ‘Safety Signs and Colours’ should be followed where applicable such that the format of signs corresponds with the examples below:

Mandatory	as page 22 of current Part 7
Prohibition	as page 22 of current Part 7
Warning	as page 22 of current Part 7
Safe Condition	as page 22 of current Part 7
Fire related	as page 22 of current Part 7

12.3 Evaluating symbol meaning

12.3.1 To ensure symbols clearly represent what they are supposed to represent they should be evaluated experimentally. Several test methods exist, eg ISO 9186 Procedures for the development and testing of public information Symbols, Geneva ISO. Such methods typically incorporate three types of trial.

(a) ‘Naming tests’, in which operators are presented with symbols and must describe their interpretation of the meanings, often within a specified number of words.

(b) ‘Matching tests’, which operators must match a list of symbols to a list of meanings.

(c) ‘Ranked matching tests’, in which operators must rank several alternative symbols for each listed meaning.

12.3.2 Particular significance should be given to the results of the naming test if the symbols are used for status indicators and warnings. The results of the matching tests are more useful for search tasks, for assigning symbols to controls. Though less methodological guidelines exist, tests should also be carried out for ease of learning, familiarity and physical discrimination.

13 Use of Text

Although pictograms and symbols can provide useful perceptual short cuts (see **10.4** and clause **12),** text can often out-perform graphical presentation of information, especially if information has to be named. Guidance on the physical form of characters is given in section four. The following sub-clauses provide guidance on the effects of meaning and format of text on comprehension.

13.1 Semantics. The meaning of words not only affects correct comprehension, but also the speed of reading. Performance is influenced by: the type of material read; the number of propositions within the statement; and how the information is used (eg read for later recall takes longer than straightforward comprehension). The designer should use the principles described below to optimize reading performance.

13.1.1 Accurate, fast comprehension: design checklist

13.1.1.1 Style:

(a) Use short expressions.

(b) Use active expressions, eg ‘the target passed interrogation’ rather than ‘interrogation was passed by the target’.

(c) Avoid statements for which the meaning hinges on punctuation. For example, ‘the ship, changing course, took evasive action’ (with appropriate commas) means ‘the ship took evasive action by changing course’ whereas ‘the ship changing course took evasive action’ (without commas) means ‘the ship that was already changing course took-evasive action’.

(d) Avoid informal or humorous expressions, eg ‘best shot’ meaning ‘best chance’.

13.1.1.2 Order:

(a) Ensure the meaning is presented early in a sentence.

(b) Where a statement describes a sequence of events, order the words to correspond with the sequence (eg for instructions requiring sequential actions).

(c) Use consistent ordering for noun verb pairs, eg ‘target tracking’ vs ‘tracking target’.

(d) Use relative pronouns to introduce phrases, eg ‘which’, ‘that’, etc.

(e) Use short text (preferably single words) for rapid serial visual presentation (also use a fixed location and present fewer than 10 words per second).

13.1.1.3 Negatives:

(a) Avoid negative statements, eg ‘This is not an infra-red display’.

(b) Avoid multiple negatives, eg ‘Non-thermal images are invisible’.

13.1.1.3 (Contd)

(c) Avoid qualifying negatives, eg ‘except’.

(d) Avoid nested clauses, eg ‘the target that the aircraft from the ship acquired took evasive action’.

13.1.1.4 Modifiers:

(a) Use noun modifiers rather than successive subordinate clauses, eg ‘moving tank’ rather than ‘tank which is moving’.

(b) Avoid vague modifiers, eg ‘many’.

(c) Avoid weak modifiers, eg ‘quite’, ‘rather’, ‘well-’, ‘fairly’, etc.

(d) Avoid redundant modifiers, eg ‘sufficient enough’.

(e) Avoid contradictory modifiers, eg ‘quite extreme’.

13.1.1.5 Confusions:

(a) Avoid phonetic confusions, eg ‘there’ vs ‘their’.

(b) Avoid common semantic confusions, eg ‘continually’ vs ‘continuously’.

(c) Avoid phonetic and semantic confusions, eg ‘fire’ (flames) vs ‘fire’ (launch).

13.2 Format. Aspects of the format of text can influence comprehension, including the character typeface, use of typographical cueing, text alignment and grouping.

13.2.1 Character typeface. Under ideal reading conditions (suitable physical conditions, no time pressure, etc) typeface has little effect on the accuracy of text perception. Where fast reading under adverse conditions is required however, most sources favour simple ‘gothic’ typefaces without serifs, such as Arial, Helvetica, Sans Serif, etc. The characteristics that make such typefaces easier to read are not entirely clear but opinion is agreed that desirable properties include appropriate height-to-width and strike width-to-height ratios (see **16.2** and **16.3),** a basic vertical orientation, and the absence of detail that is extraneous to the unique geometric shape of characters, eg serifs.

13.2.2 Typographical cueing

13.2.2.1 Typographical cues can be used to differentiate specific text. Some common methods are listed below which either alter the geometric shape of characters or use additional characters to draw attention to the text.

13.2.2.2 Bold characters. Increasing the stroke width-to-height ratio can impede easy reading where characters are small and can be missed in low contrast presentations or where large characters are used.

13.2.2.3 *Italic/slanted* characters. Slanting characters are commonly used for phonetic emphasis but can make them more difficult to read, especially if the typeface has serifs.

13.2.2.4 Change of polarity. This is highly effective but can alter the perceived clarity of the displayed image (see clause **17** and **18.1.2).**

13.2.2.5 Indented text. This is most effective for blocks of text but has the disadvantage that it relies upon a relatively large area of non-indented text.

13.2.2.6 Underlining characters. This often has the disadvantage of obscuring lowercase descenders (eg ' gpjy ').

13.2.2.7 Separators, eg using - dashes - or blank spaces around text. Dashes can be confused with hyphens and minus symbols and spaces may not be obvious, especially in text that is both right and left aligned.

13.2.3 Case. Text with a conventional mix of upper and lowercase characters is about 13% quicker to read than text that is all uppercase. Several reasons account for this, including the semantic associations with uppercase (beginning a sentence, proper noun, etc), recognition of the shape of words and the grater geometric differentiation of lowercase letters (eg ‘FE’ vs ‘fe’, ‘BR’ vs ‘br’).

13.2.4 Alignment

13.2.4.1 Sometimes referred to as ‘justification’, alignment of text and numbers can influence its readability, especially in lists. Aligning text to the left produces a ragged appearance at the right-hand edge of text blocks which provides a visual cue for the end of each line, thought to enhance readability. On this basis, right-alignment should therefore enhance performance further, since it is moving from the end of a line to the beginning of the next that involves the largest eye movement, and hence the greatest scope for error. However, there is no demonstrable evidence for this.

13.2.4.2 The more profound effect appears to be provision of consistent inter-word spacing that is possible with left- or right-aligned text. The optimum proportional dimensions that yield best performance have not been well established, but many sources recommend gaps of at least one character space.

13.2.4.3 The resolution of many media displaying generated or printed text is not sufficiently fine to space right- and left-aligned text without producing large gap variations, or requiring hyphens which make word recognition more difficult. Notwithstanding the disadvantages, aligning text on both sides can produce a stronger visual cue for column boundaries or blocks of text where grouping is necessary.

13.2.5 Grouping

13.2.5.1 When reading, the eye moves and fixates upon information in succession. The important issue for the designer is the amount of text from which useful information can be obtained by each fixation. The perceptual span around the point of fixation is generally skewed to the right (at least for readers of English). That is, the first three to four letters of a word can be perceived to the left and up to about 15 letters from the same or successive words can be perceived to the right. This

13.2.5.1 (Contd)

effect is influenced by the context in which the words are presented and there is evidence to suggest that the total perceptual span for word recognition is larger (for example, visually similar or highly predictable words are more readily perceived).

13.2.5.2 For the designer this means keeping lines and paragraphs or text blocks short is likely to enhance reading performance. This should be balanced with providing sufficient context and preserving semantic associations, using the following guidelines:

(a) Group information according to a logical and recognizable order, eg:

(i) alphabetical, chronological, numerical, or;

(ii) by importance, functional groups, frequency *or* sequence of use (see clause **14).**

(b) Separate semantic groups (eg paragraphs, lists, tabular data) with a blank line above and below and at least four character widths to the left and right (three if the text is left- and right-aligned).

13.2.6 Text format: design checklist

(a) Use a ‘plain’ typeface that has a vertical orientation with geometric proportions matching those described in **16.2,** and without serifs.

(b) Use typographical cueing sparingly and avoid:

(i) compromising appropriate stroke width-height ratios for bold text;

(ii) slanting characters;

(iii) indenting more than three adjacent text blocks or text block shorter than three lines;

(iv) underlining lowercase text;

(v) confusing separators (eg dash ´ - ´ and minus symbol’-’).

(c) Use the conventional mix of upper and lowercase characters for all words other than acronyms and mnemonics.

(d) Provide consistent inter-word spacing (see **16.2),** with double spaces at the end of sentences.

(e) Left-align text blocks unless discrimination of text columns is critical, in which case use left-aligned text or text that is both left- and right-aligned.

(f) Right-align table headings for columns containing numerical information.

13.2.6 (Contd)

(g) Right-align numerical lists not containing decimals.

(h) Align the decimal points in numerical lists containing decimals and always provide a leading zero before the decimal point for decimal fractions.

(j) Provide consistent inter-line spacing (see **16.2)**, with at least one blank line between text blocks.

(k) Separate columns by at least 4 character widths to the left and right if the text is left- or right-aligned or by three character widths if the text is left- and right-aligned.

(l) Observe standard formats, eg time format should be: ddhhmmZMMMyy, where dd is the calendar day, hh = hour (24 hour notation) , mm = minutes past the hour, Z is the reference time zone (Z = Greenwich Mean Time, A = local time, B = British summer Time), MMM is the month and yy is the year, eg '271330ZOCT86' denotes 1.30 pm GMT on October 27 1986.

(m) See also **11.1** for guidance on Alphanumeric codes.

14 Display Integaration and Grouping

14.1 Displays are rarely used in isolation and hence designing appropriate layouts for groups of displays can be as important as the design of each display. Furthermore, there may be grounds for combining more than one display or even integrating the information from several displays into one, if it would aid interpretation of the information. In designing layout and grouping, the following principles should be taken into consideration:

14.1.1 Design to support task requirements

14.1.1.1 Although it appears to be an obvious requirement, many performance failures arise as a result of well-designed displays being poorly positioned, inhibiting easy reading at the appropriate time. The designer should consider the context of use, in particular the:

(a) *importance* of the displayed information, both in terms of the overall objective and relative to other displays;

(b) *sequence* in which information may be required during normal operation and under adverse conditions; and

(c) *frequency* with which the information should, and can, be viewed.

14.1.1.2 Clearly, critically *important* information should be displayed close to the operator's 'normal' line of sight (see clause **15)**, eg altitude information on a head-up display. Similarly, *frequently used* displays should also be positioned such that they do not require gross movement of the head or eyes, especially if viewing them forces the operator to shift attention from the primary task. Where explicit or implicit task sequences

14.1.1.2 (Contd)

exist, information should be presented left-to-right and top-to-bottom or in clockwise rotation. Even if there is no overall sequence involving all the information displayed at the workstation, it may be appropriate to organize the displays into sub-groups.

14.1.1.3 Grouping the display according to the task requirements should be based on either:

(a) **Sub-task sequence**, eg start-up checks;

(b) **Functional classification**, eg all displays associated with weapon systems;

(c) **Semantic classification**, eg all displays showing alarm and warning information; or

(d) **Control-display relationships**, eg display of heading setting adjacent to the heading setting control. (Displays associated with controls should normally be placed above the control. For controls at approximately shoulder height, it may be best to position associated displays to the side - ie on the right side of controls operated by the left hand, or the left side of controls operated by the right hand to avoid obstructing line of sight to the display. In all cases, consistency and unobstructed sightlines should be given a priority.)

14.1.1.4 The designer should ensure delineation between groups is clear. This can be achieved using principles derived from Gestalt psychological theory, whereby information is thought to be mentally organized according to characteristics of its proximity and similarity. Hence, displays are typically grouped using appropriate spacing and boundaries - ie by proximity (see figure 6(a)). Where physical design constraints make this difficult, displays could be grouped using redundant coding, eg colour or some other common feature - ie by similarity (see figure 6(b)).

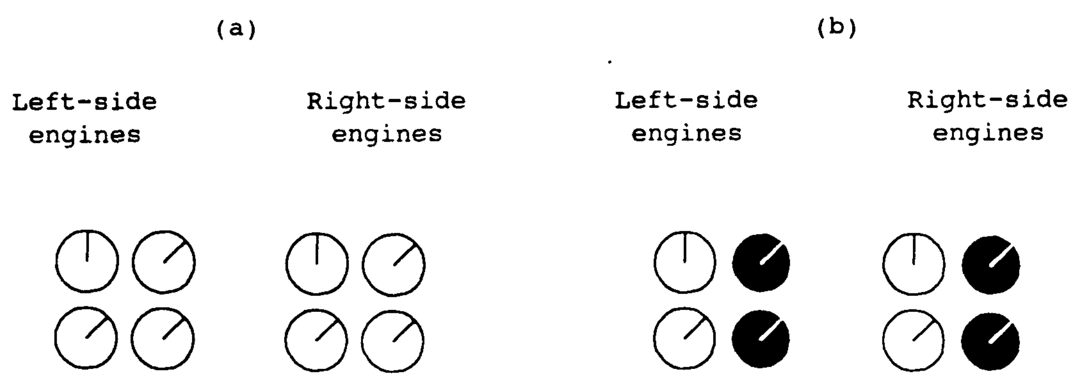

Fig 6 Examples of Display Grouping Using Human Factors Principles of Proximity and Similarity

14.1.1.4 (Contd)

NOTE: (a) shows displays related to the left engines separated from those for the left engines using appropriate spacing. (b) shows how displays can be grouped by similar features (here shade).

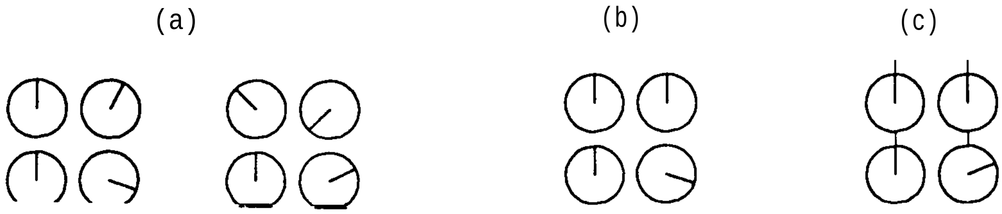

Fig 7 Examples of Display Arrangement Using Human Factors Principles of Continuation and Closure to Facilitate Check-reading

NOTE: In all cases the bottom right display of each group of four shows an abnormal value. (a) shows displays unaligned. (b) shows displays with the normal positions aligned upwards (continuity). (c) shows aligned normal positions plus supporting lines for each normal pointer position (closure).

14.1.2 Integating information. To support the operator's task requirements there may be benefit in combining information from one or more sources and presenting it in one display. Such combinations typically involve presenting one source as a function of another (temporal) source. For example, graphically presenting information about a deep-sea diver's depth against time could assist in a decision about time required for decompression. Similarly, it may be possible to integrate information about contours and enemy activity for displaying a safe flight corridor to fast jet pilots. When displaying combined information the following principles should be observed:

(a) Information should only be integrated if it supports the operators tasks directly.

(b) Information should be integrated to minimize mental workload (see **14.2)**.

(c) Where possible, the operator should have access to the constituent sources individually.

(d) Presentation of the integrated information should be unambiguous.

(e) Integrated information should not require or provoke unreliable extrapolation.

(f) Interpretation of integrated information should not require complex mental operations.

14.2 Mental workload

14.2.1 The ability to perceive information from displays as the designer intends, relies on taking account of the mental state of the operator. In order to undertake correct actions the operator must have an accurate situational awareness. This awareness is strongly influenced by the

14.2.1 (Contd)

information presented in visual displays and by the operator's level of mental workload when the displays are viewed. ISO 10075 gives guidance on design to avoid excess workload and is summarised below.

14.2.2 Mental workload can be minimized as follows:

(a) Provide unambiguous information:

(i) reduce the need for interpretation by providing adequate information;

(ii) suppress information (or detail) that is not task-relevant.

(b) Avoid reliance on long-term memory:

(i) reinforce task goals;

(ii) provide meaningful cues.

(c) Avoid forcing absolute judgments:

(i) provide a reference where possible so that relative judgments can be made instead.

(d) Present information at appropriate rates:

(i) avoid time delays that cause anticipation;

(ii) avoid rapid sequential presentation of similar information that must be recalled later (to alleviate short-term memory load);

(iii) where possible provide information sequentially in discrete 'chunks' unless comparisons must be made;

(e) maximize discriminability:

(i) reduce visual noise;

(ii) use distinctive codes (see clause **11);**

(iii) use redundancy (according to operational requirements, to increase the saliency of categorized information.

(f) Avoid mental transformation (see **10.4):**

(i) minimize the need to translate information spatially;

(ii) minimize the need to integrate information mentally;

(iii) minimize the number of dimensions upon which the information is based.

14.2.2 (Contd)

(g) Maximize compatibility with 'natural' user expectations (see clause **14):**

(i) ensure control-display relationships are consistent (see **14.1);**

(ii) exploit stereotypes (eg clock face see **9.4.1** and **9.7).**

14.3 Graphical user interfaces

14.3.1 Guidance on graphical user interfaces (GUIs) is given in Def Stan 00-25 (Part 13). These are essentially software display environments in which the user interacts with applications via icons and pointers. Interaction is normally facilitated by the use of the mouse or other pointing device, with which the user interacts with displayed objects on the screen. The main benefit is in allowing the use of metaphors (see **10.4)** to increase the intuitiveness of operator input by graphically representing familiar scenarios, such as 'the desktop' in office work. This input is often referred to as 'direct manipulation'. Direct manipulation GUI displays have not been widely employed infield systems, but are increasingly used in military aircraft for representation and configuration of mission variables (eg fuel distribution, selective jettison, etc).

14.4 Multi-media displays

14.4.1 There may be benefit in combining various methods of information presentation, such as words, pictures, video (and sound). Dealing with multiple sources and types of information is a common phenomenon in human interaction and therefore may be a 'natural' method of communicating information. Combining media has the advantage of aiding learning by reinforcing information in different modes. Alternatively, using different media for different tasks can theoretically allow more than one task to be carried out simultaneously. However, the combination also introduces complexity and can make the cognitive task (of processing the information) more difficult, especially where displays combine more than one visual presentation medium.

14.5 Multi-media: design checklist

(a) Tasks can be easier to carry out if more than one display medium is provided.

(b) Different tasks can be easier to carry out if different media are provided for each task.

(c) Use still graphics for:

(i) representing objects and highlighting features;

(ii) representing objects that do not exist;

(iii) displaying large amounts of numerical information (eg showing statistics; and

(iv) showing space and time relationships.

14.5 (Contd)

(d) Use still images for portraying detailed pictorial, or real-world information.

(e) Do not use moving images (videos) or moving graphics (animations) unless they are central to the task.

(f) Use moving graphics for showing trends, or expressing hypothetical scenarios (figures or events).

(g) Use moving images for portraying processes, actions, and descriptive information.

(h) Do not use moving images for presenting large amounts of detailed information.

(i) Allow the operator control over moving images or graphics (replay or skip sequences of information).

(j) Do not use simultaneous moving images or graphics unless they are complementary to each other and are used for the same task.

(k) Observe the principles for auditory display design given in Def Stan 00-25 (Part 8), and for the use of text in clause **13.**

Section Four. Physical Characteristics of Displays

Many physical factors influence the effectiveness of visual displays, including viewing position, the size of information, contrast, and the quality of the displayed image. This Section provides guidance on these factors, in relation to the physical design of displays. Though most principles apply to various display media, issues concerning specific media are included.

NOTE: For completeness, guidance on physical aspects of scales is included in section three.

15 Viewing Position

The optimum position for a display is governed by perceptual and physical considerations. The physical issues are related to the abilities and limitations of the visual system. The optimum position in the field of view is related to the position of the image on the retina, while the optimum viewing distance is predominantly influenced by the size of the retinal image, governed by the optics of the eye. However, other practical considerations and constraints may also affect the design position, such as anthropometric reach and clearance (see **16.2** and Def Stan 00-25 (Part 2)).

15.1 Field of view

15.1.1 Displays should be positioned according to the viewer’s normal field of view.

NOTE: The most important information may be that of the real world, and hence additional displays should be positioned so as to avoid obscuring this view.

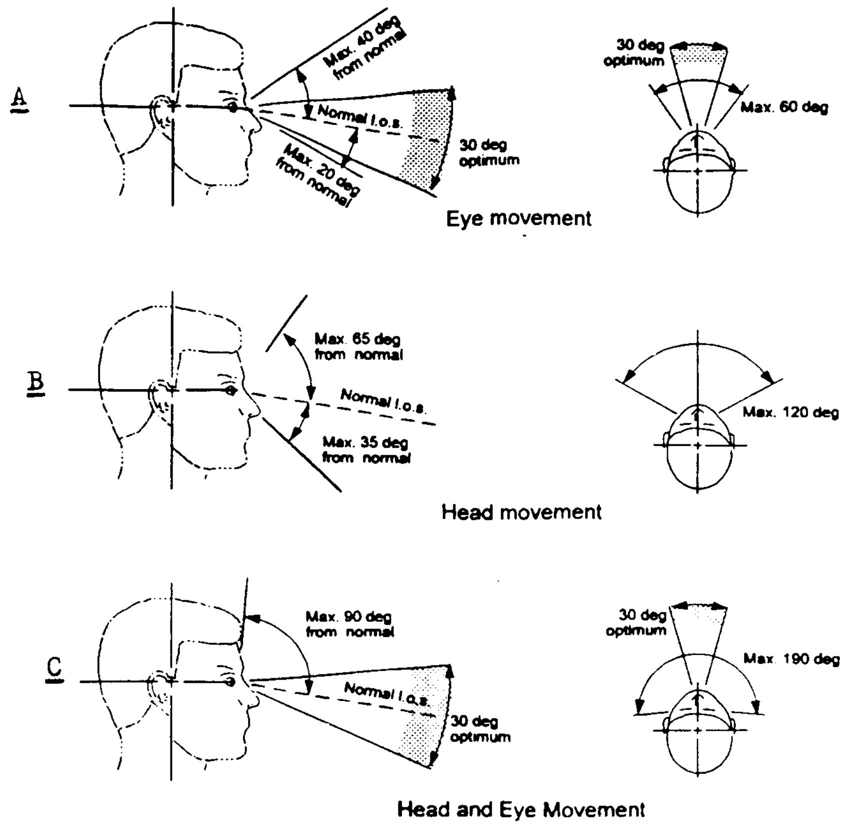

Fig 8 Optimum and Maximum Positions for Displays in the Visual Field, Allowing for Eye Movement, Head Movement and Eye and Head Movement (LOS = Line of Sight)

15.1.2 Generally, important information should be displayed in the centre of the visual field. Def Stan 00-25 (Part 6) shows that the field of view for each eye is an irregular ellipse biased towards the horizontal periphery. The preferred viewing positions for types of display information are determined by the viewer’s visual perceptual capacity with the integration of the two monocular fields of view. However, the position of the field in which displays should be positioned changes if the head and eyes move.

15.1.3 Figure 8 shows the optimum and maximum locations for displays for three operating scenarios: (A) if only eye movement is possible, (B) if only head movement is possible and, (C) if both head and eye movements are possible. Integrating these recommendations, based on visual acuity, comfort and minimal obstruction, the optimum location for displays is within the central 30° of the viewer’s binocular field of view, up to 15° below the ‘normal’ line of sight. (The normal line of sight is often referred to as between 10° and 15° below the Frankfort plane. However, recent research indicates that it may be as much as 30° below.) The designer should avoid positioning displays beyond 40° above and 20° below the viewer’s line of sight, and beyond 30° either side, depending on the viewing distance (see **15.2).**

15.1.4 the following characteristics of the displayed information, and the environmental requirements however, should also be taken into consideration:

(a) Visual fields for accurate perception of yellow and blue information are up to 25% larger (up to 60° within the horizontal field of view) than for red which is 25% larger than for green (up to 30° within the horizontal field of view).

(b) Perception of red information is about 75% slower than other information in peripheral vision.

(c) Perception of movement increases with the distance from the fovea.

(d) Peripheral vision is poor for detecting low contrast or small objects.

(e) Over-reliance on representational displays can cause psychological entrapment whereby operators neglect real world information.

(f) Clothing, optical equipment and safety devices can reduce fields of view (eg binoculars, NBC headgear, HMDs).

(g) Many types of display becomes difficult to read if their surface is more than 40° from the perpendicular of the normal line of sight (eg anisotropic LCD FPDs).

15.2 Distance

15.2.1 The optimum viewing distance depends on the apparent size of display information, usually expressed in terms of the angle it subtends at the eye, eg 3.5 mm characters need to be at about 600 mm to subtend 20 minutes of arc. The resting focal distance, sometimes referred to as ‘tonic accommodation’ varies between individuals but for many it is about 1.7 dioptres (about 590 mm), hence typical recommendations for viewing distances for CRT displays vary between 600 mm and 750 mm, depending on the size of the displayed information.

15.2.2 The following should also be taken into consideration:

(a) If controls associated with the display are adjacent to the displays, the distance should be no greater than 635 mm (well within functional reach).

(b) Visual acuity when trying to focus at infinity is best between about 5 m and 12 m away from the eye.

(c) For very close displays blue information can be focused nearer than red.

(d) The eye becomes nearsighted in dimlight (eg from twilight onwards).

(e) Other physical constraints may exist. For example, if clearance is required for ejector seats, the viewing distance may have to be at least 760 mm, in which case the size of the displayed information should be taken into account (see clause **16).**

15.2.2 (Contd)

(f) Less susceptibility to veiling reflections means many FPDs can be placed lower in the visual field and nearer to the viewer (closer to the normal reading distance of documents).

15.3 Viewing position: design checklist

(a) Place displays showing important information within 15° from the centre of the normal field of view (see figure 7).

(b) Place CRT displays at least 500-700 mm from the viewer.

(c) Displays designed for dark viewing should allow for variation in accommodation between 1 and 2.25 dioptres.

(d) Increase the contrast of information on displays in the periphery of the field of view by up to five times.

(e) Do not place displays requiring accurate colour perception beyond 30° from the centre of the normal field of view.

(f) Red should not be used for information that requires very close viewing.

(g) Place representational displays (such as primary flight displays) as close as possible to real world information, eg near the windscreen or using head-up displays.

(h) For transposed image displays (eg head-up displays 'HUDs') display information should be presented at a focal distance close to (preferably just in front of) the background information, eg 2.5 - 5 m for land vehicles, 10 - 12 m for aircraft (though background information may be much farther away, the focal distance for comfortable visual accommodation at 'infinity' tends to approximate to around this figure).

(i) Avoid designing large movements in displays of secondary importance in the periphery of the field of view.

(j) Incorporate movement into warning displays requiring attention in the periphery of the field of view.

(k) Position displays such that their surface is within 40° of the perpendicular to the viewer's normal line of sight for glass fronted displays and FPDs and within 45° for printed or mechanical displays.

16 Size of Displayed Information

The optimum size of a displayed character depends on the viewing distance, ambient illumination, the importance of the text, numerals or symbols, and the display medium (for example, objects on touch screen control-displays are restricted by the need to designate the displayed image as a control area - see Def Stan 00-25 (Part 10).

16.1 Character height. The minimum size which is recommended for reliable general readability is 16 min of arc (about 3.25 mm at a viewing distance of 700 mm), although 20 min of arc is preferred for most CRTs and FPDs (see below).

16.1.1 Printed characters

16.1.1.1 Table 4 is a general guide for printed characters assuming a luminance above 3.5 cd/m^2 and a perpendicular line of sight to the display surface.

Table 4

Character Size and Viewing Distances

VIEWING DISTANCE (m)	CHARACTER HEIGHT (mm)
> 0.5	2.3
0.5 - 1	4.7
1-2	9.4
2-4	19.0
4-8	38.0

16.1.1.2 Table 5 is a guide assuming a viewing distance of 600 mm. For any other distance multiply the values below by the desired distance, divided by 600, eg for non-critical information at 710 mm with luminance above 3.5 cd/m^2, the character height should be between $\frac{710 \times 1.25}{600}$ - $\frac{710 \times 4.25}{600}$ mm.

Table 5

Character Size and Luminance

	HEIGHT	
PURPOSE	BELOW 3.5 cd/m^2	Above 3.5 cd/m^2
Non-critical information (eg familiarization markings, routine instructions)	1.25 - 4.25 mm	1.25 - 4.25 mm
Critical information in fixed positions (eg emergency instructions, fixed scale numerals)	3.50 - 6.75 mm	2.10 - 4.25 mm
Critical information in variable positions (eg numerals on moving scales/counters)	4.25 - 86.75 mm	2.50 - 4.25 mm

16.1.2 CRT characters. Character heights from 20 to 22 mins of arc are preferred for most tasks. The minimum character height should be 16 mins of arc. Most CRT displays produce dot matrix images for which a matrix of 5 x 7 is the minimum that is required to display legible numerals or uppercase letters. For more complex lowercase letters or where accuracy is important, a 7 x 9 matrix is required (see figure 8). With dot matrix technology, it is important that the character shapes are recognisable and distinct. It is often difficult to distinguish such characters as U and V or 8 and B. If diacritics are used the matrix should be increased upwards by 2 pixels. Similarly, if lowercase letters with descenders are used (eg 'j') the matrix should be extended downwards by 2 pixels.

16.1.3 Flat Panel Display (FPD) characters. The same heights apply as for CRT display, with the following exceptions: for achromatic and monochrome FPDs the height should exceed 16 min of arc; for pseudo-monochrome and multicolour FPDs the height should exceed 20 min of arc. Character height can be expressed in terms of the number of pixels times the vertical pitch of a pixel (see figure 9).

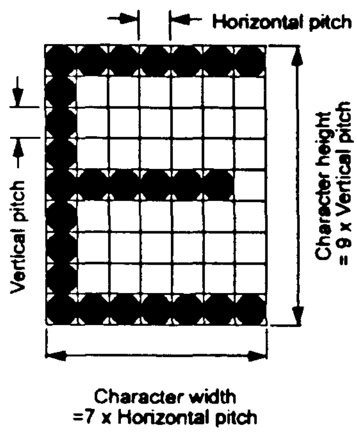

Fig 9 Height of FPD Characters

16.2 Character width and spacing. The optimum width of characters is dependent upon their height and case. For letters width-to-height ratios of 0.8:1 are appropriate (ratios up to 1:1 for capital letters may be preferred but yield little performance improvement). The ratio for numerals should be 0.6:1 plus one stroke width (see **16.3).** The exceptions are for the letters 'M' and 'W' for which a width-to-height ratio of 0.8:1 is preferred and for the letter 'I' and numeral '1' which are one stroke width (see **16.3).** The spacing between characters should be two stroke widths for most characters and a minimum of one stroke width between pairs of characters that can be proportionally spaced, eg between capitals 'A' and 'Y', 'L' and 'T', etc. The spacing between words should be at least one character width.

16.2.1 CRT characters. The width-to-height ratio for CRT characters should be between 0.7:1 and 0.9:1. The spacing between characters is also important for legibility and should be no less than one pixel between horizontal characters and between the lowest descender and the highest ascender between rows. The spacing between words should be 7 pixels for non-proportional spacing and between 4 and 7 pixels for proportional spacing.

16.2.2 The character width-to-height ratio is the width times the horizontal pixel pitch divided by the character height. The ratio should be from 0.7:1 to 0.9:1 for optimum legibility and readability (see figure 9). The same spacing as CRT characters should apply.

16.3 Character stroke width. Dark characters upon a light background (positive polarity) with a stroke width of 16-20% of the character's height yield the best performance in terms of speed and accuracy in reading. For printed positive contrast displays the ratio should be 0.125:1 - 0.1:1. However, irradiation in (lower resolution) CRT displays causes light characters to 'bleed' into dark backgrounds, hence the ratio for negative polarity (positive contrast) presentation should be 0.16:1 - 0.08:1 on emissive displays. For FPDs the stroke width to height ratio should be between 0.08:1 and 0.2:1.

16.4 Parallax

16.4.1 Moving pointer display scales should be designed where possible to avoid parallax by ensuring the pointer tip and scale markers are at the same depth. This could be achieved by recessing the centre of the display such that the surface of the outer part of the display containing the scale markers and numerals is at the same as the height of the pointer tip. Computer-generated displays incorporating touch screens also suffer from parallax.

16.4.2 Similarly, the curvature of the unit 'drums' on mechanical counters can make the printed numerals difficult to read, hence the designer should choose the typeface carefully to avoid confusion with the increased perspective at the top and bottom of each numeral (see **13.2.1).**

17 Contrast

Information displayed must have either a higher or lower luminance contrast than the background to be legible. Luminance is described in Def Stan 00-25 (Part 6). The contrast is the difference between the luminance of the target and background, expressed as a ratio (also described in Def Stan 00-25 (Part 6)) eg

$$\text{Contrast Ratio, } C_R = \frac{L_{max}}{L_{min}}$$

Where L_{max} and L_{min} luminance represent the maximum and minimum luminances in cd/m^2, respectively - ie the luminance of the target and background.

In general, high contrast in the detail of the display will improve performance. However, contrast should not be so high that it causes glare (see **17.5).** There are various methods of achieving appropriate contrast such as the use of back illumination (see clause **19).** For non-emissive

17 (Contd)

displays the contrast is determined by the differences in reflectance - the amount of incident illumination reflected from the surface of the displayed background or image. The designer should be aware that the difference in contrast also influences the perceived absolute lightness, eg a given grey square appears darker against a white background than a black background. A similar effect occurs with presentation of colours, eg white and yellow can be difficult to distinguish against a black background (see **18.1.2).**

17.1 Printed detail. Characters, pointers, scales, symbolic detail, etc should have a minimum contrast ratio of 1.5:1.

17.2 CRT displays. CRT displays should be capable of a minimum of 35 cd/m^2. Where luminance is used for coding (see **11.1.2),** this should be the lower luminance, the ratio between the higher and lower luminance should be at least 1.5:1. The minimum luminance contrast of character details should be 3:1.

17.3 FPDs. FPDs can achieve very high contrast, low luminance displays without causing glare. In all cases the peak luminance for each pixel should be at least 20 cd/m^2. The minimum contrast for monochromatic or achromatic tasks on displays with a lower luminance of 10 cd/m^2 should be 3:1. For colour difference tasks using multicolour displays or for pseudo-monochrome displays, the minimum contrast ratio should be 1.5:1.

17.4 Transposed image displays. Designers of displays transposing an image onto the ‘outside world’ (eg HUDs and transposed image HMDs) clearly cannot manipulate background luminance because of task requirements, and hence adequate contrast depends on providing sufficient image luminance for the displayed information. This is especially significant for cockpit designers, where background luminance (eg bright sky) are very high, commonly resulting in minimum specifications for peak image luminance that are as high as possible with the given technology (typically up to 17000 cd/m^2). For such displays, active adjustment of the luminance using sensors means pilots do not have to take their hands from the primary controls. The speed of response for this type of system should be governed by the task requirements. In cockpits, for example, a fast response is likely to be necessary, whereas for static command positions, the speed may have to be at a similar pace as dark adaptation.

17.5 Glare and reflections. Glare is the discomfort or impairment of vision experienced when parts of the visual field are excessively bright in relation to the background. Types of glare and their measurement are described in Def Stan 00-25 (Part 6). Direct glare can make it difficult to read displays. A reduction in visibility of the display increases with the luminance of the glare and its proximity to the line of sight. Luminescent displays may in themselves constitute a source of glare if the contrast between the display and surroundings is high (eg status indicators in a dark cockpit). Alternatively, the glare may be a reflection - either specular (mirror-like) or diffuse (veiling) - of another source, such as interior lighting, other displays, sunlight or an external event (eg fire, flare, etc).

17.5 (Contd)

Incident light in veiling reflections increases the luminance of both screen and background and hence reduces the contrast ratio of the displayed information. The effect of the veiling reflection depends on the surface of the display (see **17.5.2)** and the display technology. Back-lit LCD screens do not suffer as much as CRTs, partly because their surface is more uniform than the uneven surface of the CRT phosphor and partly because of their back-lit operation.

17.5.1 Methods for control and minimization

17.5.1.1 Although removing or minimizing the source of the reflection is the most effective method for reducing effects, this is clearly not always possible or desirable (eg for warning lights). Similarly, moving the display to avoid the reflection may also be impracticable (eg within a vehicle command position). A hood over the display often helps avoid reflection upon the display and also helps prevent the display reflecting on another surface (eg vehicle windscreen), but these are not always effective for the whole display. Using reflectance and colours at the workstation and in the immediate working environment is also important (see Def Stan 00-25 (Part 6)).

17.5.1.2 Active adaptive luminance controls are used for suppression of direct glare from displays, and for adjusting to veiling reflections upon displays (eg in cockpits). However, problems arise in the positioning and number of the sensors used to accommodate shadows upon the display area. Similarly, active glare adaptation systems for operators using NVGs suppress only the red wavelengths in the cockpit displays which can cause problems for others present in the cockpit not wearing NVGs and for discrimination of luminance coding.

17.5.1.3 Another control measure for reflected glare is to use positive polarity displays where possible, since the reflections are more noticeable on the larger dark parts of the display that negative polarity screens provide.

17.5.2 Display surface. Many mechanical, CRT and FPD displays have a glass surface. Unless etched or otherwise optically treated, flat glass display surfaces can produce clear specular reflections from incident light that occupy a large part of the display. The convex curvature on many CRT displays however means that incident light from a wider field is visible as a reflection than with a flat display. Various coatings and filters therefore may be used where reflected glare cannot be eliminated by other means. Surface treatments should be in accordance with ISO 9241 Part 7. The main types of filter that exist have certain advantages and disadvantages:

(a) Mesh filters are cheap and effective but also distort the displayed image. They are difficult to keep clean and may produce distracting 'moiré' effects if close to the screen surface.

(b) Neutral density filters simply reduce the amount of light passing through - rather like sunglasses. This reduces the reflections twice (in and out) and the displayed image once. Thus they also enhance the contrast. The problem is that they also have a reflective front surface and this itself can be a source of reflections.

17.5.2 (Contd)

(c) Polarized filters are more effective, and expensive, and eliminate reflections from the CRT surface. However, they also suffer from external surface reflections.

(c) Quarter wavelength interference filters are effective against screen reflections and surface reflections but are expensive and difficult to maintain since finger marks become highly visible.

18 Displayed Colour

18.1 Guidance on perception of colour and colour coding are given in Def Stan 00-25 (Part 6). This clause provides guidance on the physical presentation of colour in displays. When a task demands that the operator must discriminate or identify displayed colours using a CRT or FPD, the set of colours should conform to ISO 9241 (Part 8).

18.1.1 Object size. For isolated images where accurate colour identification is required, the image should subtend at least 30 mins of arc, preferably 45 reins of arc. For small objects and characters, the height should subtend at least 20 mins of arc - and the colour contrast ratio should be greater than 1:5 (see clause **17).** The use of highly saturated blue should be avoided for objects subtending less than 2 degrees.

18.1.2 Background. Achromatic backgrounds (eg black, dark grey) optimize discrimination and identification of colours on emissive displays. Adjacent spectrally extreme colours, eg red and blue, are perceived different depths (especially if highly saturated) and should therefore be avoided of reading tasks. Extremely achromatic objects can take on the appearance of the background colour, eg medium grey on red may appear cyan.

19 Electronic Display Characteristics

With the advance of display technology, the quality of the image presented by electronic displays has fundamentally improved. Though the quality will doubtless continue to improve there are intrinsic features of the display media that make them better or less well suited to certain applications. It is the intention here to provide an overview of the various electronic displays, to help the designer in selecting the most appropriate media.

The overview includes the oldest and bulkiest technology - the cathode ray tube - and proceeds to the more recent, light and flat panel structures based on liquid crystals, gas discharge and electroluminescence. Other displays based on vacuum fluorescence and field emission arrays will also be covered briefly. All displays mentioned here, apart from those based on liquid crystals, emit light and are therefore termed *active* displays. Liquid crystal devices, on the other hand, modulate ambient light - ie they are inherently non-emissive - and are therefore termed *passive* displays. A table is presented in **19.8** identifying the types of display most suitable for various application domains.

19.1 Cathode Ray Tube (CRT). The cathode ray tube (CRT) technology is almost 100 years old and is manufactured in enormous numbers, with over 100 million units produced annually world-wide. The CRT-based displays range from 0.5″ screens for the head mounted displays (HMDs) for pilots in military fighter aircraft to over 42″ screens for high definition television (HDTV) entertainment systems. CRTs with 3000 x 3000 pixels are available for Computer-aided Design (CAD) systems. CRTs employ electron emitting guns, phosphors (inorganic luminescent materials that emit visible light when energized by electrons, ultra-violet light, and other forms of energy), masks and deflection yokes. Though written-off many times, CRTs have a proven and reliable track record for numerous functions, and with ever greater optimization they will continue to be useful for many applications.

19.2 Liquid Crystal Displays (LCDs)

19.2.1 Unlike most other displays, LCDs modulate ambient light and are inherently low in power consumption. Most early LCDs were reflective types based on the twisted nematic (thread-like) materials. With a field applied, the liquid crystal material aligns, and light is transmitted leading to the formation of an image. These twisted nematic materials suffer from a very low viewing angle and slow speed of response leading to flicker as well as poor temperature performance. Occasionally, a backlight was employed to render the display visible in low ambient light.

19.2.2 The early problems of the LCDs have been overcome to a large degree by more advanced materials and improved driving techniques. Colour has been added by providing individual organic based filter screens printed under each pixel. Most recent LCDs are based on super twisted nematic (STN), active matrix drives employing thin film transistor (TFT) and ferroelectrics (with memory), amongst others. Full colour displays operating at video rates and with HDTV aspect ratio (16:9) have been fabricated with 16.5" screens. LCDs now have a prominent position with uses in both the civil and military avionics sectors.

19.3 Plasma Display Panels (PDPs). The principle of operation of the plasma display panels (PDPs) is the same as in a neon light or a fluorescent tube. A gas at low pressure is ionized by an electric field leading to the emission of both visible light (eg neon orange-red signs) and vacuum ultra violet (VUV) light. In more recent displays, the VUV is used to excite phosphors to produce the three primary colours. Unlike most other flat panel technologies, a large display size is not difficult to produce using PDPs, and displays with 1 m diagonal and over 4 million pixels have been fabricated. Hence these appear as obvious where large sized displays are required, eg for large screen video applications. However, PDPs are not very energy efficient and the monochrome orange-red colour is not very pleasing to the eye over long-term use. At present, over 1 million PDPs are manufactured per annum comprising both the AC and DC types. Though available in limited numbers, the full colour displays are still expensive.

19.4 Electroluminescent Displays (ELDs)

19.4.1 In CRTs electrons are accelerated in a vacuum and strike a phosphor screen which then emits visible light. In electroluminescent displays (ELDs), however, the phosphor layer is sandwiched between two conducting electrodes, one of which is transparent. An electric field is applied

19.4.1 (Contd)

across the structure that accelerates the electrons which in turn excite the activator ions in the phosphor layer. the relaxation of these excited ions leads to the emission of visible light. Additional layers may be used to enhance the basic stability of the structure. the most successful of the ELDs is based on a thin film structure driven by AC fields.

19.5 Vacuum Fluorescent Displays (VFDS). Vacuum fluorescent displays (VFDS) are the mainly green emitting devices used in small domestic displays for car clocks, microwaves, etc). Other colours are available including red and orange. The operation is very similar to CRTs but special phosphors are used which operate at much lower voltages, for example ~1OeV compared with over 15 keV.

19.6 Light Emitting Diodes (LEDs). These semiconductor solid state displays are based on electron and hole recombination in a p-n junction with the colour of the emitted light being a property of the band gap of the material. LEDs are mainly used for status indicators (often replacing incandescent lamps) , and are available in red, green, orange, yellow and more recently in blue. LEDs are extremely bright and hence are well suited to applications in avionics displays. the number of LEDs manufactured runs into millions per annum.

19.7 Field Emission Displays (FEDs). This is a relatively new technology which promises to retain mot of the useful characteristics of the CRT but operate at much lower voltage like the VFDs. Like ELDs, LCDs and PDPs, the field emission displays (FEDs) are lightweight, flat and thin. FEDs are based around the concept of cold cathode electron emission from ultra-small cone shaped microtips. As the distance between the phosphor-coated anode and the microtips (cathode) is less than a few millimetres, the emitted electrons excite the phosphor which emits visible light without the need for focusing coils, deflection coils, etc, that are necessary for the CRT. There are thousands of these miniature electron emitting cathodes per pixel, providing both high current density as well as built-in redundancy. Significant progress has been made in fabricating both monochrome and multicolour displays based on this principle in the last few years.

19.8 Electronic display characterises: design checklist. The following summarises the suitability of display technologies for applications. Suitability is indicted by ✓ (most = ✓✓✓✓ , least = ✓, x indicates not suitable.

Image reproduction - Is it important to:	CRT	LCD	PDP	ELD	VFD[1]	LED[2]	FED[3]
(a) show fine detail information?	✓✓	✓✓	✓✓	✓✓	x	x	✓
(b) show medium detail information?	✓✓✓	✓✓✓	✓✓	✓✓	x	x	✓✓
(c) show no perceptible flicker?	x	✓	✓✓	✓✓	x	✓✓	✓
(d) show fast movement?	✓✓	x	✓	✓	x	✓	✓
(e) distinguish slight differences in contrast?	✓✓	✓	✓	✓	x	x	✓✓
(f) show images with a wide range of tonal contrasts?	✓✓	✓	✓	x	x	x	✓
(g) show images with a wide range of colour contrasts?	✓✓✓	✓✓	✓✓	x	x	x	✓
(h) display high brightness?	✓✓✓	✓	✓	x	✓	✓✓	✓
(i) reproduce colours very accurately?	✓✓	✓	✓	x	x	x	✓
(j) show brightness uniformity across the screen surface?	x	✓	✓	x	x	x	x
(k) show colour uniformity across the screen surface?	x	✓	✓	x	x	x	x
(l) display a very large image (> 40-inch diagonal)?	✓[4]	x	✓✓✓	x	x	✓✓✓[5]	x
(m) display an average size image (about 13-inch diagonal)?	✓✓✓✓	✓✓	✓✓	✓	✓	✓✓	x
(n) display a small image?	✓	✓✓	✓	✓✓	✓✓	✓	✓
(o) present an image that is relatively insensitive to the ambient illumination?	x	✓	✓	✓	✓	✓	x

Other considerations - is it important for the display to be:	CRT	LCD	PDP	ELD	VFD[1]	LED[2]	FED[3]
(a) versatile?	✓✓	✓	x	x	x	x	✓
(b) cheap?	✓✓✓✓	✓	✓	✓	✓✓	✓✓✓	x
(c) reliable?	✓✓✓	✓✓	✓✓✓	✓✓	✓✓	✓✓✓	✓
(d) durable?	✓✓✓	✓	✓✓✓	✓✓	✓✓✓	✓✓✓	✓
(e) mass produced?	✓✓✓✓	✓	✓	✓	✓✓	✓✓✓	✓
(f) thin?	x	✓✓	✓✓	✓✓	✓✓	x	✓
(g) lightweight?	x	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓
(h) energy efficient?	✓✓	x[6]	x	x	✓	x	✓✓
(i) safe?	✓✓✓	✓✓	✓	✓✓	✓✓	✓✓✓	✓✓

1 VFDs are not normally made for displaying graphics.
2 LEDs are not normally made for displaying graphics.
3 All comments on FEDs are somewhat speculative since no commercial products were available at the time of going to press
4 CRTs are limited to about 45 inch diagonal, unless projection systems are considered. Both CRTs and LCDs are ideally suited for projection-based systems.
5 Large, coarse resolution LED-based units are available but not mass produced.
6 LCDs are only efficient if not backbit. Once they are backbit, the backlight has to be on all the time. The efficiency is therefore reduced considerably.

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Related Documents

A.1 A Guide to Task Analysis (1992) Eds B Kirwan & L K Ainsworth, London: Taylor & Francis

STANAG 3647	Edition 3 Nomenclature in Air Crew Stations, NATO
BS 5378	Safety Signs and Colours Part 1 Specification for Colour and Design
BS 5499	Fire Safety Signs, Notices and Graphic Symbols Part 1 Specifications for Fire Safety Signs

Display Screen Equipment Work, Health and Safety (Display Screen Equipment) Regulations 1992, Guidance on Regulations L26 (1992)

EN 29241	Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) Part 3 Visual Display Requirements

IEC 845-04-57: (CIE 17.4) International Lighting Vocabulary, International Electrotechnical Commission

ISO 2575	Road Vehicles, Symbols for Controls, Indicators and Tell-tales
ISO 2631	Guide for the Evaluation of Human Exposure to Whole-body Vibration
ISO 7000	Graphical Symbols for Use on Equipment
ISO 9241	Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) Part 1 General Introduction
ISO DIS 10075	Ergonomic Principles Related to Mental Workload
ISO DIS 9241	Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) Part 7 Display Requirements with Reflections
ISO DIS 9241	Ergonomic Requirements for Office Work with Visual Display Termainsl (VDTs) Part 8 Requirements for Displayed Colours
Def Stan 00-25	Human Factors for Designers of Equipment Part 3 Body Size Part 4 Workplace Design (Workplace layout includes displays) Part 5 The Physical Environment: Stresses and Hazards Part 6 Vision and Lighting Part 8 Auditory Information Part 9 Voice Communication Part 10 Controls Part 13 Human-Computer Interaction

Military Symbols for Land Based Systems, NATO Publication APP6

A.1 (Contd)

PULHHEEMS Administrative Pamphlet (1987)

Staff Officers Handbook (1993) Army Code No 71038

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The following Defence Standard file reference relates to work on this Standard - D/D Stan/328/l/7.

Contract Requirements

When Defence Standards are incorporated into contracts users are responsible for their correct application and for complying with contract requirements.

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