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HUMAN FACTORS

FOR DESIGNERS OF EQUIPMENT

PART 4: WORKPLACE DESIGN

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Revision Note

Historical Record

Arrangements 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 - Workplace Design
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

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 4: WORKPLACE DESIGN

PREFACE

i This Part of this Defence Standard provides designers of military equipment with an approach to workplace design, reflecting a knowledge of factors likely to affect equipment operators such as user capabilities and limitations within a workplace envelope.

ii This Part of this Defence Standard is published under the authority of the Human Factors subcommittee of the Defence Engineering 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.

viii This Defence Standard is being issued as an INTERIM Standard. It shall be applied to obtain information and experience of its application. This will then permit the submission of observations and comments from users using D Stan form No 22 enclosed.

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HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT

PART 4: WORKPLACE DESIGN

Section One. General

0 Introduction

A knowledge of the sizes and shapes of human beings and an appreciation of their capabilities and limitations is essential if a workplace or environment is to suit the human operator. A workplace may be defined, for the purposes of this Standard, as any environment within which an operator is required to carry out tasks. Consequently, within this definition, a workplace can range from a simple desk through to a complex compartment with several operators in Land, Sea or Air Systems.

To configure the individual operator's workspace, the designer will have to arrange all of the equipment according to the principles of display and control layout and the ease in which it can be maintained (See Parts 7, 10 and 11 of this Defence Standard). In providing satisfactory space for the operator to carry out his tasks, the designer will need to take account of the basic human data considerations of body size, strength and stamina (see Parts 2 and 3 of this Defence Standard). To configure the operator's workplace, the designer will need to consider both its physical surroundings and its internal and external environment, to ensure that the workplace neither endangers nor neglects the health, safety or efficiency of the operator. Achieving a satisfactory workplace free of stressors and hazards will require the equipment designer to comply with the basic human data contained in Parts 5 and 8 of this Defence Standard, the design guidance in this Part, also Parts 6 and 9 of this Defence Standard. For a systematic approach, the designer will need to consult Part 12 of this Defence Standard.

1 Scope

This Part of this Standard provides general guidance for the development and evaluation of workplaces. The workplace is considered as the complete working environment in which all operators and equipments are arranged to function as a unit. This unit could be a land, sea or air system, either static or mobile. In terms of the human operator, the important concepts of structural and dynamic anthropometry are discussed, outlining the physical limitations of man within the workplace and workspace envelope. Also included are general considerations associated with working positions and postures within the operational environment. This part of this Standard is written as a systems approach to human factors operation of the workplace, and harmonises closely with all other parts of Defence Standard 00-25. It describes a process and a systematic procedure, as well as providing data, design aiding and evaluation techniques. It defines the designer as a member of a design team, being part of a multi-disciplinary group of professional engineers and human factors specialists, concerned with all aspects of design of the workplace. As the design of the workplace is such a broad area, it is only possible to provide general guidance on the methods and techniques which can be used. Much of the available data is specific to certain types of workplace, and could be quite different from those pertaining to vehicle or static consoles.

1 (Contd)

(It is strongly recommended that, in layouts of any degree of complexity, human factors specialists suitably qualified in military ergonomics should be consulted). There is some deliberate repetition between the various sections of this part of the Standard, because it is envisaged that designer(s) will require information in detail for a particular procedure within the process, as well as knowledge of the whole process and their role(s) within it.

Section Two of this part of the Defence Standard, which serves as an introduction to the remainder of the document, describes the role of human factors in the workplace design process, and the stages in workplace design.

Section Three prescribes the human factors methodology for the design of the workplace including the working environment and physical surroundings.

Sections Four, Five and Six provide guidance on how to apply workplace design and design evaluation techniques.

Finally, in Section Seven, guidelines (including check lists), are provided for designers in their approach to workplace design.

2 Related Documents

2.1 The documents and publications referred to in this Part of this Defence Standard are listed in Annex B.

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

DOCUMENT	SOURCE
British Standards	BSI Sales Department Linford Wood MILTON KEYNES MK14 6LE Tel: 0908 221166

3 Definitions

3.1 For the purpose of this Part of the Defence Standard the following definitions apply:

3.2 Design team. A multi-disciplinary group of individuals concerned with, and responsible for, all aspects of the design of the workplace including human factors.

3.3 Designer. A member of the design team.

3.4 Man-machine interface. The controls and displays which an operator uses to control, monitor, or otherwise interact with, the workplace.

3.5 Methodology. An integrated and coherent set of methods (notations and techniques) and roles applicable to the overall design goal (eg human factors methodology).

3.6 Mock-ups. A mock-up is a three-dimensional, full-scale replica of the physical characteristics of a system or subsystem (of model). A mock-up can be developed only after equipment drawings are produced, although these drawings may be only preliminary ones.

3.7 Stressor. An impelling force which causes a demand upon physical or mental energy.

3.8 Task. A set of related functions performed by one or more individuals and directed toward accomplishing a specific functional objective and, ultimately, to the output goal of a system.

3.9 Workspace envelope. The personal space within which an individual works and where the controls operated and displays viewed are arranged for efficient use.

3.10 Workplace. The complete working environment within which all of the operators and equipments are arranged to function as a unit.

Section Two. The Workplace Design Process

4 The Role of Human Factors in the Workplace Design Process

4.1 Human factors activities. The design of the workplace is recognised as a major activity conducted during system design and follows on from Task Description. Workplace design is highly interactive and iterative with task analysis, the design of equipment, user manuals, and the design of the training programme, all of which contribute to design evaluation. (For definitions of these activities, consult Part 12 of this Defence Standard). It is essential that specialists in human factors are included in the workplace design team or at least consulted throughout its process, because their involvement at the earliest stages will ensure that the workplace is designed for safe, efficient, and reliable human use.

4.1.1 Having established the workplace design, an evaluation of the workplace effectiveness is carried out to determine its method of operation, including system hardware and software, and the performance of the personnel operating it. This evaluation will include testing by the military user, as ultimately the workplace design must meet the operational requirements. User evaluation is normally carried out at the prototype stage when a complete working system has been produced. More recently, working groups including the military user and the specialists in human factors have become involved earlier in the design process, for example when:

(a) New sub-systems are either retrofitted or demonstrated within an in-service workplace.

(b) In-service sub-systems are designed into a new workplace.

(c) a simulated workplace is used to assess the effects of stressors which may exert an overwhelming influence on the performance of the operator. Examples of stressors include external and internal environmental parameters and dynamic properties such as motion and vibration. The inclusion of simulation in the workplace design process will normally depend on whether its cost is justified, and whether the simulation is realistic. It does however enable complex aspects of system and sub-system design to be evaluated.

4.2 Military considerations related to workplace design

4.2.1 Military staff responsible for operational requirements demand maximum performance from both their equipment and service personnel. The military place strict requirements on equipment designers in Industry. If done effectively, this should ensure that service personnel can operate equipment with maximal crew efficiency. Military human factors specialists are particularly concerned with avoiding the problem of developing equipment which mismatches the skills of service personnel. This not only delays the acceptance of the equipment into service because of extended development time, but imposes prolonged and costly training demands on the services when equipment is found to be difficult to operate.

4.2.2 As weapon systems, including workspaces, become more complex, the Ministry of Defence expect equipment designers to ensure that they design for current service personel. It is important that the capabilities and limitations of service personnel are understood, for it is their attributes that form the baseline for design considerations of equipment. It is recognised that training can improve the service personnel's proficiency, but it must not be considered a substitute for poor design. Equipment should be designed to be as procedurally simple as possible and not require service personnel to perform intellectually demanding skills in order to operate it. Designers must design for service personnel performing under states of emergency and thus being stressed and fatigued from many causes. Operator performance decrements will readily occur, not by the service personnel's inability to perform, but because they will be physically and mentally overloaded. Therefore in order to utilize equipment properly, it must be designed for the specific target population. This constraint may seem obvious, but must be the primary consideration of the designer.

4.2.3 Human factors specialists must play a significant role in deciding not only the details of the workplace design to be constructed, but also on how the workplace will be used. For example, full scale wooden mock-ups are constructed for evaluation as design tools of representative build standard, and not merely used by Industry as a sales incentive.

4.3 Equipment designer difficulties

4.3.1 This part is written to provide the designer with a better insight and understanding of the human factors role in workplace design, and does not replace the military human factors specialist's input into the design process. The workplace designer never has a 'carte-blanche' for the construction of the workplace purely on human factors aspects. Conflicting requirements invariably impose restrictions and constraints on the designer and the end result is often a compromise. It is therefore very important for designers to have access to the relevant human factors data base as early as possible so that their thinking is influenced by the requirements of the human operator, rather than arranging the workplace from the shapes and dimensions of the subsystems within it. The designer must be made aware that his background in terms of training and personal experience probably mismatches with the user's requirements. For example he is often likely to be more intelligent, older, less agile and unfit, compared to the operator he is designing for.

4.3.2 Generally, the anthropometric data base for military personnel is well documented (See Part 2 of this Defence Standard). The range of body sizes defined in anthropometric survey studies can provide the equipment designer with an immediate static dimensioned input to his scaled drawings. Unfortunately it is often difficult for the equipment designer to interpret the anthropometric data for dynamic use to arrange the workplace for efficient operation by the required range of human operators'. As a first level approach, the construction of either scaled manikins based on nude anthropometric data with simple pivoted joints or, where access to computerized design aids are available, by the manipulation of man-model imagery in pseudo - three dimensions within the line construction of displayed drawings, is probably the best he can do.

4.3.2 (Contd)

What is most difficult for the equipment designer is to interpret the derived resultant working postures in terms of human factors acceptability, because he is unlikely to have the background experience and knowledge of the military human factors specialist.

4.3.3 The construction of the full scale wooden mock-up can have a significant role in deciding the internal layout of the workplace design. However the designer must neither base the workplace layout of the wooden mock–up on his own personal dimensions and preconceived theories, nor consider himself to be representative of the user. At this stage of workplace design, the human factors specialist input is vital because initial assessment can be carried out using representative subjects from the required range of the user population wearing their relevant clothing assemblies, as well as thinking through their roles and activities in the real system. Various alternatives in workplace layout can be easily constructed and considered before the final design choice is made. See Part 2 of this Defence Standard.

4.3.4 Design evaluation at the prototype stage must include the full participation of the user, because his assessment and opinions are essential. At this stage, before making any required modifications, the designer should be most flexible, responsive, and able to readily accept constructive criticisms of his design, before making any required modifications. Prior to acceptance by the user, considerable modifications are often required because most of the faults are then highlighted, particularly if the designer has not heeded human factors advice. For a mobile workplace such as a land, sea or air based equipment, probably all of the human factors aspects contained in the remainder of this Defence Standard will be brought together into the complete system. Also in some instances, human factors aspects will interact with each other, and may even conflict with the workplace design requirements.

5 STAGES IN WORKPLACE DESIGN

5.1 Preliminary design

5.1.1 Introduction. At the preliminary design stage, alternative layout concepts of the new workplace are examined to investigate whether or not they are workable prior to detailed design. Their main feature is that they are quickly adjustable and easily changed. For description of methods of preliminary design, see Section 5, Clause 11.1.

5.1.2 Paper mock-ups in two-dimensions. Paper mock-ups are low cost and quick to prepare. Two dimensional layouts are constructed in reduced scale orthographic projection. The operators' locations are usually depicted by a circle with an indication showing the operator's line of sight. Magnetic boards can also be used thus enabling layouts to be displayed vertically to the design team. Collective discussions of this first-step evaluation of alternative layouts can be easily viewed and changed for assessment. In addition, magnetic boards are also suitable for the preliminary examination of full-scale relationships on a vertical surface, and give a first opportunity for evaluating spatial relationships and defining reach.

5.1.2 (Contd)

Scaled manikins at each end of the population range are manipulated to ensure that the required range can be accommodated equally well. Paper mock–ups should neither be regarded as toys nor ignored by the professional designer. High cost mock-ups do not provide any further useful information than low cost paper ones at this early stage, but can establish important criteria for the development of more detailed mock-ups later on in the workplace design process.

5.1.3 Foam model in three dimensions. Techniques such as expanded foam (see figure 1), soft wood and 'Lego'–type models (see figure 2), can be generated for evaluating alternative workplace layouts. These models are usually on a reduced scale and constructed from materials which are easy to cut and assemble.

5.1.4 Preliminary mock-ups in three dimensions Preliminary mock-ups can be either in reduced scale model or in full scale form. Reduced scale models are especially useful for evaluating either the total arrangement and layout of large items such as buildings and structures, or furniture and fittings within a building or vehicle. They are particularly beneficial for interpreting the user’s layout requirements. Their scale should be selected to suit evaluation purposes, and will depend on the overall number of large scale elements within the total arrangement.

5.1.4.1 The basic full-scale three dimensional mock-up is principally valued for representing spatial inter–relationships between the operator and their controls and displays. Clearance, reach and viewing parameters can be established as well as deciding upon whether or not the operator is required to sit and (or) stand. Also they are extremely useful for identifying requirements for ease of maintenance of equipment. (For further details on design for maintainability, see Part 11 of this Defence Standard).

5.1.4.2 Higher level preliminary full-scale mock-ups may be required once the general layout of controls and displays is established. Actual instruments can be mounted and activated to various degrees, depending on the purpose of the simulation. For example, instrumentation can be powered, by linking with a computer system, to simulate and evaluate alternative control and display concepts.

5.1.4.3 A more advanced level of the full scale mock-up can be mounted on a dynamic platform to simulate the motion of a land, sea or air based vehicle. This level of mock-up, in terms of time and cost can only be justified if the dynamic aspects of the man-machine interface are particularly critical to the functioning of the operator(s). Mock-ups at this level of sophistication can approach the potential of a training simulator but for operator safety must be ruggedised.

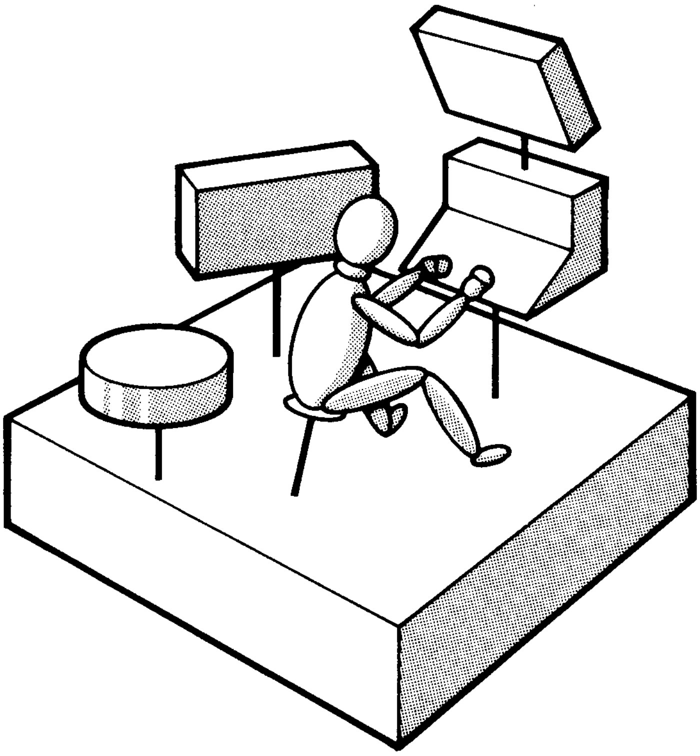


Fig 1 Diagrammatical Representation of Foam Model

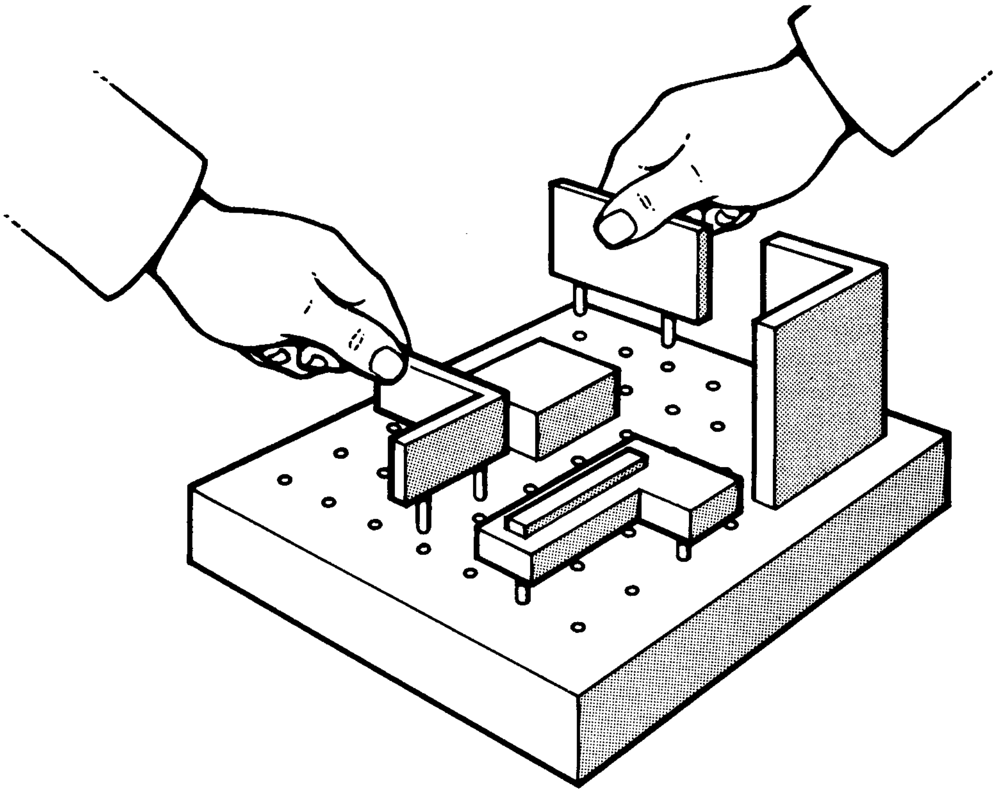


Fig 2 Representation of 'Lego' Type Model

5.2 Detailed design

5.2.1 Introduction. At this stage, the proposed workplace design is expanded to include more detail. Scaled drawings are constructed, and the design is evaluated using mock–ups and simulation, leading to the prototype workplace. During this period, test and evaluation procedures are carried out by human factors specialists as well as others with competing interests, and often become highly iterative and interactive. This characteristic of detailed workplace design requires the designer to be flexible and responsible to constructive comments. (For further information see Part 12 of this Defence Standard. Description of methods for detailed design, see Section 5, Clause 11.2).

5.2.2 Scaled drawings including manikins

5.2.2.1 Engineering drawings for workplace design are usually scaled between 1/10 to ½ scale and are more often depicted in side elevation rather than in plan or end elevation. Scaled two-dimensional manikins representing the physical dimensions of the unclothed human body provide a guide for initial estimates of workplace fit. Fabrication of sets of manikins to scale require a skill not generally taught in standard engineering courses. Drawing the human figure from life under formal training will aid the designer to draw manikin templates from the limited number of anthropometric dimensions available. They are usually made to represent the two-dimensional aspect of a human as seen from the side (sagittal plane). Front (coronal) and plan view (transverse plane) manikins, however, are less common and are probably more difficult to construct. To aid in their construction, dimensions of body linkages expressed as a percentage of stature are contained in Part 2 of this Defence Standard. Dimensions for constructing manikins in the seated posture obtained from static anthropometric data should not be used in the standing posture or vice versa, because they will be inaccurate due to the complexity of joint articulation. Pairs of manikins are usually constructed from nude anthropometric data to represent the 5th and 95th percentile range of the target population in all dimensions, but wider ranges have been required for specific military populations.

5.2.3 Computer Aided Design (CAD)

5.2.3.1 Computer Aided Design (CAD), can assist in the workplace design process provided it:

(a) reduces design time.

(b) improves design.

(c) reduces the designer’s workload.

(d) reduces design cost.

Engineering companies have mainly used CAD for three-dimensional (3D) geometric drawings and have included the man-model only as a secondary feature. The fundamental difficulty of incorporating the man-model has been because the computer memory capacity required to manipulate the model is excessive and the provision of establishing and updating an adequate human factors base has not been provided. An advantage of CAD is the ability to provide instant drawings without the need for draughtsmen.

5.2.3.2 The 3D modelling of the workplace is available on several CAD systems. SAMMIE (System for Aiding Man-Machine Interaction Evaluation) for example, has been specifically developed to enable human factors evaluations of workplace design at the concept stage, prior to the construction of full scale detailed mock–ups (see Figure 3).

5.2.3.3 Stereophotogrammetry has also been considered for portraying anthropometric data and the production of 3D envelopes of the clothed person. Pairs of stereophotographs are taken of the subject and analysed to produce contour maps of his/her outer surface. From these photographs, 3D co-ordinates are obtained from any point on the surface. It is considered to be the best method of producing 3D anthropometric data and body envelopes. Unfortunately, it does not produce a mobile anthropometric clothed model of the man for articulating in an interactive CAD system. Video-grammetry using close circuit television may provide a better data base of clothed anthropometric dimensions for future use in a CAD system.

5.2.4 Full-scale wooden mock-ups

5.2.4.1 The construction of the wooden mock-up provides the means for deciding the internal layout of the workplace. Alternative layouts can be easily considered before the final design choice is made. Workspace and clearance estimates must be assessed using a range of representatives of the User population wearing their likely maximum clothing bulk. Examples of Land, Sea and Air Systems are provided in Section 5.

5.2.5 Dynamic simulation of workplace and equipment

5.2.5.1 Introduction. The construction of any physical mock-up of the workplace is, in a sense, a simulation of the man-machine environment. As workplaces become more complex, there will be external factors which may exert overwhelming effects on the operator(s) performance. Both external and internal environmental parameters may require simulation and control because these may influence how well the man-machine system functions. The extent of realism may depend on several aspects including:

(a) How important each variable is in effecting the eventual performance of the operator.

(b) How realistic the important variable can be simulated (ie poor realism can be worse than none).

(c) The length of time required to develop the simulation.

(d) Whether the cost of simulation is justified: If it exceeds the cost of the final hardware, the simulation cannot usually be justified. The designer must also avoid the temptation of creating an exotic simulation just because it is a design challenge.

5.2.5.2 When the dynamic environmental characteristics of the workplace are considered to have a marked effect on the behavioral response of the operator, the design of a simulator is justified. If critical physical conditions are considered to effect the efficiency of the operator, such as noise, vibration, gravity forces, atmospheric pressures and temperatures outside of normal limits, special simulations of the workplace may be constructed.

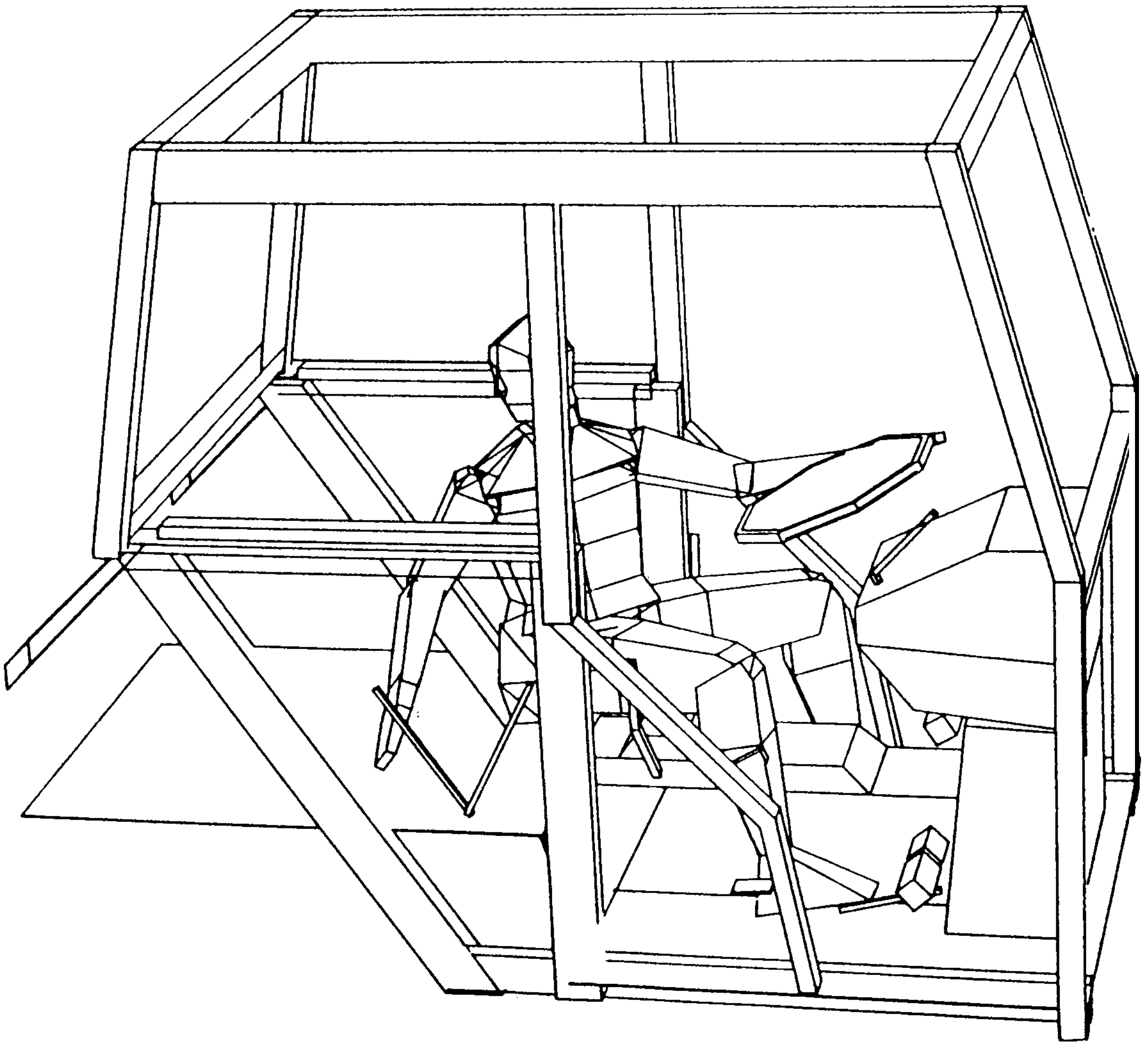


Fig 3 Sammie CAD

5.2.5.3 For example, human factors aspects considered highly pertinent to combat operations for military aircraft are the pilot's external vision requirements and the control of the aircraft. Among the more significant visual aspects are:

(a) Formation flying.

(b) Aerial combat.

(c) Ground reconnaissance.

Typical considerations for aircraft control are the effects of:

(d) Physiological stressors such as high 'g' forces on the pilot caused by tactical and combat requirements.

(e) Data and task saturation caused respectively by information and performance overload.

(f) Disabling wounds to the pilot.

(g) Critical aircraft control damage which makes the aircraft difficult to fly.

However, the designer should note that when simulation of physical conditions explores stressors that are hazardous to the health and safety of the operator, human factors specialists, ethical bodies, and medical staff must be highly involved early on in their design, to closely monitor any testing which involves human subjects. Further information can be found in Woodson (1981).

5.2.5.4 When the simulator designer cannot guarantee the health and safety of the operator, the operator must be provided with protection. Protection should either be designed into the workplace, or the design must be compatible with individual protection worn by the operator. From a human factors viewpoint, it is usually better for overall protection to be designed into the workplace, in order to protect all the operators, as individual protection often degrades operator performance by interfering with the human senses, restraining the operator in the workplace, and usually adding to anthropometric dimensions with extra clothing bulk. If, in the course of duties, the operator requires to leave the workplace and enter a hostile external environment, individual protection will need to be stowed internally beside the operator, in dedicated places close to the operating position.

Where workspace constraints makes donning of individual protection difficult, either some or all of the individual protection will need pre-wearing, before engaging in external exposure.

5.2.5.5 When simulator designers cannot either satisfactorily protect the operator within the workplace environment, or provide satisfactory workspace dimensions, the operator must be excluded from the workplace. If human factors interactions are still required for workplace control, these operations must then be carried out remotely by the operator.

5.2.5.6 There are broadly two types of workplace simulator, one designed for research and the other for training purposes. For the detailed design of the workplace, human factors activities should include them both, because each of them contribute separately to design evaluation (see Clause 4.1). A most recent example is of a virtual cockpit for investigating the concept of the 'electronic crewman'. Both research and training simulators are tending towards computer generation rather than three–dimensional representations of the task.

5.2.6 Demonstrators

5.2.6.1 Workplace demonstrators may resemble their real-life counterpart, dynamically and operationally. However, if a crew station is part of a research programme, it will not necessarily represent any specific system.

5.2.7 Rigs

5.2.7.1 Workplace rigs can be designed for both mobile and static applications. When the rig is dynamic and human operators are included, it is essential that human factors specialists rate the rig to ensure the operators safety.

5.3 Design reviews

5.3.1 The design contractors, the MOD Procurement Executive (PE), the human factors specialists and others involved, conduct regular technical and design review meetings to monitor progress and ensure that all conflicting views and opinions on the workplace design are voiced and minuted. The Chairman must ensure that any conflicts are satisfactorily resolved. Any unresolved issues must be documented by those parties who raise them, and copies sent to both the project manager and the operational requirements branch concerned. Sometimes, aspects pertinent to specialist interests may still not be satisfactorily resolved, and require further work. Experience has shown that in the workplace design of mobile land-based systems, human factors specialist advice is not always followed despite timely advice being made available to the PE. Often the reasons given are that the operator is adaptable and can work in less than optimum conditions. However adaptation can degrade the operator’s performance with subsequent loss to his efficiency. Where modifications are required, PE issue task requests to the contractors and action them to include changes in the initial build standard. At the conclusion of this stage, the design is considered frozen and drawings for the final detailed design are sealed.

5.4 Prototype system

5.4.1 The initial prototype workplace is built from the sealed drawings for subsequent test and evaluation. User opinion is essential at this stage in order to reach agreement and acceptance of the workplace prototype. Modifications if necessary, must be fed back into the detailed design of the prototype workplace prior to its production, otherwise costly retrofits will be required.

5.4.2 Regular trials panel meetings under the project manager are conducted as a forum for reporting how trials are going and to both allocate and provide the resources for trials and associated purposes.

5.4.3 Trials reports are written and are included in the acceptance report document. Comparisons are then made as to whether or not the workplace meets the Staff Requirement (SR). The acceptance report document is discussed in detail at a pre-acceptance meeting prior to the Operational Requirements (OR) branch formally accepting the workplace for in-service use.

5.4.4 Where some aspects of the workplace system do not meet the SR, and providing that further work can rectify any outstanding aspects, acceptance can be granted with provisos. Provisos are carried out during post-design services work and are specified on the acceptance certificate. When the design does not meet the SR and is unlikely to do so, even with further development, the user will not accept it hence the project is either terminated or subjected to a major review.

Section Three. Human Factors Methodology

6 Introduction

6.1 Workplace design is related to the human factors activities in the detailed design stage of system development (See Part 12 of this Defence Standard) and also includes all of the Parts of this Defence Standard. Correct workplace design will expect equipment designers to cover the basic human data of the operator (See Parts 2, 3, 5 and 8 of this Defence Standard) with design guidance (See Parts 6, 7, 9, 10 and 11 of this Defence Standard) in order to construct a workplace fit for human use.

7 Design of workspace and the workplace

7.1 Functional anthropometrics

7.1.1 Definitions. Anthropometric data is used to determine the dimensions of the workspace envelope needed by personnel to perform their tasks, and can be expressed in one of two forms. Static (or structural) dimensions are taken with the subject in a rigid standardized position. Dynamic (or functional) dimensions are measured in working positions and take account of certain degrees of body movement and flexibility.

7.1.2 The workspace envelope. The workspace envelope must be compatible with the anthropometric dimensions of the target population of operators using the equipment. Dimensions of the larger operators are used for determining clearances and near (ie minimum) limits of reach, especially when the seated operator has either a seat backrest or other obstruction interfering with the rearward movement of the elbows. Reach dimensions of the small operator should be used to determine the far (ie maximum) limits of reach, particularly when the worker is either standing behind a bench or seated and harnessed to a non–adjustable seat. The seat reference point (SRP) illustrated in figure 4, is commonly used as a standard starting point for reach dimensions of seated operators. It is defined as the midpoint of the intersection of the plane of the seat surface, with the plane of the backrest surface of the seat and tangents of the mid-line contours of the seated man. Equipment positioning should therefore be based on the reach limits dictated by both large and small operators. In addition, the effects of clothing which add to the clearance requirements and which can also restrict movement must be considered. Static human body dimensions are traditionally measured with the nude subject either standing or sitting erect and will not represent the dynamic characteristics of normal stooping, slumping, bending, stretching or moving about. It is recommended that all types of layout should be verified in either a three-dimensional, full-size mock-up or computer model, where subjects or man–models representing the extremes of the expected user population can actually be tried in the layout.

7.1.3 Critical dimensions

7.1.3.1 Although static dimensions are useful for many design purposes, they do not take into full account the flexibility and movement of joints. Dynamic anthropometry provides a better representation of the workspace envelope since in most workstations an element of movement occurs. The implications of this can be seen, for example, in the design of a driver’s workplace (figure 5) where it is undesirable to fix the operator into a rigid posture, due to the possible bending of the back and hand manipulations.

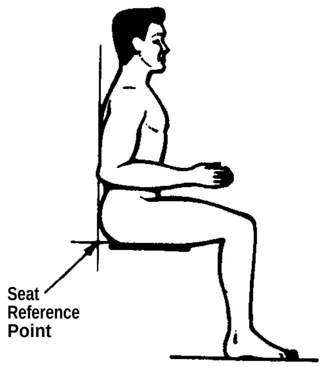


Fig 4 Seat Reference Point

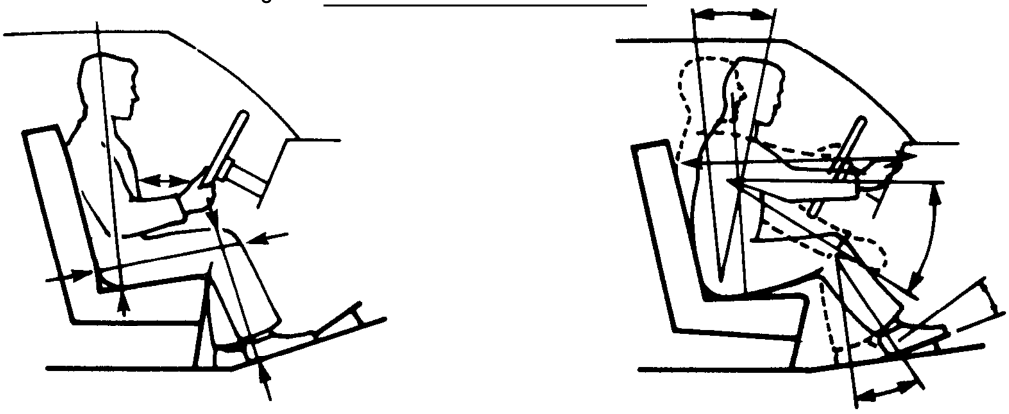
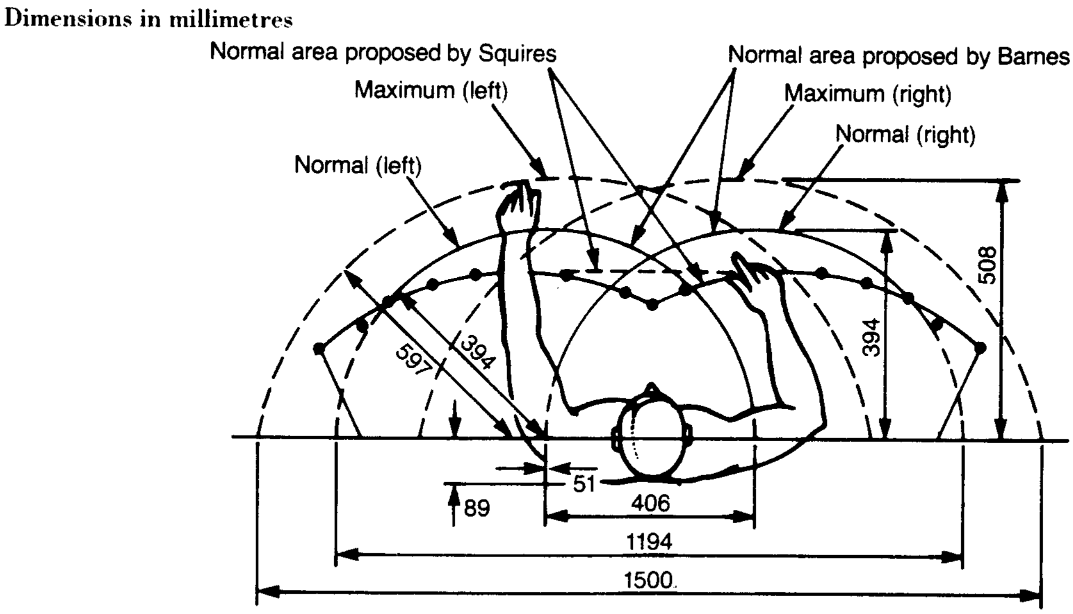


Fig 5 Fit Based on Static Dimensions (Left), Dynamic Dimensions (Right)



Normal Area. Defined as the area which can be conveniently reached with a sweep of the forearm, the upper arm hanging in a natural position at the side of the body.

Maximum Area. Defined as the area that could be reached by extending the arm from the shoulder.

Fig 6 Effective Reach Parameters

7.1.3.2 When performing physical functions dynamically, the individual body members normally do not operate independently but together. The practical limit of arm reach, for example, is not the sole consequence of arm length, as it is also affected in part by shoulder movement, partial trunk rotation, possible bending of the back, and the function that is to be performed by the hand. These and other variables make it difficult, or at least very risky, to try to resolve all space and dimension problems on the basis of structural or static body dimensions. The importance of carrying out some kind of simulation or fitting trials cannot be over-emphasised.

7.1.3.3 Many types of work activity are carried out on horizontal workbenches, desks and workstations. For such worksurfaces, normal and maximum areas have been proposed by Barnes (1963) and are based on the measurements of 30 men. These two areas are shown and described in figure 6. Related investigations by Squires (1956) however, have served as a basis for proposing a somewhat different worksurface contour that takes into account the dynamic interaction of the movement of the forearm and the elbow. The area that is so circumscribed is superimposed over the area proposed by Barnes. It can be seen that the area described is somewhat different in shape and area. The fact that the normal work area proposed by Barnes has gained wide acceptance probably indicates that it is quite adequate for most purposes, although the somewhat shallower area proposed by Squires probably corresponds somewhat better with dynamic anthropometric realities (McCormick E J and Sanders M S, 1982, Page 327).

7.1.3.4 Representative workplace layout should accommodate a range from at least the 5th to 95th percentile of the user population. However, some military specifications may be more stringent and require a range from the 3rd to 97th percentile. Specific applications where there is a well-defined population (ie female electronics assembly personnel) may enable an even wider range to be considered (eg 1st to 99th percentile). In each case, the appropriate anthropometric data should be consulted (see Part 2 (Body Size) of this Defence Standard).

7.1.4 <u>Functional factors.</u> Two functional considerations in good workplace layout are visibility and clearance both of which are related to an operator's anthropometric and biomechanical characteristics. Procedural efficiency, a third factor, is related to perception and reaction. A fourth factor is access to displays, control and work surfaces and storage areas, which can also be related to anthropometric dimensions.

7.1.5 <u>Field of view.</u> The designer must consider primary and secondary line of sight factors. 'Out of the window observation' might define a primary visual task, whereas a secondary task would be to monitor instruments or display states inside the workplace (such as a cockpit). In contrast to this, a static console may have the control/display area of the console as the primary visual task, with the wider view of other personnel as the secondary visual task.

7.1.6 Clearance. Clearance at various levels is important for: Access to and from the workplace, for ease in grasping and operating controls, for ease in adjusting the body properly to the visual control task and for the avoidance of physical discomfort or injury. All of these factors may be greatly influenced by restraints which the operator may need to wear and by the special clothing worn to insure safety and/or to provide life support. In establishing clearance requirements whether related to access, control manipulation, body position or injury avoidance, the designer must recognise the specific needs of the user and take these into account.

7.1.7 Design anthropometrics

7.1.7.1 In order to accommodate as much of the population range as possible, seating should be appropriately adjustable. The seated eye heights of both the largest and smallest percentiles are important reference points for the designer.

7.1.7.2 Restraint by a seat belt or shoulder harness and restrictions such as a fixed viewing distance can make arm reach a critical factor, but even limited body motion causes these dimensions to be less critical. Other layout requirements can then assume a higher priority.

7.1.7.3 Allowances should always be made when using anthropometric data for such factors as, seated slumped posture (40 mm), effects of bulky clothing, body movement caused by vehicle oscillations, sudden deceleration, altitude changes or weightlessness, and for dimensional alterations introduced by stooping, squatting, twisting, turning, or doubling up (refer to Part 2: Body Size).

7.1.8 Priority of design considerations. Priorities should be assessed for each individual case by human factors specialists. Equal priorities can exist and often the final solution is a compromise of several priorities. This must be conducted in a rational manner with the human factors specialists, the user, and the designer. The principles of control and display layout (ie functional grouping, sequence of operation, importance and frequency of use) are identified and referred to in Part 12 of this Defence Standard and control coding information is detailed in Annex A to Part 10 of this Defence Standard.

7.2 Design of workplace

7.2.1 General principles. Precise workplace dimensions are strongly dependent on the activities being carried out. It is therefore only possible to provide general guidelines within this document and these are based primarily on a static workplace. For specific applications such as a vehicle or an aircraft cockpit, additional constraints apply. It is not possible, within the scope of this Defence Standard, to cover all of the likely situations and the designer is recommended to consult more specialized sources of data such as the Army Personnel Research Establishment (APRE) for land systems, Admiralty Research Establishment (ARE) and the Institute of Naval Medicine (INM) for sea systems and the Institute of Aeronautical Medicine (IAM) and the Royal Aircraft Establishment (RAE) for air systems. These organisations may well recommend specialist contacts in Industry.

7.2.2 General layout. By following the general design approach and basic information requirements described below in Clause **7.2.3**, designers can develop workplace layouts for specific applications.

7.2.3 Primary considerations

7.2.3.1 Visual requirements

- view outside the compartment or vehicle.
- view within the workplace (panel mounted displays and controls etc).
- sight-lines to other personnel.
- sight–lines to other equipment (displays, status boards and maps, for
- example).

For specific guidance, the designer is directed to Parts 6 and 7 of this Defence Standard.

7.2.3.2 Auditory

- direct personal communication with other operators.
- signals from loudspeakers, earphones.
- warning bells, sirens, alarms etc.
- equipment operation eg auditory and sound unique to individual systems such as keyboard feedback.

For specific guidance, the designer is directed to Parts 8 and 9 of this Defence Standard.

7.2.3.3 Demands for control activity

- hand and foot controls.
- latches, handles, push buttons, toggle switches, rotary selector switches, knobs, cranks, handwheels, levers, pedals, touch displays and keyboards.
- restraint harness, fasteners, restricted mobility.
- seat adjustments, optical adjustments, canopy/cover opening etc.
- emergency items eg flashlight, survival gear.

7.2.3.4 Handedness

(a) Degrees of handedness vary from dominant right-handed through ambidextrous to strong left-handed. Left handedness (ie hand preference) is generally less than 10% of any large national population. A sample (N = 1124) of British Army population found that 8.8% were left handers. Individuals with truly equal preference for handedness are extremely rare. Controls particularly tools, are more often designed for right-hand operation. Left handed operators often find them difficult or uncomfortable to use, which may lead to fatigue and risk of accidents. A solution is not simple. Sometimes right and left handed tools are designed but are uneconomical or difficult to produce.

(b) Handedness may simply be classified for individuals on the basis of the writing hand. However for complex tasks this division is insufficient, because the individual can have different hand preferences for various actions which could cause difficulties when determining which hand should operate which control. For example, tightening a screw (ie with right hand

(b) Contd

thread) is easier for a right handed operator because greater torque and range of hand movement is possible. However, all people make clockwise movements better with the right hand, and counter clockwise movements better with the left hand. Therefore it is crucial to assess the job requirements and match them to the operator's capabilities including strength.

(c) Handedness may be classified as the difference in the ability to complete manipulative tasks with the preferred hand. Differences in dexterity may be due to the relative feedback control of movements. However, once sequential movements are automatic (or ballistic), either hand can perform with equal skills and operator performance becomes a direct function of practice (Flowers, 1975). Also the skill involved in hand-eye coordination are also mainly subject to feedback control. For specific guidance, the designer is directed to Part 10 of this Defence Standard.

7.2.3.5 Body clearance

- possibility of an operator bumping elbows, knees, head etc during both normal and emergency exit, crash ejection, or rescue
- possibility of inadvertent snagging or accidental operation of controls or handles
- relationship between operator's workplace and adjacent workstations.

For specific guidance, the designer is directed to Part 2 of this Defence Standard.

7.3 Working environment

The control of vibration, noise, light, thermal radiation, pressure etc, should be accomplished at the source, or if this is not possible, at the workplace. For example, proper orientation of a display panel can reduce the effects of glare from an ambient light source. Structural support for a hand or arm can reduce vibration effects and improve the precision of manual control. Independent seat suspension, seat padding and contoured seating can reduce postural stress from road shock, as well as fatigue from long duty periods in confined quarters. The application of cognitive ergonomics such as colour coding displays will help to optimise performance if used correctly in a crowded workplace. The designer should strive to eliminate or minimize any debilitating effects of the environment on operator performance. See figure 7 and Parts 5 and 7 of this Defence Standard.

7.3.1 Physiological factors. Workplace design and layout should avoid imposing any physiological stresses on the operator. Designers should recognize gross personal hazards by providing crash protection for example, and also be responsive to more subtle physiological stresses arising from simple design incongruities, eg:

(a) lack of postural control or support;

(b) improper or inadequate distribution of body weight;

(c) cardiovascular restriction;

7.3.1 (Contd)

(d) fatigue-inducing activity or awkward reaching;

(e) habitability;

(f) noise and vibration effects;

(g) visual strain due to inappropriate location of displays,

The environmental stressors and hazards which can be created within the workplace often interact and have implications on the design of the workplace. A more detailed account of the effect of environmental stressors is given in Part 5 of this Defence Standard.

7.3.2 Psychological factors. One of the primary psychological objectives of workplace design is to promote User acceptance. An operator is more likely to be motivated in his tasks if the workplace is:

(a) functional and logically arranged according to sound ergonomic principles;

(b) easily accessible in terms of entry and exit;

(c) easy to operate by following known population stereotypes, see note;

(d) operationally simple to use and understand;

(e) designed to avoid the risk of impairing the operator's health and safety.

If an operator has difficulty in attaining the working position, seeing or monitoring displays, or reaching controls because of poor arrangement, his motivation can be affected. In performing tasks, the operator's sensory cognitive and psychomotor abilities are influenced by the design of the workplace. For an operator to perceive and respond efficiently, appropriate and compatible displays and control output devices are necessary.

NOTE: Details of population stereotypes are given in Bailey (1982), pages 268 and 269; Kantowitz and Sorkin (1983), pages 325 to 331; and Annex D to Part 10 of this Defence Standard. It should be noted that differences exist between nationalities.

7.3.3 Workstation Tones and Contrasts

7.3.3.1 The choice of colours, tones and contrasts within a workstation is of greater operational importance than may be expected. For instance, strong colour can be a distraction, but can also have attention-holding properties and aid search and target acquisition. Generally, medium tones should be chosen for a workstation and should be neither excessively bright nor excessively dark.

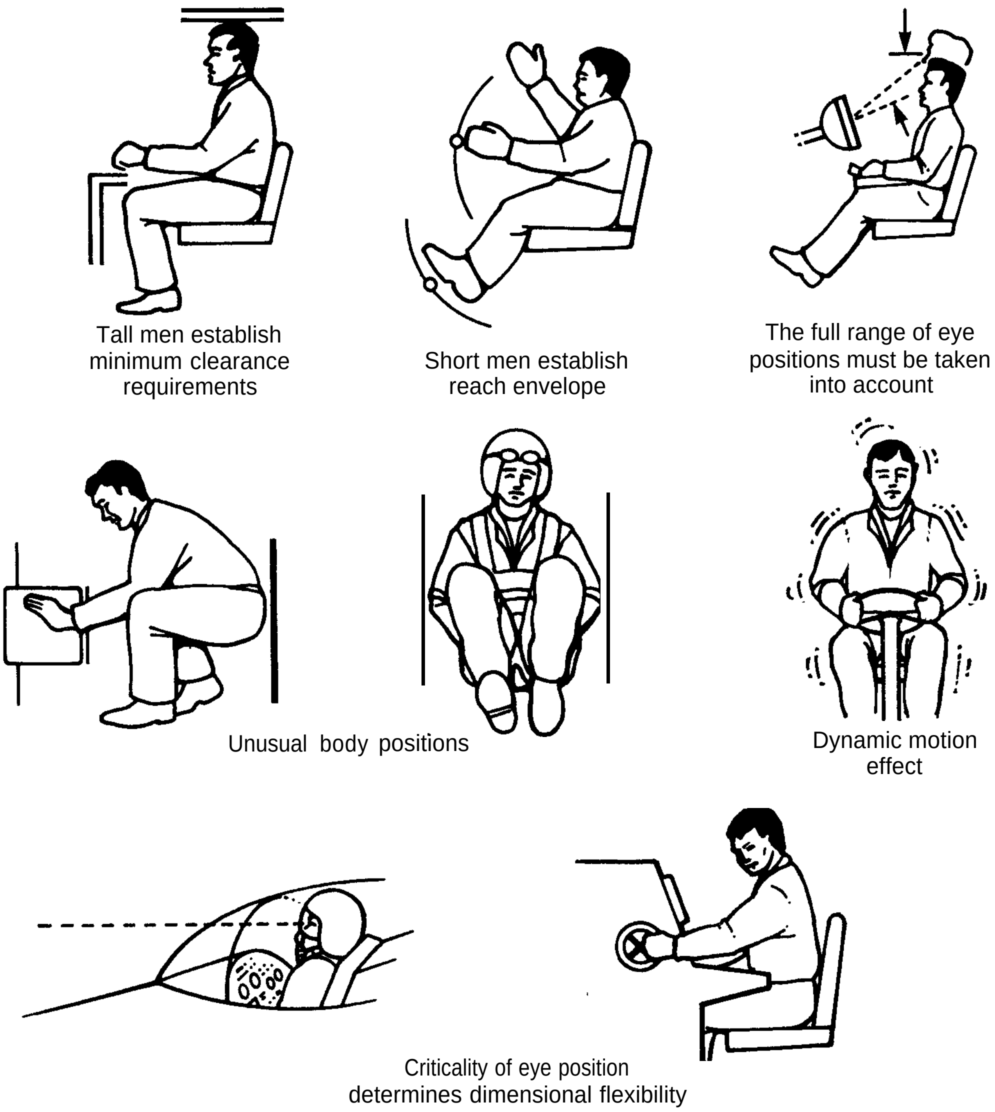


Fig 7 Some Examples of Environment Influences on Body Dimensions

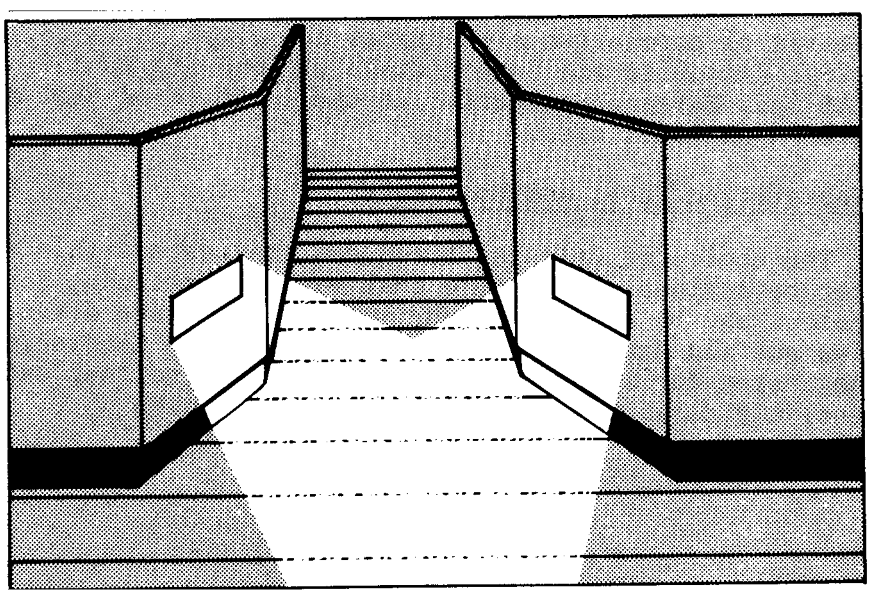


Fig 8 Console Incorporating Walkway or Emergency Lighting

7.3.3.2 In the primary visual field, contrast ratios from one tone to another should be within the ranges of 1:3 to 2:5. There should neither be harsh nor severe changes in contrast within this region. If a single operator uses more than one display screen, it should be possible to adjust the brightness to make them comparable. This will reduce the visual fatigue resulting from constant changes in adaption level when looking from one screen to another. At the periphery, a contrast ratio of 10:1 is acceptable.

7.3.3.3 Surfaces should be non-reflective so that glare sources are not created. Glare is experienced if a bright light source is within the visual field, whether this is seen directly or as a reflection in a shiny surface. Excessive glare (disability glare) makes it difficult to recognize detail without necessarily causing visual discomfort, although light sources more than 45° from the main line of sight are unlikely to cause glare problems. In many interiors, glare is more likely to cause visual discomfort than actual disability.

Discomfort glare may not be so apparent but its effects are cumulative and contribute to a sense of fatigue, especially after long shift periods. These cumulative effects are particularly serious when the visual task is demanding, as it is when working with Video Display Units (VDUs). However, they can also affect the efficiency of performing relatively simple tasks.

7.3.3.4 For these reasons it is recommended that workstations should have medium toned non-reflective surfaces. For the general interior of workstations, a lighter fresher colour, such as off white, should be chosen to avoid glare.

7.3.3.5 To aid maintenance, lift-off back panels should be completely removable to reveal light-coloured interiors, and assist the spread of light within.

7.3.3.6 To take account of the light output from display screens, the immediate surround should be similar in tone and colour to avoid harsh contrasts greater than 1:3. Surrounds should also be non-reflective to avoid the occurrence of screen reflections on the worksurface. For further information on lighting design and application see Part 6 of this Defence Standard.

7.3.3.7 <u>Room contrasts by day and night</u>

<u>Daytime.</u> In rooms which are used 24 hours per day that have windows, it is often difficult to achieve a satisfactory mixture of daylight and artificial light. It is desirable to achieve a fairly even level of illumination during daylight which can be maintained during the hours of darkness with artificial light only. To avoid large degrees of pupillary

7.3.3.7 (Contd)

adaptation to changes in light level (which can take up to a minute and is fatiguing), the eye should be gradually led towards brighter areas such as windows. The principle of avoiding harsh or severe contrast changes within the general visual field should be followed.

Night-time. Maintaining an even illumination level can be difficult to achieve. Light coloured blinds can help and should be provided over windows to avoid shadows and reduce reflections off the glass. Potentially hazardous objects such as pillars, need to be clearly seen, thus the arrangement of light sources should take account of their visibility and contrast. Walkways and throughroutes need illuminating, and this can often be conveniently incorporated within a console (see Figure 8). For specific applications such as radar rooms and particular military circumstances, see Part 6 of this Defence Standard.

7.4 Physical surroundings

7.4.1 Dimensional factors. Workplace dimensions should be compatible with anthropometric characteristics of anticipated operator populations. A dynamic evaluation should be carried out by mocking-up designs in full scale using people who represent the range of the user population, and by conducting simulated operations.

7.4.2 Safety. Safety for the operator must take overall priority in workplace design. A complete layout conception must include a full consideration of potential hazards. Projections and sharp corners are immediately obvious and must be avoided, but a poor layout likely to cause incorrect operator response is more difficult to recognize at the design and development stages.

7.4.3 Standardization. The designer should investigate previous workplace layout solutions, particularly when they reflect the guidance and specifications of published military requirements. Standardization among systems provides several important benefits including:

(a) reduction in training time for a new system;

(b) reduction of operator error in transferring from one system to another;

(c) cost of savings in the development of new hardware;

(d) reduction of logistic support costs.

On the other hand, the designer should recognize the dangers inherent in repeating a poor design concept in order to avoid the task of thoroughly analysing the operator requirements and developing a solution.

As a corollary to standardization, commercially available components should be considered. For example, control and display panels can be designed to fit manufactured console and equipment racks conforming to workplace requirements and specifications. Panel widths normally available are 575, 600 and 750 mm.

Section Four. Design Aiding Techniques

8 Functional Layouts

8.1 Inter-relationship chart

Purpose. This is a method of recording the links and relationships between several operators. It can be independent of the equipment used and is centred on the operational links between people.

8.1.1 Information required for this technique

(a) The main tasks and roles of each operator.

(b) The necessary communication links between each and every operator (see Figure 9).

8.1.2 Method

(a) List all operators, their job titles and principal roles.

(b) Identify links between all operators in items of communication links, control links and movement links. Communication and control links can be considered functional. Movement links generally reflect sequential movements from one component to another. Some versions of the three types are:

(1) Communication links between operator and equipment using the following means:

a. Visual (operator to operator, or equipment to operator).

b. Auditory, voice (operator to operator, operator to equipment, or equipment to operator).

c. Auditory, nonvoice (equipment to operator).

d. Touch (operator to operator, or operator to equipment).

(2) Control links

a. Control (operator to equipment).

(3) Movement links (movement from one location to another).

a. Eye movements.

b. Manual movements, foot movements or both.

c. Body movements.

(c) Link indexes can be used as aids in connection with either the general location of components or with their relative arrangements. In some circumstances they can be used as the basis for the assignment of priorities.

NOTE: The inter-relationship chart is not necessarily a pre-requisite for the technique described in Clause 8.2 below, but it does represent a useful source of information for these techniques.

	Supervisor A	Supervisor B	Operator A	Operator B	Radio Pos^{n}	Telephonist A	Telephonist B	Ch. Engineer	Asst. Engineer
Supervisor A		S	V	V	Ψ	V	V	V	V
Supervisor B	VS		S	S	Ψ				
Operator A				V	SΨ				Ψ
Operator B			VS		SΨ				Ψ
Radio Pos^{n}									Ψ
Telephonist A	Paper Link	Paper Link			Ψ		V		Ψ
Telephonist B	Paper Link	Paper Link			Ψ	V			Ψ
Ch. Engineer					Ψ				SΨ
Asst. Engineer			V		Ψ			V Paper	

Key

	Shared Equipment
S	Communication Link
Ψ	Interactive Link
V	Visual Link

Fig 9 Inter-Relationship Chart (IRC)

8.2 Link analysis

Purpose. Link analysis may be used to optimize the layout of controls and displays within a control panel and between sets of control panels, or to produce an acceptable arrangement of operators and equipment within a system.

General information. The term 'link' for the purpose of this Part of this Standard refers to any connection between an operator and a machine or between one operator and another. If one operator must talk to another, this need is represented by a link between them. Similarly, if an operator must see the display on a machine or operate a control on a machine, the operator has a link to the machine. Links include walking, talking, seeing, and movement of material and information.

8.2.1 Information required for this technique

(a) Main manning and equipment options.

(b) Inter-relationship chart (see figure 9).

(c) General descriptions concerning the use of each item of equipment.

8.2.2 Method

(a) Draw a circle for each operator in the system and label accordingly.

(b) Draw a square for every item of equipment used by the operator and label accordingly.

(c) Draw connecting lines (links) between each operator and any other operator(s) who have any direct interaction in the operation of the system.

(d) Draw connecting links between each operator and any machine with which the operator must interact.

(e) Redraw the resulting diagram, reducing to a minimum the number of crossing links in order to obtain the simplest possible arrangement.

(f) Using a scale drawing of the compartment area, check the feasibility of locations indicated by the link diagram.

Further information on link analysis techniques is described in Morgan and Chapanis (1963), pages 321 to 324, and Bailey (1982); pages 533 to 535. For a simplified link diagram comparing inefficient and efficient layouts, see figures 10 and 11.

8.2.3 Link analysis can be used in a wide variety of different situations. However, it is used primarily to help determine the best layout and arrangement of people and machines in systems. Keep in mind that the technique does not take into account how long a user spends with each link or the quality of the interaction.

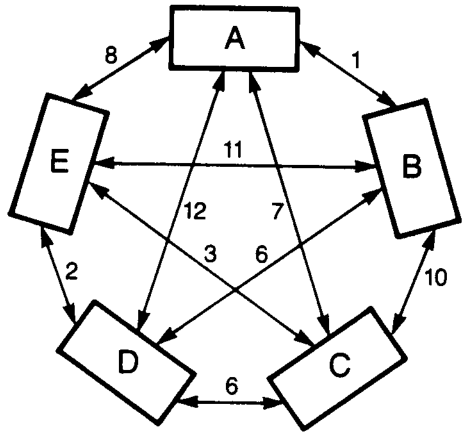


Fig 10 Link diagram - Inefficient Arrangement

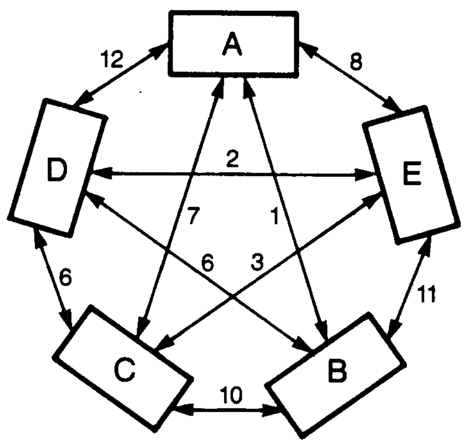


Fig 11 Link diagram - Efficient Arrangement

9 Computer aided design (CAD)

9.1 Definition. CAD is a technique whereby both the human and the computer are brought to bear to solve a design problem. The human's decision making ability combined with the power of the computer can produce a powerful tool, enabling a combined approach to workspace design, where alternative proposals or layouts can be very quickly evaluated.

9.2 Purpose. The purpose of CAD is primarily to save time (but not necessarily data collection which may still have to be laboriously done by hand). CAD is more versatile and flexible than its manual counterparts, enabling different design solutions to be examined easily and aiding conceptualization of the man-machine interface.

Computer technology also offers another design aid in the form of graphics facilities. Computer graphics drawing and manipulative modes can assist designers in their design work.

There are frequently too many human factors tasks to be completed manually in accordance with the system design programme. This results in either minimal consideration or heavy reliance on professional experience and judgement. CAD offers a means of making the human factors contribution to system design more effective.

Drawings aided by two-dimensional 'manikins' and mock-ups are still useful if resources are limited and/or their application is simple. However, computers can play a larger role in design layouts and feasibility studies with graphics, by providing designers and ergonomists with a 3D representation, thus allowing the implications of movement and different percentiles of the population to be more accurately predicted. The increasing availability of graphics hardware and standard software is helping to reduce the costs of CAD. As a result, the purely routine aspects of workspace design, such as anthropometry and dimensions, can be far more easily and accurately applied with less effort.

9.3 Benefits of CAD in evaluating man-machine interaction. One of the more common complaints made by ergonomists is that they are not consulted early enough in the design process for their contribution to be really effective. However, methods of evaluation are more suited to 3D mock-ups and prototypes, rather than drawings. Consequently the ergonomist's contribution is more limited when only such drawings are available.

What is required therefore, is a method of 3D evaluation which can be based solely on the information from two-dimensional drawings. The most powerful and flexible means of achieving this is to model the design by computer, whereby changes can easily be made. Evaluations, in terms of ergonomics, can then be very accurate even at an early stage in the design process.

Two of the computer programmes currently available are SAMMIE (System for Aiding Man-Machine Interaction Evaluation see clause **5.2.3.2** and figure 3) and COMBIMAN (Computerized Biomechanical Man Model). They provide the ergonomist/designer with the facility to visualize, plot and even move through the simulation of 3D workspace, in order to evaluate the design using a fully variable man–model.

9.3 (Contd)

These computer programmes help the user assess the man-model's reach capability, its visual field, the access to the workspace and its fit within it. The user can also model reflections in mirrors, quantify obscured areas and remove 'hidden lines' to create realistic 'clear views'. SAMMIE has already been used in a wide range of applications, including transportation (eg bus, aircraft, spacecraft), material handling (eg fork-lift truck, straddle carriers), manufacturing applications (eg assembly jigs, assembly workstations), and interiors (eg office, control room, kitchen). Further details of the benefits of SAMMIE are presented in Porter et al, 1986.

For further Design Aiding Techniques, the designer is referred to Part 12 of this Defence Standard.

Section Five. Workplace Design Evaluation Techniques

10 Purpose. The purpose of employing evaluation techniques is to verify that the proposed design of the workplace, conforms to human factors standards and that the whole system and subsystems function for their intended purpose.

11 Methods

11.1 Preliminary design

11.1.1 Two - dimensions. Designers with imaginative inspiration and flair for workplace design often begin their design in an unstructured manner by employing the use of a 'back of the envelope' technique. However, two-dimensional paper shapes in reduced scale enable structured design to begin. The ability to easily manipulate and adjust paper layouts ensures that design changes and alternatives can be quickly explored, and thus provide important criteria for developing more detailed mock-ups.

11.1.2 Paper mock-ups and magnetic board

Paper mock-ups representing items of equipment, workstations or group of operators and workstations

11.1.2.1 Purpose. To generate alternative layout of equipment, workstations, groups of workstations and equipment or personnel within a compartment. The examination is in two dimensions only but could be in plan, elevation, or both according to the specific requirement.

11.1.2.2 Information required for this technique

(a) Details of the overall size and shape of the compartment, scaled plans and all major items are to be modelled.

(b) General information on the use of all equipment with the location and siting of major controls and displays are to be provided.

(c) Functional layouts would be a preferable starting point for recording links and relationships between several operators (see clause 8).

(d) Information on the layout constraints imposed by the compartment (eg location of walkways and hatches) are to be provided.

(e) Approximate size of individual operator or groups of operators with their associated equipment.

(f) Important 'sightlines', if required, from the compartment to the outside.

11.1.2.3 Method

(a) Draw up outlines of items in plan and or elevation at one-tenth scale; a smaller scale, however, may be required with larger compartments.

(b) Cut out items using different coloured thin card - several sets should be made so that alternative layouts can be compared. The colour can be used to help identify different types of consoles or equipment.

11.1.2.3 (Contd)

(c) For magnetic board, cut approximate shapes for items of equipment and operators with equipment from magnetized rubber sheet. Use colour coding to represent common equipment types or functions.

(d) Grid the compartment area (see figure 12), and indicate non-usable areas on the plan.

(e) Generate alternative configurations by laying card cut-outs onto the gridded compartment plan or magnetic board (see figures 13 and 14).

(f) Prepare cut-outs for standing and or seated personnel. These must represent dimensionally the space requirement and must show the operator's orientation or direction of view.

(g) For recording layout, either draw around shapes or photograph.

11.1.3 Three-dimensions. The employment of three-dimensions enables designers to visualize the space envelope required for the workplace and the workspace(s) within. Spatial relationships between the controls and displays for manipulation and monitoring by the operator, as well as arm and leg reach and viewing angle parameters, can be arranged for analysis. Clearance, fit and reach parameters can also be derived by the construction of three-dimensional scaled manikins. Pairs of manikins can be constructed by skilled modelling craftsmen using anthropometric data sources (See Part 2 of this Defence Standard). The large sized manikin should be principally used to evaluate clearance, fit and near reach parameters, whereas the small sized manikin should be primarily employed to evaluate far-reach parameters. Manipulating manikins will require careful consideration, otherwise the normal range of joint movement will be exceeded beyond their limiting range and result in a poorly derived posture. Access to the preliminary, three-dimensional workplace can be achieved by the hinging of roof sections, and one or more side sections, thus allowing plan, side and end elevation views to be seen.

11.1.4 Expanded Polyurethane foam model

11.1.4.1 Purpose. To generate and evaluate alternative equipment configurations in three-dimensions. To check basic anthropometric feasibility, usually for an individual workspace layout.

11.1.4.2 Information required for this technique

(a) Approximate equipment size.

(b) Location of critical controls and displays.

(c) Some preliminary layouts and sketches suitable for evaluation.

11.1.4.3 Method

(a) Size of the equipment model should be based upon the large sized manikin (1:5 scale is recommended), see figure 1.

(b) A sufficient quantity of expanded polyurethane foam to form a base should be obtained.

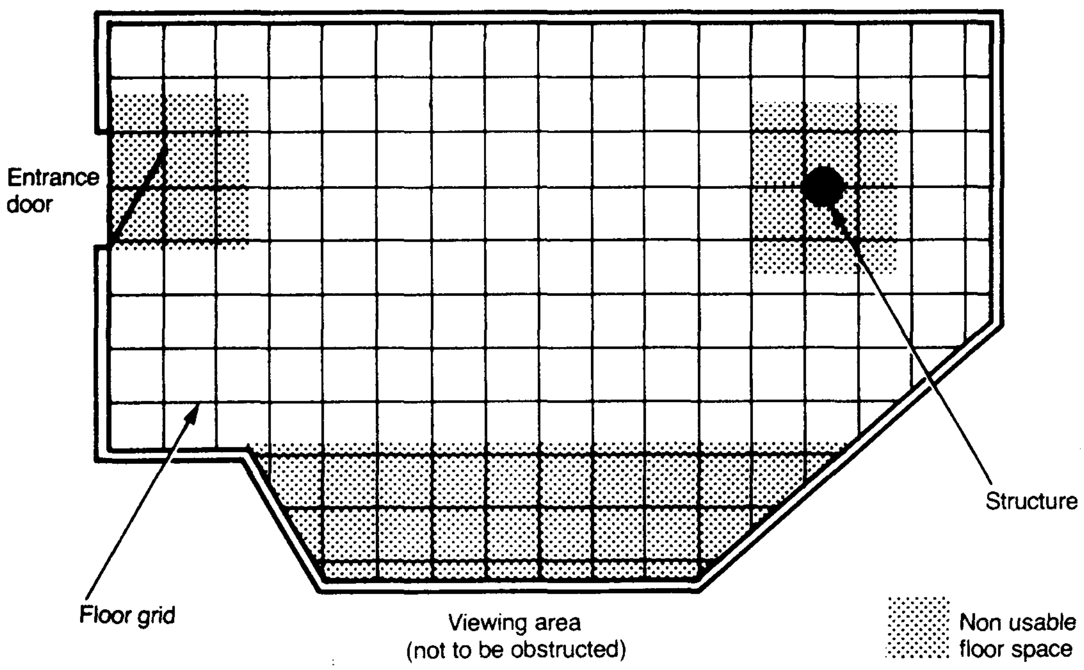


Fig 12 Scale Grid Compartment Area

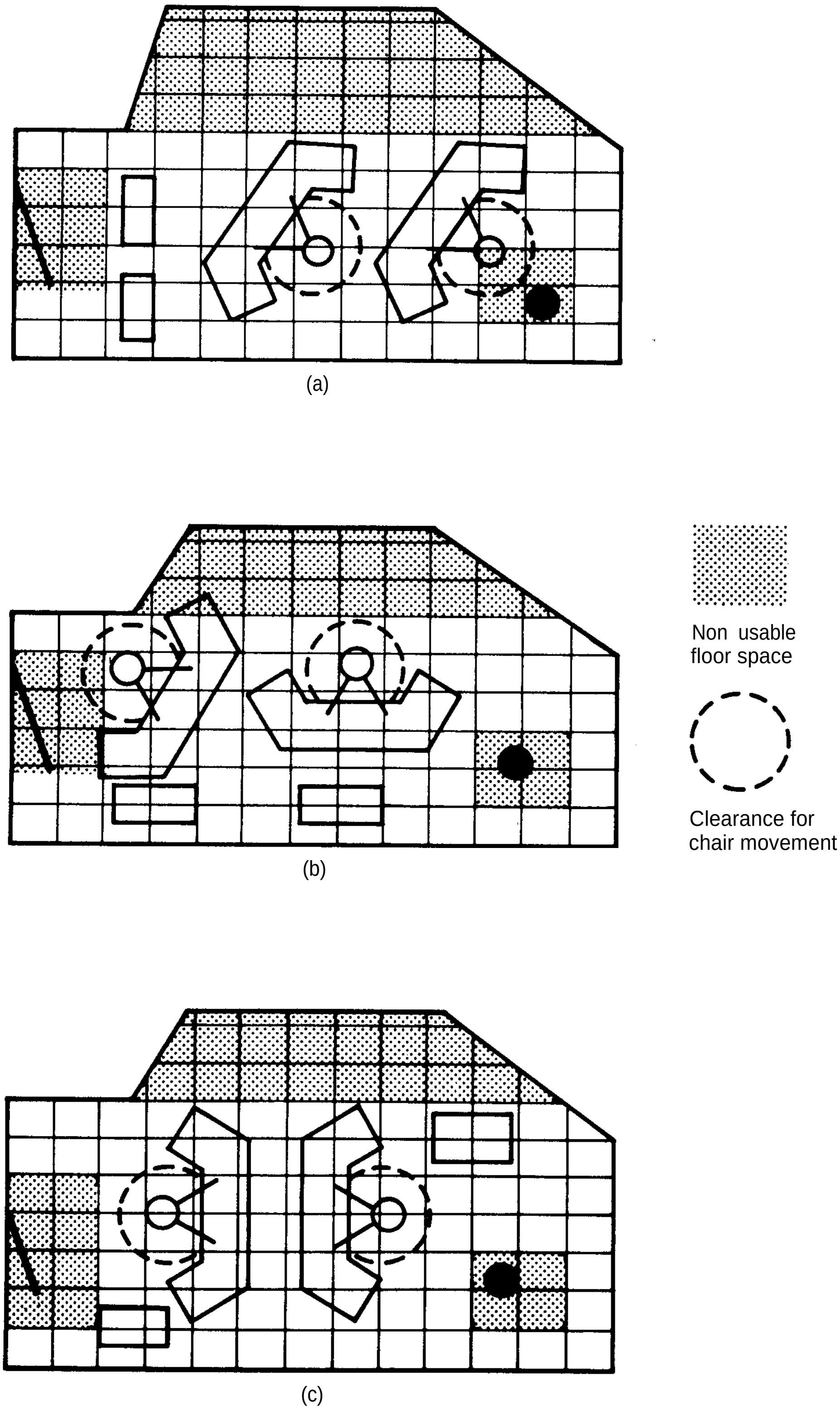


Fig 13 Alternative Grid Configurations

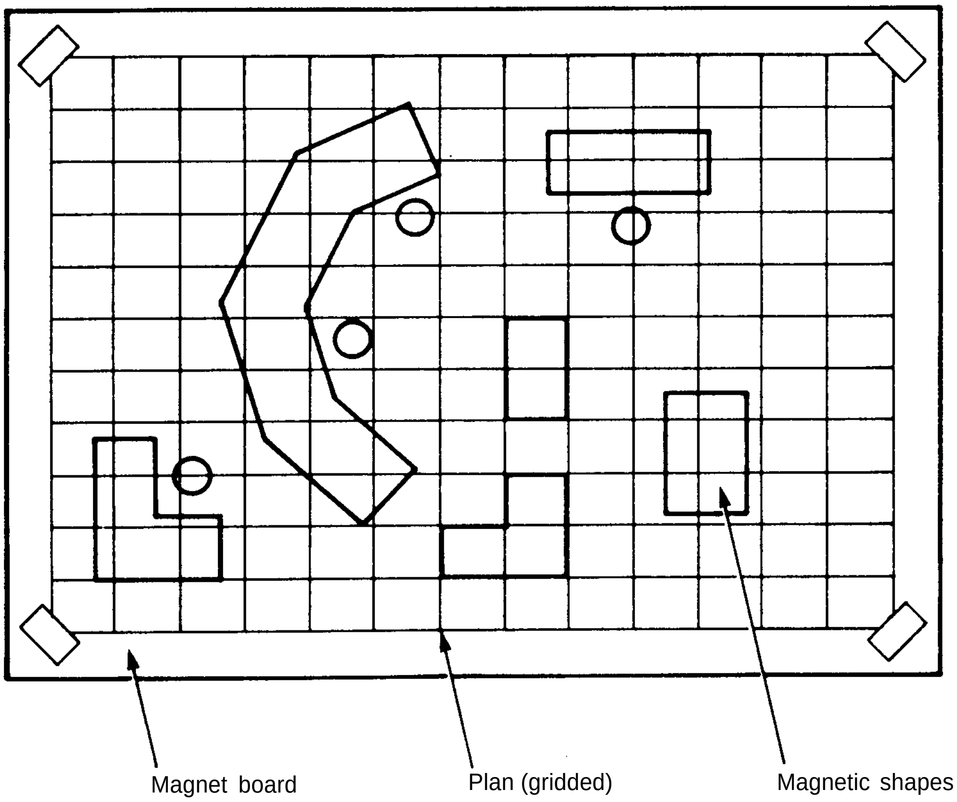


Fig 14 Example of Magnetic Board Representation

11.1.4.3 (Contd)

(c) The equipment should be modelled using a fine saw and file for any required details. It is not necessary to simulate every detail - only those which may affect the equipment location.

(d) Use wires to attach manikin and equipment models to the base, such that their positions can be easily adjusted. Wires will allow for height as well as angular adjustments.

(e) The equipment should be positioned around the manikin and variability of layouts examined in both plan and elevation.

(f) Feasible layouts should be recorded and overall dimensions measured.

11.1.5 'Lego' type model

11.1.5.1 Purpose. An alternative three-dimensional technique (based on the principles outlined in the foam modelling procedure), allows a systematic approach to the ergonomical design of offices and workstations by positioning scale representations of equipment/furniture on a grid board (see figure 2).

11.1.5.2 Information required for this technique

(a) Equipment sizes and values for scaling.

(b) Location of critical controls and displays.

(c) Scale floor area of the workstation or compartment.

(d) Location of windows, doors etc and any non-usable areas.

11.1.5.3 The accuracy of this method is dependent on the density of the locating holes within the grid and can, undesirably, constrain the designer to a square and oblong cubed design scheme.

11.1.6 Preliminary mock-ups. These can be either in reduced scale model form or in full scale.

11.1.6.1 Reduced scale models need not contain any fine detail, but should be precisely scaled for realistic assessment. For interiors, a fifth scale representation is recommended for evaluating the position of displays, sightlines and illumination requirements. Furthermore, this scale will provide continuity for the designer when fifth-scale drawings of the detailed design are produced. Components of the model can be magnetized on to a suitable metal base enabling them to be easily moved about and reduce the risk of their displacement.

11.1.6.2 The full scale mock-up is constructed by using a laminated wooden base for rigidity, on which either sheets of cardboard or expanded polystyrene are attached. Panel drawings and or simulated controls and displays can then be attached. Controls and displays can also be made out of stiff cardboard on which either pictures or photographs are mounted, thereby giving a three-dimensional appearance similar to that of the hardware they represent. If it appears desirable to alter the plane of a particular panel from either the horizontal or vertical, a low cost independent structure can be made to which the mocked-up components are

11.1.6.2 (Contd)

fitted. Suitable metal panels can also be attached to the structure enabling the magnet technique previously described for panel components to be implemented.

11.2 Detailed design

11.2.1 Scaled drawings including manikins

11.2.1.1 Once scaled engineering drawings are produced and issued, scaled two–dimensional manikins can be constructed to provide initial estimates of workplace fit. Sets of manikins should be prepared in a range of sizes and scales. For land based systems, 1/10 and 1/5 scale drawings in orthographic projection are often employed to depict initial detailed design and therefore manikins of these scales should be constructed. Basic design strategy for land-based vehicles using anthropometric data is to design for a specified range of operators by providing adjustments, and this strategy should be used whenever economically feasible. Seating is a common example of this design strategy. However, if the cost of seat adjustment within the constraints of the workstation is low, and there is available sitting height, the percentile range should be extended to accommodate a wider population range.

11.2.1.2 Manikins representing the 5th and 95th percentile are usually constructed. The 5th percentile is used to evaluate reach parameters with the exception of near reach, when the 95th percentile is used. The 95th percentile is used to evaluate clearance and fit parameters. Both manikins are required to evaluate eye–level reference requirements, since both short and tall operators must be accommodated. An exception to this percentile range would be for escape hatches and tunnels, where all the percentile range (ie up to the 99th percentile operator) must be accommodated. Manikins can be made out of transparent plastic. Simple side-on manikins are usually constructed in six parts (head, trunk, upper arm and leg, lower arm and leg), and are riveted about pin joints for free but simplistic articulation. Greater accuracies may be obtained by making the manikin more elaborate, provided that the basic anthropometric data are available. In this case, the trunk of the body member is usually articulated in 3 places, the head and neck separately about prescribed slots, and the foot separately pivotted from the lower leg at the ankle joint. Normal and limiting joint angles can also be depicted. Further information on manikins are contained in Part 2 of this Defence Standard, and Pheasant, (1986). Examples of 5th and 95th percentile applications to design problems are contained in the AJ Metric Handbook, Section 8.

11.2.2 Scaled drawings including computer aided design

11.2.2.1 The SAMMIE system for aiding man-machine interaction evaluation is a good example of the computer modelling of anthropometric data. The computer stores anthropometric data to generate a 3D image of an operator as a specified percentile. The displayed image is projected on a graphics screen in either plan, elevation or perspective, and manipulated under user control in the same environment, for evaluating projected layouts with respect to clearance, reach, fit and field of view.

11.2.2.2 SAMMIE UK Ltd state that, "The user communicates with the computer by selecting various commands from those displayed on the graphics screen, using either the keyboard or by pointing with a light pen or mouse.

11.2.2.2 (Contd)

These commands are presented in either functional groups or menus of which there are nearly 40. Among the factors which CAD can help evaluate are reach, fit, working postures, comfort, vision, and reflective surfaces."

11.3 Full-scale mock-ups and models

11.3.1 Introduction. Full scale workplace mock-ups are so useful that all major system development agencies and many minor ones construct them. The simplest mock-ups must be developed as early as possible to have the greatest value, as theoretical analysis are not infallible. They can be applied throughout the design process to show immediately whether or not a design is practicable. Mock-ups serve a variety of purposes including assisting in:

(a) The evaluation of the workplace and the visualization of the man-machine interface.

(b) Control room and compartment layouts.

(c) Design reviews.

(d) Serving as a training aid.

Also they serve a useful purpose for obtaining comments from the experienced user and human factors specialist as to the practicality of the workplace design, by ensuring that items are not overlooked.

11.3.2 Land systems

11.3.2.1 For current armoured vehicle applications, special human factors aspects to consider in full scale mock-ups include entry to and rapid exit from every crew-station through a hatchway, usually located overhead. The seat is invariably used as a step during these operations and must be sufficiently robust to withstand being jumped on from the height of the hatch opening during entry, and stood on when leaving the vehicle. A means of emergency escape by an alternative route and hatch, as well as rescue of an 'injured' crewman from any crew station requires evaluation. Head-out and head-in operation are also special requirements, particularly for the commander and driver of the vehicle. Currently, seating for them must have sufficient adaption and adjustment to allow for both seated head-out and head-in operation. Seats must be designed to provide correct postural support and reduce the dynamic effects of road and cross country vehicle vibration. Safe interior design including satisfactory restraints, also requires special consideration in order to avoid contact injuries from sharp corners and projections. Hand-holds should be fitted to assist crew exit and for riding the vehicle motion.

11.3.2.2 External vision, when head-in and closed down under operational conditions, is also a major feature for design evaluation, particularly external close-in vision. Viewing requirements must be defined at the mock–up stage, before the external shape and structure of the vehicle has precluded their potential effectiveness. Where viewing devices are fitted, an assessment of potential blankspots for close-in vision should be identified. The commander will require the greatest all-round visual coverage in order to enable him to command and control the vehicle. Sighting systems for surveillance and target acquisition will also need to be defined.

11.3.2.3 Special attention at the mock-up stage must be given to provide spatial requirements for an integrated environmental life support system which can be controlled from under armour.

11.3.2.4 The force required to open and close armoured hatches and doors cannot usually be assessed on the wooden mock-up, but estimations of their weight should be made available by the equipment designer, to enable the human factors specialist to consider whether or not power assistance is required. In the event of power failure, a reversionary means of manual control must be designed into the mock-up.

11.4.1 Sea systems

11.4.1.1 Workplace design for sea systems should be maximized for crew effectiveness. The principle space-related features on a vessel affecting crew performance are:

(a) Head clearance.

(b) Cramped living and working conditions.

(c) Passageway clearance.

(d) Space organisation.

11.4.1.2 Special features aboard sea systems which are particularly important with respect to crew efficiency and safety include:

(a) Lighting.

(b) Ventilation.

(c) Communications.

(d) Safe design of ladders, stairways, railings, and handholds, non-slip decking and stair surfaces, and overhead equipments.

(e) Escape, survival and rescue.

(f) Crew protection in combat.

(g) Special equipment-produced hazards.

11.4.1.3 At this stage of sea workplace design, the designer should include those spatial features which relate to the anthropometric clearance dimensions of the User population, as well as integrating as many of the aboard-ship special features as possible. Further information can be found in Woodson (1981).

11.5.1 Air systems

11.5.1.1 For air systems a satisfactory standardized workplace is considered to be more important than designing an optimal one. Military agencies are particularly adamant that cockpits are standardized in order to minimize pilot confusion when transferring between aircraft. These arguments should also be applied to land and sea systems as well. Anthropometric dimensions which have proved to be of greatest value with respect to workspace in air craft are:

11.5.1.1 (Contd)

(a) Sitting height.

(b) Sitting eye height.

(c) Forward functional reach.

(d) Elbow functional reach.

(e) Buttock to knee length.

(f) Shoulder breadth.

(g) Hip breadth (sitting).

(h) Knee height (sitting).

Restrictions of importance are a minimum height limit for selecting pilots, and a maximum limit of thigh length to account for clearance during pilot ejection.

11.5.1.2 Typical air systems design areas requiring human factors consideration in the aircrew workplace are:

(a) Workplace arrangement, as this promotes efficiency, safety and avoidance of discomfort for the pilot.

(b) Vision (external and internal) to include optical quality of windshields, fields of vision, cockpit and cabin illumination.

(c) Seating (normal and ejection).

(d) Separable crew compartment.

(e) Controls and displays for:

(1) Flight.

(2) Engineering.

(3) Special operations.

(4) Communications (internal and external).

(5) Weapons systems.

(6) Lighting (internal and external).

(7) Internal environmental systems (including heating, ventilation and air conditioning), cabin pressurization, and design of oxygen equipment.

(8) Navigation.

11.5.1.2 (Contd)

(f) Map stowage.

(g) Sound proofing.

(h) Safety factors for take off, landing, (including crash landing on ground and water).

11.6.1 Models

11.6.1.1 Models are reduced-scale representations and are less useful than a mock-up because they can deal with fewer man-machine interface features. However, they can be used for preliminary room layout, equipment location studies, and aiding design reviews and presentations. As design tools, they are simple, inexpensive, lightweight and portable.

11.6.1.2 Models may also be used for the purposes of simulation, for example, in terrain model boards for certain types of simulator, or as the 'picture-source' for image processing in a computer simulation.

11.7 Workspace and workstation requirements

11.7.1 Introduction. Workstations are designed for seated or standing operations or for combined 'sit-stand' operations. In some cases the decision as to which type is used will be defined either by specification or by equipment constraints. In other cases the advantages and disadvantages of each will need to be considered before a decision can be made. Vehicle workstations and those where equipment is shared require particular attention in terms of equipment layout. Consequently the designer should fully consider the relative advantages of each equipment layout concept in relation to the tasks to be performed. The appropriate type of workstation (seated, standing or sit-stand) can be chosen on the basis of the following principles and general considerations:

11.7.2 Seated operator workstations

11.7.2.1 For a seated task, the choice of work seat is an obviously important factor where postural support and attention require maintaining over long periods. A correctly designed workseat profile (see figure 15) produces little pressure in the spinal invertebral discs and requires very little static muscular effort. Therefore any incidence of discomfort would be reduced and provide for:

(a) improved body stability and equilibrium;

(b) a reduction in overall static muscular workload and reduced energy consumption;

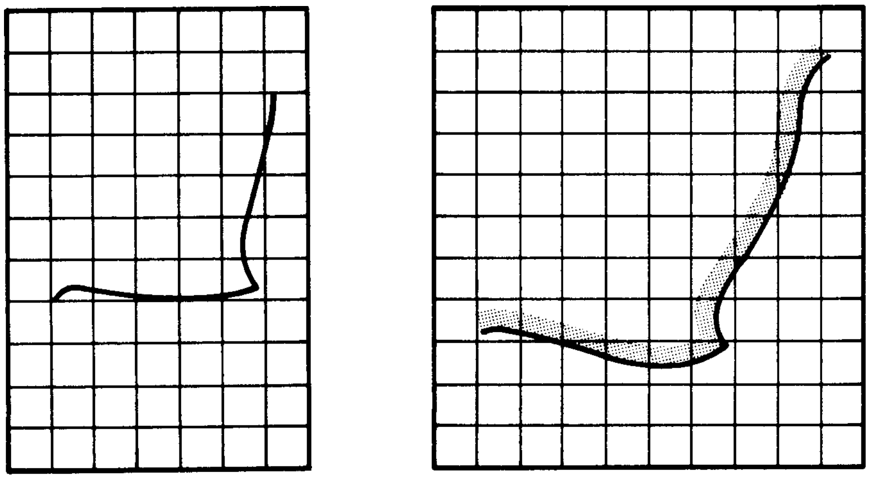
(c) the operation of pedals or foot controls by:

(1) the ability to use both feet.

(2) improving accuracy.

(3) allowing larger control force and movement application.

(d) the achievement of fine and precise hand movements.



Seat profiles of a multi-purpose chair (left)
and an easy chair (right) both of which cause the
minimum of subjective complaints.

Grid: 100 x 100 mm

Fig 15 Seat Profiles

11.7.2.1 (Contd)

(e) better blood circulation in the body.

NOTE: A disadvantage is that the mobility of the seated operator can be restricted to a certain extent.

11.7.2.2 Critical dimensional factors for the development of the seated operator workstation includes

(a) the correct eye position relative to sights, displays and any other visual requirements;

(b) an adjustable seat height, the seat squab, backrest depth and breadth, along with the squab and backrest angles to provide correct postural support;

(c) clearance for the lower limbs, including space for entry and exit;

(d) hand and or foot reach requirements for operating controls;

(e) a common eye height for large and small operators, achieved by adjusting the seat.

11.7.2.3 Figure 16 shows typical dimensions based on the US population. These should be regarded merely as guidelines, as the exact dimensions will be specific to each individual situation. They are, however, sufficiently close to the dimensions for the UK population for the data to be used without modification. Dimensions for chairs, desks and tables are given in BS5940, Part 1.

(a) Worksurface. A horizontal workspace of at least 760 mm wide and 400 mm deep should be provided where space is required for writing or other similar tasks, and should be consistent with operator reach requirements (see Figure 6).

(b) Worksurface height. Desk tops and writing tables should be 740 to 780 mm above the floor. It should be noted that sitting height is related to worksurface height and is not an independent dimension. However, where a keyboard is to be used, the work surface should be lower to allow for the key height. Consequently, the height of this section should be set at a lower height between 650 mm and 680 mm (Grandjean 1980). However thin keyboards can be placed on desk tops and writing tables thus providing more kneespace for the seated operator. When a seat height is fixed, worksurface height should if possible be made adjustable.

(c) Display placement, normal. Visual displays mounted on vertical panels and used in normal equipment operation should be placed within a vertical arc of 30° either side of the seated horizontal line of sight. The viewing distance should be appropriate for the size of detail to be resolved.

(d) Display placement, critical. Indicators that must be read precisely and frequently should be placed within a vertical arc between the horizontal and 15° below the horizontal line of sight. They should be placed no further than 530 mm laterally from the centre line of the operator.

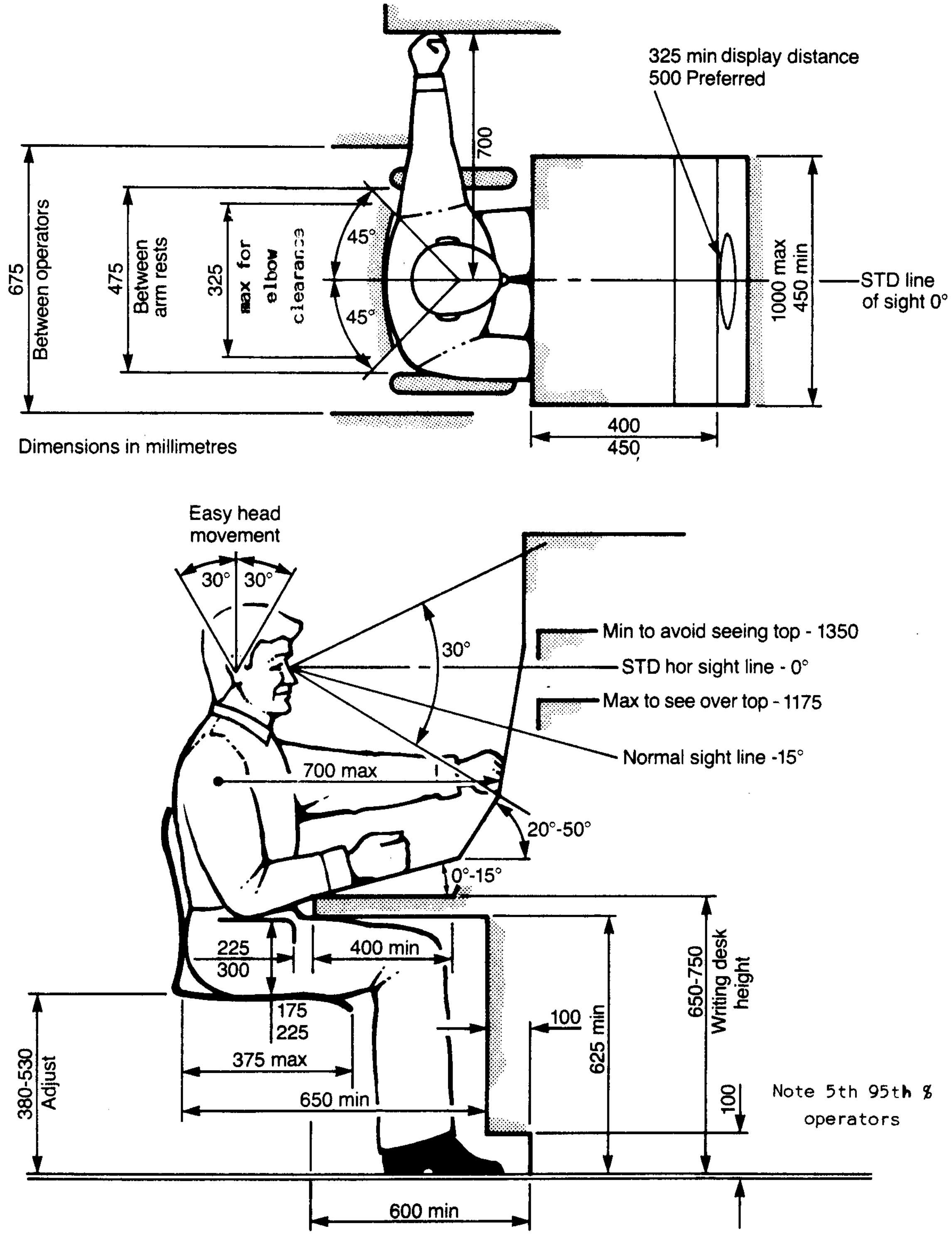


Fig 16 Suggested Dimensions for a Seated Operator's Workplace

11.7.2.3 (Contd)

(e) Warning displays. Critical warning displays should be located immediately in front of the operator and should have special attention alerting properties, such as flashing.

(f) Control placement, normal. All controls mounted on a vertical surface and used in normal equipment operation should be located between 720 mm and 1380 mm above the floor level. The precise location is dependent on the nature of the control action to be performed and seat height.

(g) Control placement, critical. Controls requiring precise or frequent operation should be mounted between 720 mm and 1260 mm and 1260 mm above the floor level. Naturally the precise location and orientation of the control is dependent on the control type and nature of the control action to be performed, and the seat height. When the control panel width exceeds 1800 mm, a 'wraparound' console is one solution which allows all controls to be within reach. Left and right segments should be at an angle of 110° to the central segment, which minimizes excessive movement and stretching (see Figures 6 and 17 for effective reach parameters).

NOTE: For a fuller coverage of display design and control layout etc, refer to Parts 7 and 10 of this Defence Standard.

11.7.3 Workseat design

11.7.3.1 Workseating should provide an adequate supporting framework for the body relative to the activities that must be carried out. Chairs used with 'sit' consoles are chosen to be operationally compatible with the console configuration in terms of arm rest dimensions, provision of castors etc. In order to provide adequate support for the body, a workseat with a high backrest is recommended. This is convex in the lumbar region to provide support, and is also slightly convex in the shoulder region. This support is essential to avoid postural discomfort over long periods in a seated position.

11.7.3.2 The multi-purpose chair shown in figure 15 provides support to the lumbar region when the operator is sitting upright in a working posture, and reduces the muscular activity necessary to maintain this position.

11.7.3.3 The ability to change and vary the sitting posture is important for reducing muscle fatigue, and many commercial office chairs now move and pivot with the movement of the occupant. These are called 'active' chairs. As the occupant leans backwards, the angle between seat pan and backrest is increased by the combined movement of the backrest and the seat pan, simulating the profile of an easy chair (see figure 18).

11.7.3.4 General recommendations. Recommendations for the design of a workseat shown in figure 19 are as follows:

(a) Compatibility. An important consideration is the distance from the seat height to the work height which should be between 270 - 300 mm, assuming that the elbows are held downwards with the arms at right angles.

(b) Stability. The seat should be stabilized against tipping or slipping. It should have five feet set in a circle at least as large as the seat surface itself (ie 400 - 450 mm diameter).

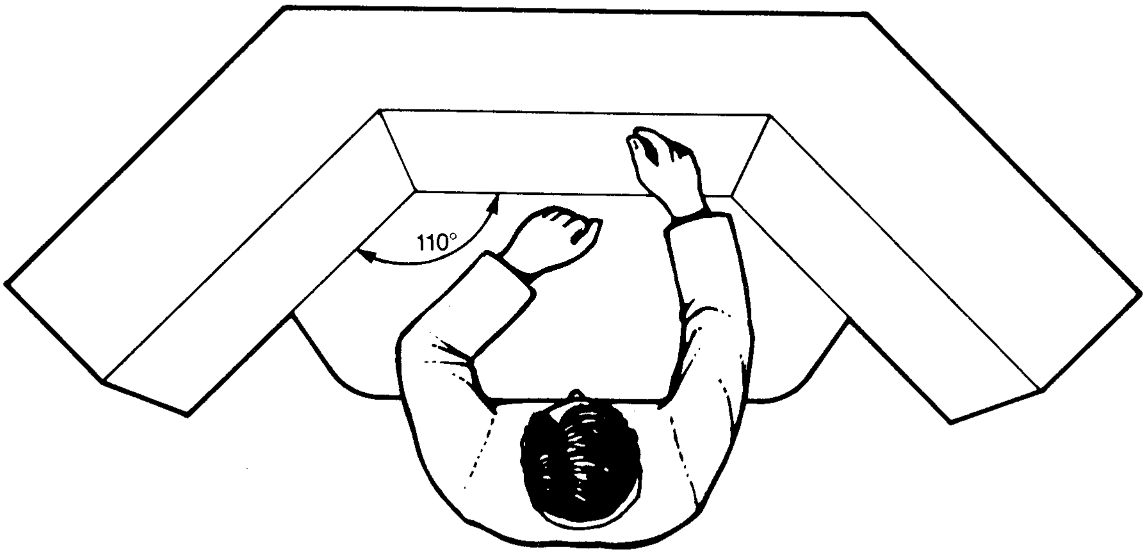


Fig 17 Horizontal Wrap-Around Console

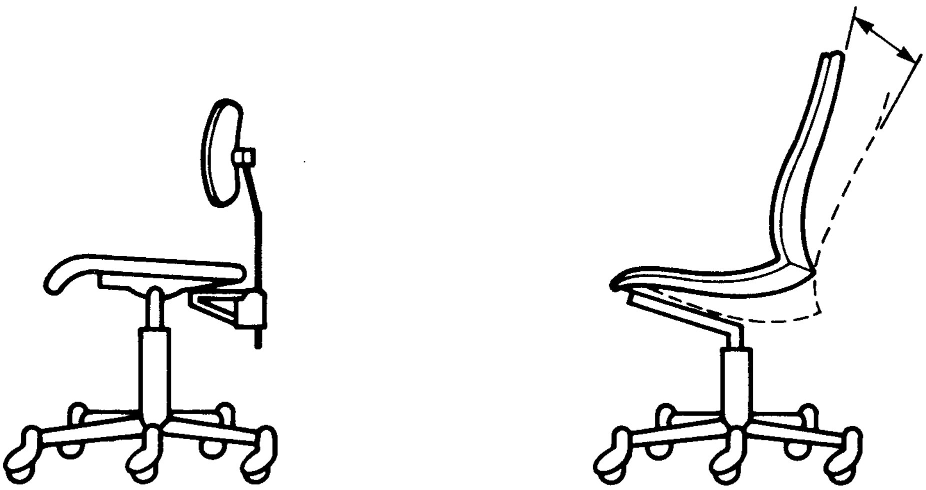


Fig 18 Tilting Chair Type with Backrest (Right)
Commercial Chair Type with Adjustable Backrest (Left)

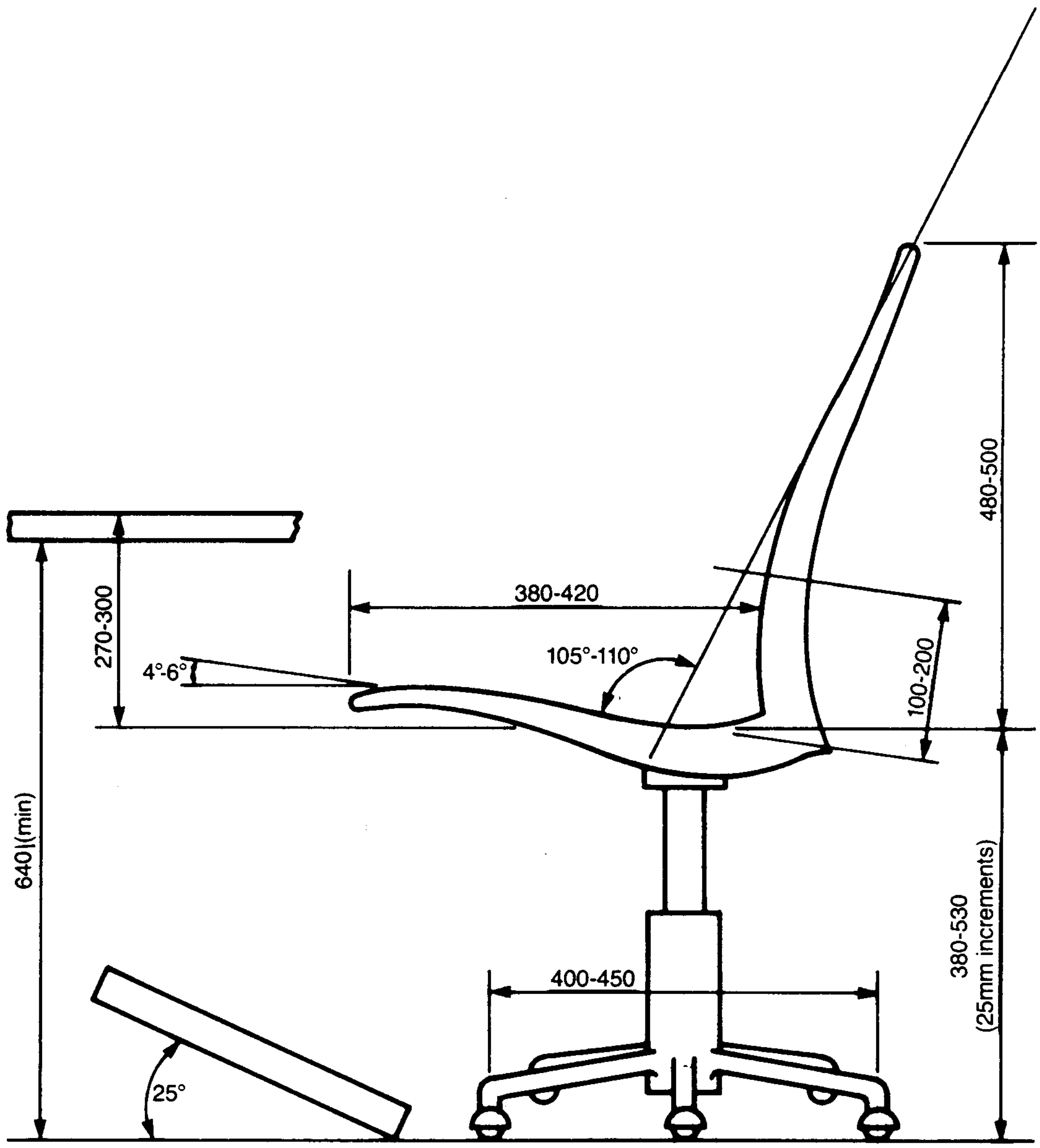


Fig 19 Typical Work Seat Design

Note: Dimensions are in millimetres

11.7.3.4 (Contd)

(c) Vertical adjustment. Provision should be made for vertical seat adjustment from 375 - 530 mm in increments of no more than 25 mm each. Continuous adjustment is desirable as it can more easily be carried out whilst seated. All seating adjustments should be easy to make when seated.

(d) Backrest. A supporting backrest that slopes at an angle between 105° and 110° should be provided. The backrest should provide correct and adequate postural support for the lumbar and thoracic regions of the spine.

(e) Cushioning. The seat pan needs sufficient padding and firmness to help distribute the body weight pressures particularly from the ischial tuberosities (Oborne D J, 1982, page 179).

(f) Seat covering. The covering should dissipate the heat and moisture generated from the sitting body dependent on the environment. The fabric should resist the natural forward slipping movement of the body, particularly when there is fidgeting over a long period of time. Adequate thermal and mechanical techniques exist to allow the designer to make the appropriate measurements (Oborne D J, 1982, page 179).

(g) Seat surface. Should be 400 - 450 mm across and 380 - 420 mm from front to back. A slight hollow in the seat should be provided, with the front edge rounded and turned upwards at approximately 4° - 6° to prevent the buttocks from sliding forwards.

(h) Arm rests. Unless otherwise specified or unless the nature of the task precludes it, eg typing, driving, 'high-density' passenger seating where restriction to free movement of the arms and shoulders may occur, arm rests should be provided. Arm rests that are integral with operators chairs should be at least 50 mm wide and 200 mm long. Modified or retractable arm rests should be provided if necessary to avoid contact against an associated console, and should be adjustable from 180 mm to 280 mm above the compressed seat pan.

(i) Foot rests. Foot rests are required for short legged people if their worksurface or seat pan is too high and non-adjustable. Their design should not obstruct long-legged users.

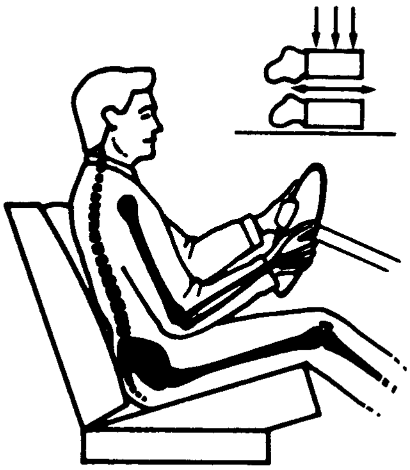
(j) Knee room. Knee and foot room beneath worksurfaces should not be less than the following dimensions:

(1) Height 640 mm. If a foot rest is provided this dimension should be increased accordingly:

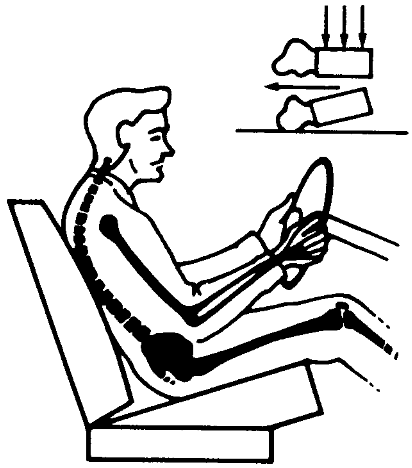
(2) Width: 510 mm;

(3) Depth: 460 mm.

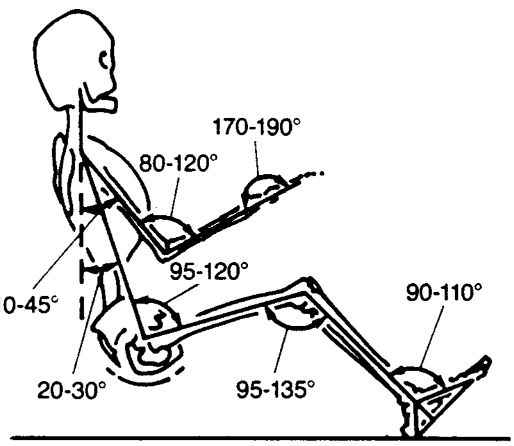
11.7.3.5 Automobile driver's seat. Adequate back support is required for seating including automobile driver seats. Figures 20A and 20B illustrate desirable and undesirable postures in relation to the spine. With unsatisfactory support (shown in figure 20B) and angles between the vertebrae (shown in the inset) can generate discomfort and conceivably cause spinal complications. The angles of the various body joints shown in figure 20C are those proposed by Rebiffe (1969), and provide the basic driving posture considered to be desirable in items of anthropometric considerations.



(A) Desirable



(B) Undesirable



(C)

Fig 20 Anthropometric Considerations in Designing Seats for Automobile Drivers

11.7.4 Standing operator workstations

11.7.4.1 A standing posture for the operator is advantageous in the following specific situations:

(a) for mobility to reach controls and monitor displays over a particularly large panel area;

(b) when precise manual control actions are not required;

(c) when it is impossible to provide leg room for a seated operator;

(d) for sightlines to adjacent surroundings;

(e) for simple go/no-go or on/off foot controls where large force applications are not required.

Standing operator workstations are not recommended for long duty periods. For short duty periods, operators can minimize fatigue by moving about. The design of workstations should insure that controls and displays are located within the smallest operator's reach and visual field. Portable platforms for small operators to stand on are a safety hazard and are not recommended. Generalized workplace dimensions for a standing operator at an equipment console are shown in figure 21. Again, these are provided purely as a guide and need to be contrasted against the requirements for each specific situation.

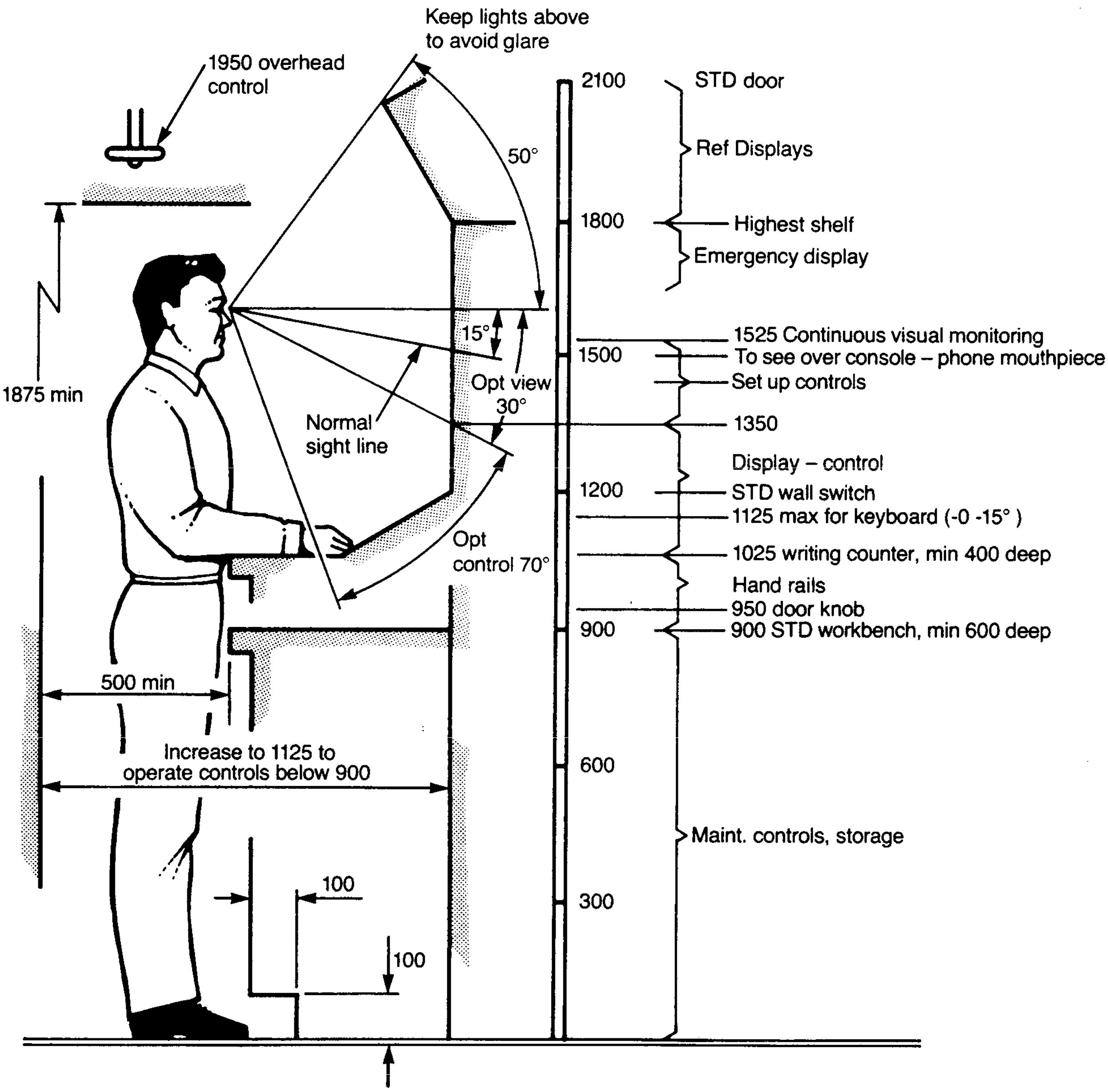
Manual plotting on a rotating table or tactical plotting board is another common standing operation. Although plotting boards are generally vertical and drafting tables generally horizontal, there are instances where plotting angles between these extremes may be desirable. Because of constraints imposed by plotting board configurations, operators may be unable to reach as far when the board is horizontal, as when it is in various upright positions, see figure 22. Therefore these applications should be developed for the smallest representative user.

11.7.4.2 Standing operations. Figure 21 shows some typical dimensions of a standing operator's workspace. These dimensions are based on the USA population but are sufficiently close to the UK Population to allow the data to be used without any modification.

(a) Worksurface height. Convenient worksurfaces to support job instruction manuals, worksheets etc should be provided for standing operators. Work benches and other work surfaces should be 915 ± 15 mm above the floor, unless the task or other operational factors override this.

(b) Normal display placement. Visual displays mounted on vertical panels and used in normal equipment operation, should be placed in an area between 1040 mm and 1780 mm above the floor and should be easily accessible.

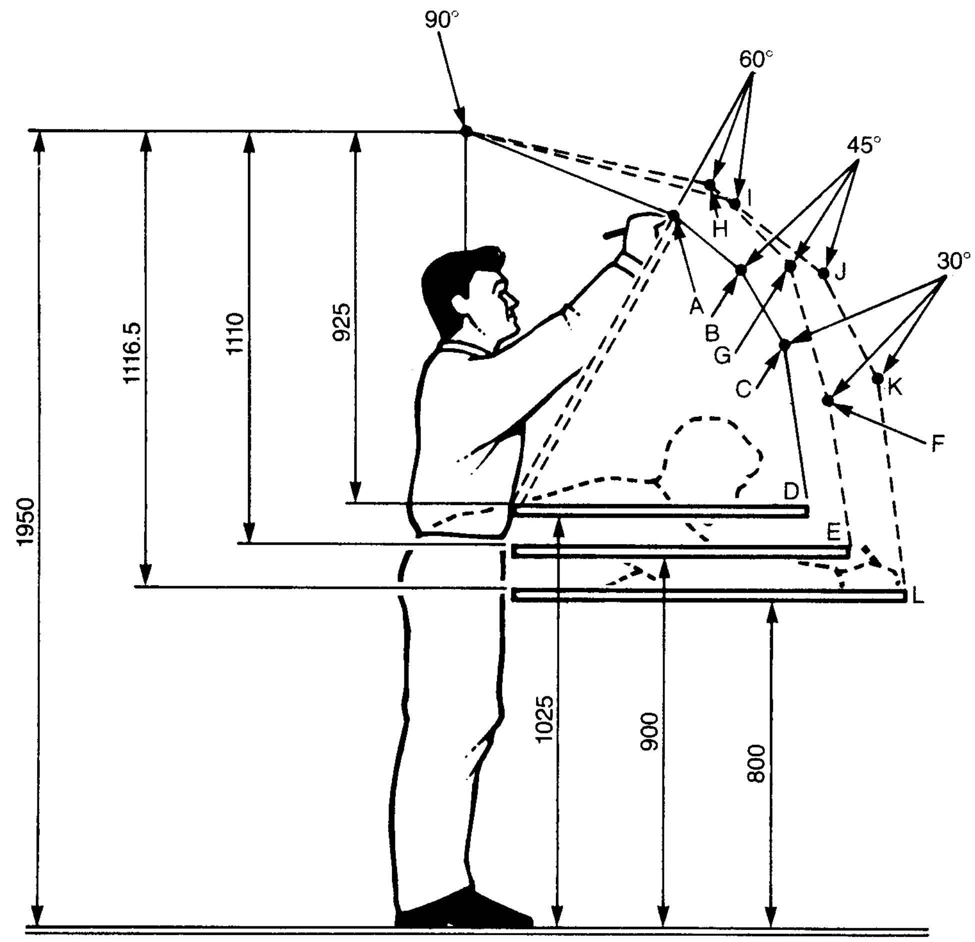
(c) Critial control placement. Controls requiring precise or frequent operation and emergency controls should be mounted between 870 mm and 1350 mm above the floor and no further than 530 mm laterally from the centreline of the standing operator.



Note: 5th to 95th % operators

Fig 21 Suggested Parameters for a Standing Operator's Workspace

Note: All dimensions are in millimetres



Depth of board

A – 876	G – 1003
B – 838	H – 1041
C – 813	I – 1130
D – 762	J – 1092
E – 902	K – 1080
F – 952	L – 1029

Fig 22 Drafting and Plotting Board dimensions
(Based on an approximate 5th percentile man)

Note: All dimensions are in millimetres

11.7.5 Sit-stand operator workstations

11.7.5.1 Combination sit-stand operator workstations are recommended from a physiological and orthopedic point of view. Standing and sitting imposes stresses upon different muscles, so that each changeover relaxes some muscles and stresses others. For example, the operator may require the stability provided by a seat for precise control actions and the mobility provided by free standing operation for the monitoring of large functional panel areas.

11.7.5.2 The combination sit-stand operator station is also useful when the operator is required to be on duty for extended periods of time and would benefit by alternately sitting and standing to relieve muscular fatigue.

11.7.5.3 The sit-stand operator station provides a compromise position, giving the operator a high chair for maintaining a seated eye height approximately the same as the standing height. Common uses of this type of arrangement are illustrated in figure 23.

11.7.5.4 One situation in which the sit-stand operator station can be difficult to achieve is where a VDU should be viewed with a minimum of parallax whilst sitting or standing. Variations of the illustrated workplace are possible. Seated and standing operator station configurations should be modified to provide for a common line of sight and adequate knee space.

11.7.5.5 An independently adjustable footrest in the sit-stand layout is a necessity, to allow the ratio of footrest to seat height to be adjusted.

11.7.6 General considerations

(a) Kick space. All cabinets, consoles and worksurfaces that require an operator to stand or sit close to their front surfaces should allow for a kick space at the base of at least 100 mm deep and 100 mm high, or greater to allow for protective or specialized footwear.

(b) Handles. Handles on cabinets and consoles should be recessed whenever possible to eliminate projections on the surface. If handles cannot be recessed, they should be designed to eliminate the risk of injuring personnel and the snagging of their clothing and equipment. For further information on handle dimensions see Parts 10 and 11 of this Defence Standard.

(c) Workspace. Whenever feasible, free floor space of at least 1220 mm should be provided in front of each console. For equipment racks that require maintenance, free floor space should be provided whenever feasible, using the following criteria:

(1) Depth of work area. The distance from the front of the rack to the opposite surface or obstacle should be not less than 1070 mm.

(2) Lateral workspace. The minimum lateral workspace for racks having drawers should be as follows (measured from drawers in the extended position):

(a) for racks having drawers weighing less than 20.4 kg: 460 mm on one side and 100 mm on the other;

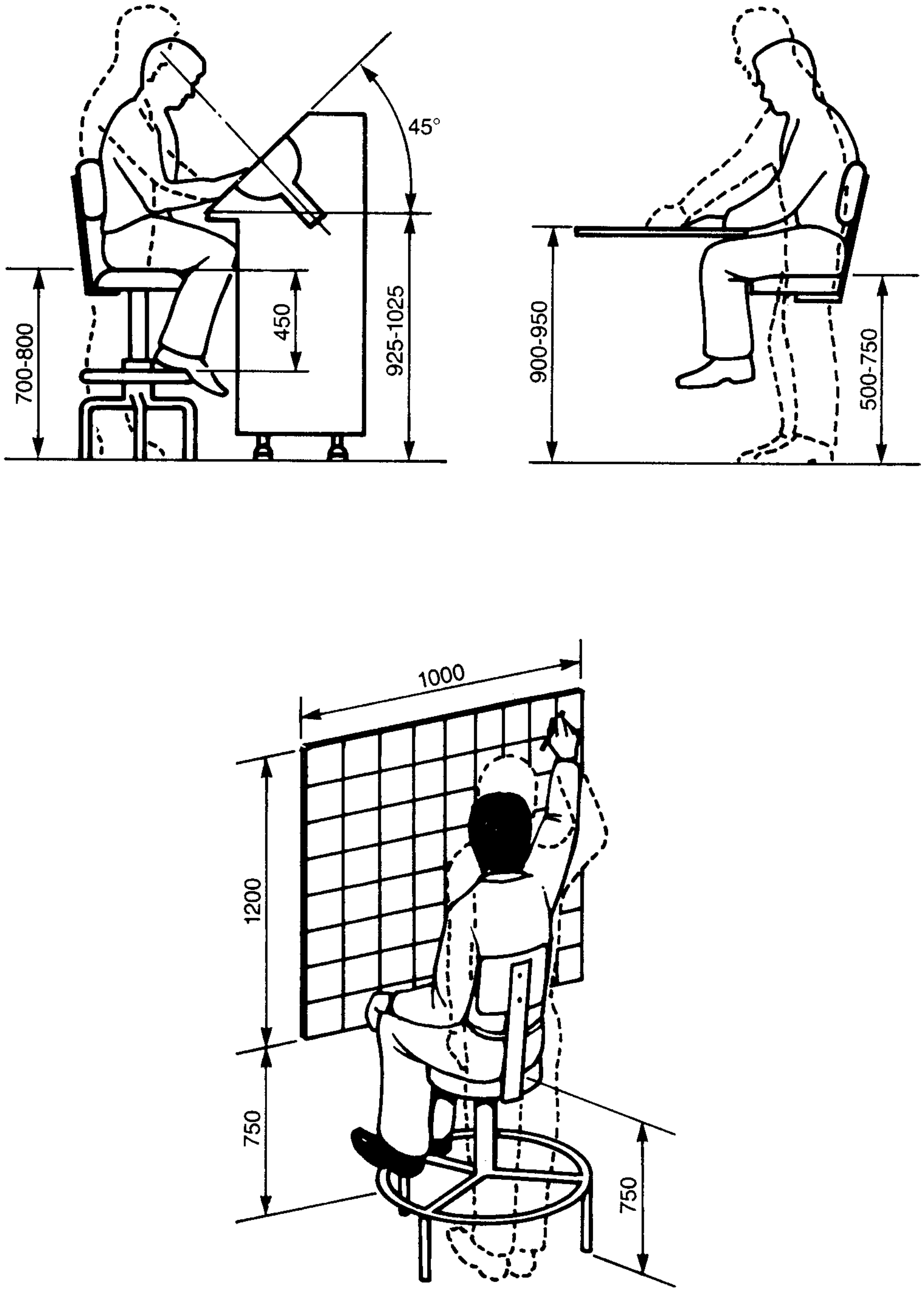


Fig 23 Sit-Stand Workstations

Note: All dimensions are in millimetres

11.7.6 (Contd)

(b) for racks having drawers weighing over 20.4 kg: 460 mm on each side.

(3) Storage space. Sufficient space should be provided adjacent to the workspace for the storage of manuals, worksheets and other materials that are required for use by operational or maintenance personnel.

11.7.7 Common working positions. Some basic anthropometric dimensions of the human operator are given in table A, the standing and sitting positions in which these dimensions are taken are illustrated in figure 24. The male dimensions are based on British Army anthropometric surveys, whilst the female dimensions are based on British civilian figures. These figures are drawn from data in Part 2 of this Defence Standard (Body Size) which should be consulted for more detailed and accurate coverage of anthropometry. The figures given include 33 mm for shoe height and (where appropriate), 64 mm for combat helmet and boots.

11.8 Dynamic simulation of workplace and equipment

11.8.1 Research Simulator

The research simulator in its physical form is equivalent to the functional mock-up, because controls, displays and electronic equipment installations are equivalent to the real workplace. The research simulator is primarily used for investigating operator performance as part of the evaluation of workplace design. For an example of evaluating a research simulator, the following technique can be applied to examine the simulated running of a control room.

11.8.1.1 Some variables which can be examined by simulation

(a) Supervision and verbal communications links.

(b) Circulation of staff including operators, supervisors and maintenance engineers.

(c) Influence of structural elements, hatches, windows etc, on operators and on the layout of the workplace, room or compartment.

(d) Design of information presentations, such as menu structures.

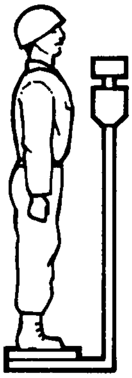
(e) Siting of major shared displays and any other shared equipment.

(f) systems design features including manning levels, task allocation, equipment sharing, normal systems operation and system failures.

(g) workstation performance including maintenance requirements, user requirements (this can be evaluated in more detail for individual workspaces).

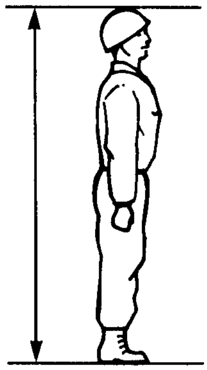
(h) Consideration of environmental lighting schemes.

1



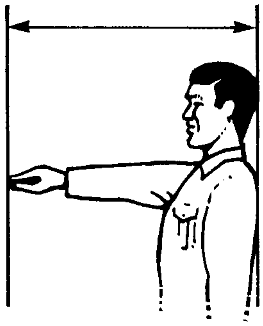
Weight, clothed (including combat clothing, helmet and boots).

2



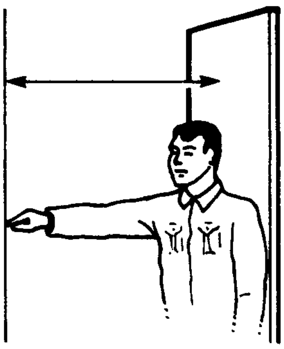
Stature, clothed (including combat clothing, helmet and boots). Standing erect, heels together, measured from floor to top of helmet.

3



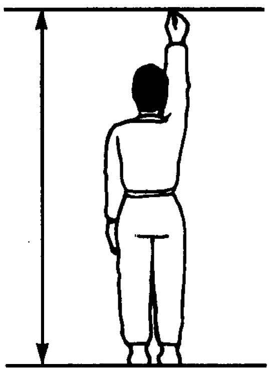
Functional reach, standing erect, looking straight ahead. Both shoulders against wall. Right arm horizontal. Measured from wall to thumbtip in pinch-grip.

4



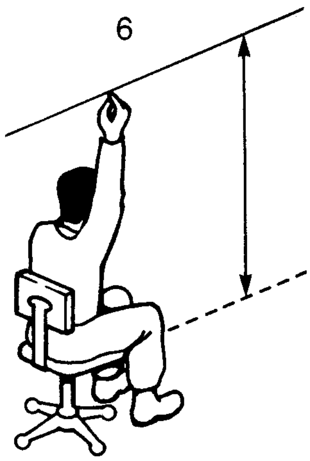
Dynamic torward reach, standing erect, looking straight ahead. Right shoulder extended as far forward as possible with back of left shoulder firmly against wall. Arm horizontal, measured from wall to thumbtip in inch-grip.

5



Vertical functional reach, standing with heels slightly apart. Right arm extended overhead. Measured from floor to thumbtip in pinch-grip.

6



Vertical functional reach, sitting, Right arm extended overhead, Measured from seat surface to thumbtip in pinch-grip,

Fig 24 Anthropometric Data for Workspaces

11.8.1.2 Running trials - method. Simulation should be based upon a previously prepared scenario which should be conducted in real time within the control area full-scale mock-up. For each simulation run, two teams are required to cover all of the roles within the new control room. The simulation would be driven by one of the teams acting to the scenario, who convey the stream of messages (by simulation computer, radio and telephone links) to the second team, who respond to them while working within the mocked-up complex. Throughout the running of each simulation trial or scenario, a detailed record is made of the performance of the layout being tested. This maybe in terms of errors and numbers of calls or messages handled, for instance. At the end of each trial, participants are asked to comment on the performance of the layouts by discussion, and by means of individual questionnaires. Any video recordings taken may be reviewed at this stage, together with other performance measures.

11.8.1.3 Equipment required. The precise requirements will depend on the system which is being simulated. Some of the following need, typically, to be provided:

(a) Samples of all job aids used (eg message pads, wall maps, directories, orders, and specialist equipment such as electronic displays etc).

(b) Scenarios; these involve pre-arranged scripts for identifying the range of expected external inputs to the system. The precise method of presentation would be dependent on the system being tested, but might include voice inputs, communication channels, pre-recorded CCTV pictures, and computer output, for example.

(c) Pre-recorded background noise should be introduced if this is likely to be a significant operational factor (eg a control room close to a landing strip, a vehicle’s engine noise).

(d) Intercom system.

(e) Radio system.

(f) Furniture including appropriate chairs for each workplace, stacking chairs for briefing and reception areas and tables.

11.8.2 Demonstrators

11.8.2.1 Equipment demonstrators are built to illustrate future trends and possibilities in design, by introducing new technology and techniques. A demonstrator may range from a functioning laboratory workspace to a complete workplace system.

11.8.2.2 An example of a land based research demonstrator is the Vehicle Research Defence Initiative (VERDI) programme, where it is proposed that a joint MOD/Industry collaborative programme will build a demonstrator of an integrated electronic system based on a future Armoured Fighting Vehicle. The overall effectiveness of the integrated system will be demonstrated on a vehicle platform having adequate mobility, to enable the functions of the system to be demonstrated on trials or exercises, and assist the completion of the firm Staff Requirement. The demonstrator will be available for

11.8.2.2 (Contd)

adaption in future years as other sub-systems evolve, thus minimizing the problems of retro-fitting new sub-systems into developed vehicles. However, to maintain commercial awareness, the programme would be balanced between demonstrating advanced technology solutions and practical implementation (RARDE, 1988). For Air systems, an example of the complete workplace system is the Experimental Aircraft Programme (EAP) for the European Fighter Aircraft.

11.8.3 Rigs

11.8.3.1 Static Rig

(a) Static adjustable spatial rigs have been designed for investigating operator control and defining display positioning. Instead of establishing control and display positioning by general reach criteria, human factors specialists can establish the optimum positions by placing the operator in a 3 dimensional framework, unobstructed by preconceived consoles, racks, and bulkheads. For these rigs, the designer should provide an open framework, as this has proved an ideal method of positioning controls and displays relative to the operator. Control and display elements should be mounted on fully adjustable supports so that adjustment can be carried out, until the best position is identified in terms of line of sight or reach and the control device can be operated throughout its intended excursion. It should also be possible to attach key visibility elements to evaluate fields of view.

(b) Static spatial rigs can also provide a means of obtaining the critical workspace dimensions required by the user population. Using a multi-adjustable seat, limits of dynamic reach and clearance dimensions can be established for a range of reclined seated postures, and identify possible constraints on reach dimensions and reduced clearance dimensions caused by clothing bulk. Limits to reclined seated postures with respect to lines of sight to displays; the operation of both hand and foot controls, and be identified within the spatial rig.

11.8.3.2 Mobile rig

(a) Manned land-based workplaces such as mobile test rigs, can be designed to test vehicle suspension and automotive performance. In these circumstances, the human operator is suitably protected to ensure that excessive vibration and noise spectra are not exceeded.

(b) Also a static vehicle hull motion simulator can be used as a base and combined with a fire control turret rig, in order to investigate the stability aspects of, for example, a Main Battle Tank (MBT) main armament. when human operators are included, it is essential that such a rig is man-rated by human factors specialists, to ensure the safety of the occupants.

11.8.4 Training simulator

There are many different types of training simulators (ie weapon trainers, operational control room, and flight simulators). A training simulator should be used when:

(a) It is less expensive than the actual equipment, but still represents the essential and realistic task elements.

11.8.4 (Contd)

(b) It is the only feasible way to practice a task, where lack of practice on the actual task would be dangerous, particularly if an error was made.

(c) It is more reliable for practice purposes than the actual equipment.

(d) It permits more effective control over the learning process than the actual equipment.

11.8.5 Training simulator design

11.8.5.1 Each training simulator is unique, and it is impossible to state specific design principles which are applicable to all of them. However, certain general principles can be stated. These are to design:

(a) for both usual and unusual operational patterns.

(b) for easy access.

(c) to ruggedise the training simulator.

(d) for reliability and maintainability.

(e) for simplicity.

(f) to provide efficient conditions for learning.

(g) to teach specific tasks.

(h) to provide proper feedback.

(i) for practicing difficult procedures that require learning.

11.8.5.2 In summary, design principles for training simulators should be relevant to specific training objectives. The designer must decide when symbolic representation, fidelity of displays and controls, or simulation of operational equipment will facilitate learning.

11.8.6 Simulator fidelity

The best overall design guideline for fidelity of simulation is how realistically the task situation is represented by the training situation.

Fidelity of simulation consists of three different components:

(a) equipment fidelity;

(b) environmental fidelity;

(c) subjective fidelity.

11.8.6.1 Equipment fidelity is the degree to which the simulator duplicates the appearance and 'feel' of the operational equipment.

11.8.6.2 Environmental fidelity is the degree to which the simulator duplicates the sensory stimulation (excluding control feel) which is received from the task situation.

11.8.6.3 Subjective fidelity is the degree to which the simulator is perceived by the trainee as being a duplicate of the operational equipment and the task situation. As a general rule, if the trainee cannot discriminate between different levels of equipment or environmental fidelity because of perceptual limitations, the least expensive fidelity level is best.

11.8.6.4 Equipment Fidelity

(a) In order to duplicate the appearance and 'feel' of the operational equipment, the designer should be aware of the following aspects of equipment fidelity: workplace realism, location of instruments, controls and control feel.

(b) Factors such as accessibility, trainee observation and instructor participation should influence design requirements. The workplace design should provide efficient conditions for learning. Where simulation is unlikely to enhance training, and distract the trainee from the task, high equipment fidelity is not desirable.

11.8.6.5 Environmental Fidelity

In the design of training simulators, the design issues concerning environmental fidelity are:

(a) displaying an abstract representation of the external visual world for those systems where the operator perceives the environment directly.

(b) duplicating the effects of the environment on system displays.

(c) duplicating the sensation of motion for those systems where the operator is subjected to movement.

11.8.6.6 In general, design recommendations concerning environmental fidelity are that:

(a) The required degree of environmental fidelity can be determined on the basis of subjective fidelity.

(b) In a complex task, transfer of training may be degraded by an abstract representation of the visual world.

(c) High environmental fidelity is required when the actual task demands a difficult distinction to be made between different stimulus events.

(d) Where the operator must learn to compensate for motion in the actual task, motion cues should be provided, although high fidelity is not demanded. See also Part 12 of this Defence Standard.

11.8.7 Training Work Stations. In every training context there is an area set aside for the student. Most training situations also provide a separate and distinct area for the instructor. Both stations can assume many forms depending on what is being trained and how training is being conducted. Optimum student and instructor workstation design will usually be system specific. Regardless of the particular configuration of training workstations, certain basic human factors requirements must be considered.

11.8.7.1 In the design of any student station, both the workspace and equipment are devised to help someone learn to operate equipment in other settings, whereas for an instructor station, they are devised for an actual operator whose task it is to train. Considered jointly, both training stations must be designed to enable a specified set of training functions to be carried out efficiently and effectively between them.

11.8.7.2 The training simulator is designed to permit and facilitate an exchange of information between the two training stations. Human factors considerations should focus on these two major aspects, on the design and layout of the training station work area and on the equipment which makes it possible for dynamic interplay between student and instructor.

11.8.7.3 Human factors recommendations in which decisions for design are often required are in:

(a) the general housing arrangements for training stations,

(b) the work-station layout,

(c) the environmental controls,

(d) the equipment design.

Design considerations

11.8.7.4 Physical Aspects. One aspect of good training workstation design involves consideration of physical design principles. For many aspects, specific design recommendations have been developed and can be easily referenced. In other instances, the human factors specialist must bring his experience, ingenuity, and common sense to bear on the design problem.

11.8.7.5 Functional aspects. The second aspect of good training workstation design involves functional design principles. They include consideration of such factors as location of the instructor relative to the trainee, training station complexity, function allocation among instructor personnel, and methods of interstation communication. Functional design considerations are dictated primarily by experience and common sense. There are few hard and fast rules or principles for decisions about the functional design of any particular training workstation. To develop good functional designs, the designer must be familiar with the general conditions which facilitate learning. General recommendations for the physical layout and design, and the functional design of training stations can be found in Van Cott and Kinkade (1972). For further information on simulator design, see Part 12 of this Defence Standard.

11.8.8 Part task trainers

Typically, training simulators are exact replicas of the actual workplace, but part-task trainers can be designed to simulate either one or several elements of the workplace tasks. The decision of when to use part-task trainers depends on whether transfer from the component to the total task will be expected. Usually, component skills can be practised separately from the total task with considerable transfer, if a task has been analysed correctly. However, the two exceptions are time-sharing, and when there is interaction between the task components.

11.8.8.1 The advantages of designing part-task trainers are that:

(a) They are less expensive to build and to maintain than whole task trainers. Thus, a greater number of training hours can be achieved for the same financial outlay, compared to whole task trainers.

(b) Part-task trainers maybe made available at the time of, or preceding, the delivery of the operational equipment, which is usually not feasible for whole-task trainers.

(c) They can be modified to meet changes in the operational equipment more readily than a whole-task trainer.

(d) Since maintenance is not as difficult, fewer training hours are lost in keeping the trainer in operation.

(e) Specialist instructors can be utilized on part-task trainers, which may mean that less time is required to train instructors) and that one instructor can instruct students on several trainers simultaneously.

(f) Practice on part-task trainers may be carried out over shorter time periods, thus allowing for more frequent and extended training on the component task.

(g) Training on part-task trainers may be as good as, or better than training on a whole-task trainer, since the student can concentrate on the learning of one particular skill, without dividing his attention among several activities.

11.8.8.2 Disadvantages, or arguments against designing part-task trainers are that:

(a) Whilst a whole-task trainer usually represents a substantial cost investment, the number of related part-task trainers necessary to achieve the same level of proficiency may cost as much, or more than the whole-task trainer.

(b) The use of several part-task trainers in a training school would involve extensive housing facilities.

(c) If specialist instructors are required for each part-task trainer, the instructional cost could increase far beyond that associated with a whole-task trainer. Therefore, the requirements of the training system must be analysed, before a decision can be made concerning the number and type of component tasks to be included in the training device.

Section Six. Design Evaluation

12 Prototype Workplace

12.1 Introduction

12.1.1 The purpose of evaluating the prototype workplace is to verify the operating and maintenance effectiveness of the workplace under actual operating conditions. The prototype workplace should be tested prior to committing it to production. Tests should include operation by the military users and maintainers who represent the final user population. Although initial tests may be made by specialists in order to ensure practicality and safety of operation, the key test is whether typical users can and will operate the workplace as planned. Quantitative measurement of human-machine performance should be carried out whenever the complexity or safety of the workplace is critical.

12.1.2 For mobile land-based systems, early prototype trials (including user functional assessments), are normally carried out for the user by specialist Ministry of Defence trials groups or units. These units keep a running log of defects arising from prolonged operation of the workplace prototype. Often an employee from the contractor’s design team is assigned or on immediate call to the unit to repair or replace defective components as necessary. When defects are either frequent or require a major re-design, they also become the subject of task requests for consideration by MOD, before action is placed on the designer to introduce them into the next prototype rework.

12.1.3 Later prototype trails are usually carried out in the theatre of use and under quasi-operational conditions. For a mobile land-based system, its interaction as a new sub–unit within the larger organisation will become part of the workplace assessment.

12.2 Systems Effectiveness

12.2.1 Introduction

12.2.1.1 Nothing provides a more conclusive demonstration of adequate design than the actual field test of a prototype workplace. The test and evaluation of the workplace in its theatre of use and environmental conditions, is one of the most important requirements imposed by the Ministry of Defence (MOD). In order to demonstrate that military demands can be effectively met and design modification requirements are defined prior to its production. The military require an early and continuing human factors test and evaluation programme during system development. Plans for this work programme must be integrated along with other engineering test plans, in order to preclude either their duplication or omission.

12.2.1.2 Some early testing may rely only on the subjective opinions of specialists, eg test pilots, test drivers, special trials groups. Although there is often a good reason to utilize these specialists (for reasons of safety and because they are perhaps more skilled and perceptive in their analysis of features that may not be quite right), the real proof of design acceptability comes when the intended user can also operate the system.

12.2.1.3 The final test, however, is one in which all elements of the total system (including hardware, software, documentation aids, and trained personnel) are tested together as the ultimate measure of total system effectiveness. It is here that the design, procedures and training are tested to demonstrate whether operational requirements have been properly met.

12.2.2 Field test design

12.2.2.1 The main objective of most field tests is to demonstrate that the workplace will do what it is designed to do. In addition, the field test should provide other information that is important to the eventual user: Previously described tasks can be verified, training objectives can be confirmed, and training aids can be evaluated.

12.2.2.2 The field test should be designed:

(a) to demonstrate the reliability of the hardware under all operational and environmental conditions.

(b) to demonstrate that the training programme has provided the user or maintainer with the necessary skills to cope with the operational conditions under which the system is used.

(c) to highlight any hardware, software, operator interface, or procedural discrepancies, by identifying deficiencies and providing recommendations for solutions.

(d) to allow the verification of proposed manning levels.

(e) to allow evaluation of time factors such as time into action, target engagement, loading, boarding, emergency escape, etc are correctly estimated.

(f) to determine any safety hazards that may not have been anticipated.

(g) to provide an initial impression of user acceptability of the workplace.

The designer should note that if their is any doubt as to how to carry out field test design, a human factors specialist is to be consulted.

12.2.3 Method

12.2.3.1 The field test should be designed and implemented so that systematic exercising of the man-machine workplace has been carried out through all phases of the operating scenario. Both normal and emergency conditions should be included. The scenario should contain all of the man-system interactions such as visual, auditory, mobility, dexterity, communications, decision making, and control elements. Testing should occur in the theatre of operation, both by day and night and under different environmental conditions.

12.2.3.2 All subjects should be properly briefed prior to participating in field testing. A brief statement of the purpose and objectives for the field test, and a general overview of what will be expected of the subjects prior to, during, and following the test should be developed. The statement should be written out and distributed to all subjects, so they receive the same instructions.

12.2.3.3 During the test, it is generally best to leave the subjects alone as much as possible in order to reduce the possible influence of the experimenter. Sometimes it is desirable to have the subjects verbalize what they are doing whilst the test is in progress. This should be included in the briefing along with possible reinforcing reminders by the experimenter if the subjects should forget. When several observers are used, they should be allowed to practice until they can demonstrate that they perform consistently and in a similar way. Rotation of observers in contact with test subjects will decrease the risk of observer bias occurring.

12.2.3.4 The responsibility for test safety should be given to an experienced person to provide general overall safety monitoring, although individual observers are responsible for the safety of their own subjects during the field test. This is especially important when several workplace components are interactive with each other. Safety equipment should be provided to deal with emergencies in potentially hazardous field tests along with medical personnel.

12.2.3.5 When testing involves both subjects and observers in a hazardous environment, it is extremely important to fully instrument both the workplace and the people involved. This requires monitoring in real time to be carried out, so that the exact status of the hardware and the individuals involved, such as a pilot performing unusually hazardous manoeuvres in an aircraft are known. Fail-safe information links must be provided so that communications are not broken as a result of physical conditions or environmental abnormalities. Wherever practical, rescue personnel must be available for quick emergency response. In addition, workplace system experts should readily be to hand to advise test personnel in the workplace on how to either correct problems, reject or abandon the system. All possible emergency scenarios that can be anticipated should be analysed and procedures practised prior to the field test beginning. Above all, the test personnel should be provided with as much on-board capability as possible for taking care of their own emergency, as they may not have enough time to both communicate with and receive instructions from the experimenters. Where extended duration workplace tests are conducted, accommodation, food and off-duty activities for both test subjects and observers is to be provided.

12.2.3.6 Where appropriate, the use of trained independent observers to take notes while the test is being conducted should be considered, because the actual observer may sometimes be too involved to observe critical events for himself. These independent observers should be equipped with recording devices where appropriate.

12.2.3.7 A means of documenting the subjective opinion of test subjects, not only in terms of post-test debriefing, but also during on-line evaluation testing should be provided. Debriefing questionnaires should be designed to obtain specific, design-related comments, as opposed to general verbal descriptions of the equipment.

12.2.3.8 A quantitative measure of operator and maintainer performance in terms of time and error should be provided. Actual measurement of the performance of test subjects participating in the evaluation should always be generated wherever practicable.

12.2.3.9 Depending on the nature, location and duration of a particular field test, it may be important to provide facilities and equipment for analysing data on the spot. Such data may be important to the experimenter(s) in terms of deciding whether to make modifications to the test schedule or procedures. Alternatively, it maybe possible to transfer data via various tele-communication methods to a base site or a laboratory, where large computer facilities are available. Such remote analysis is often required when the workplace system is operating in the theatre of use.

For further information on observation, interview and questionnaire techniques, objective measurement, workload assessment, and experimentation see Part 12 of this Defence Standard.

Section Seven. Guidelines for Designers

13 Approach to Workplace Design

13.1 Introduction

13.1.1 In order for operators to complement the effectiveness of a workplace system, they must be integrated with the workplace in such a way that their capabilities are utilized to the maximum. This can be achieved by selecting the human sensor link which makes the best use of human capacity, sensitivity and reliability. By choosing a linking approach between the operator and the workplace, the total system effectiveness will be maximized. Human limitations must be recognized, and machine and equipment alternatives should be put forward instead.

13.1.2 The requirements for the proposed workplace should be reviewed until everything possible about the basis for the workplace and the conditions under which it is to be used, is fully understood. All critical workplace features should be identified including talking to potential users, and wherever possible examining equivalent workplace systems in use. Consideration should be taken of what functions need to be carried out to fulfil the workplace objectives. If there are any reasonable options available, consider which of these should be performed by the operator. If there is provision for adequate redundancy in the workplace system, especially of critical functions, redundancy should be provided in the form of either a back-up system or by parallel components (either operators or machines).

13.1.3 Where practical, the services of a qualified human factors specialist should be engaged to assist and advise throughout the development of the proposed design and in its final production. The specialist will need to prepare a specification list of human factors issues in their order of apparent importance. These should be identified in terms of safety, operational importance and so on, and the data required for their solution should be identified. The criticality of the data should be determined by the importance of the issue to which it relates.

13.1.4 When this is impractical, the acquisition and or development of a human factors check list for use throughout the design, development and production cycle should be utilized. Check lists should be used with caution. They should neither be confused with operating procedures nor considered a substitute for human factors expertise. Although general checklists are provided in this section, the creation of a checklist tailored to the nature of the proposed workplace design should be developed. Check lists typically require modification as the design development progresses, and as more knowledge is gained about the workplace design features. As these additional user-hardware interface details are generated, further human factors questions will require addressing and monitoring throughout the workplace design cycle.

13.1.5 Initial workplace design concept should be reviewed to ensure that all potential user interface aspects of the proposed concept have been properly identified and considered. The purpose of this step is to avoid establishing constraints to good human factors practice.

13.1.6 Using the checklist, each design activity should be monitored as it progresses, from preliminary through detailed design steps, making sure that the human factors aspects are kept constantly in mind, and that good

13.1.6 (Contd)

human factors practice, principles and criteria are being considered during each step of the workplace design process. If compromises are being made, how and why these are being introduced into the design should be recorded. This record may be extremely important for example, if the Ministry of Defence (MOD) requires evidence that human factors have been taken into account, or justification for ignoring them is required. If the user brings proceedings in law against the designer, the designer will need evidence to prove that he did his best to prevent misuse of the workplace (ie that all practicable means to minimize the probability of either misuse or potential hazard to the user had been taken).

NOTE: Documentation of human factors during design is becoming more urgent as legal aspects of design-induced injuries place the burden of safety on the designer as well as the manufacturer.

13.1.7 Mock-ups should be used to test the efficacy of all user-hardware interface designs, with subjects taken from either end of the required anthropometric range of the user population. Examining and evaluating the mock-up operator interfaces in terms of human performance efficiency (ie time, error, protrusions, fouls, encroachments, avoidance of discomfort, inadvertent hazard potentials etc, should be carried out). Observations should be recorded and appropriate design modifications made where necessary. The mock-up should then be modified and re-evaluated.

13.1.8 Experiments when necessary, should be performed to establish workplace design criteria, especially where previously cited reference guides do not provide adequate information for design decisions. This may require development of special, dynamic, real-time simulations of procedural and environmental conditions.

13.1.9 A hardware workplace prototype should be fabricated and evaluated under real–life conditions using typical user subjects. Subjects should again be representative of the range of potential users, and any trials that are carried out should be realistically representative of the workplace system. It should be ensured that measurements taken from subjects are relevant and will result in usable guidance for setting the workplace system parameters. Through short 'pilot trials', checks are to be carried out to ensure that the trial techniques proposed are viable. Measurements can then be taken and the results derived. Trials should be designed so that the minimum of redundant data is generated.

13.1.10 Quantitative performance measures of the total User-hardware operation should be obtained to prove that the combined human-machine operation is satisfactory. Any deficiencies should be fed back into the workplace design cycle, and appropriate design modifications made. Retesting may then be necessary.

13.1.11 Final production drawings should be critically reviewed prior to releasing them for final production, fabrication and assembly. Critical areas should be identified where lack of proper production quality control might result in poor user-hardware interface results, because of unsatisfactory manufacturing or assembly procedures. Steps should be taken to establish necessary procedural control and inspection in order to preclude mistakes in the factory.

13.1.12 Production (field) tests of hardware should be performed before they are approved for final delivery to the Ministry of Defence (MOD). These tests should include operator testing, as well as visual inspection and or tests of hardware and software components.

13.2 Procedure

13.2.1 A procedural approach to workplace design will require functions to be allocated by a combination of professional engineers and human factors specialists. There are few individuals who possess enough professional expertise in both advanced hardware/software technology and human factors technology, to efficiently allocate functions. Hence a workplace design group will require both an engineering team and a human factors team. The engineering team should describe the engineering workplace concept, and the human factors team the role of the humans operating it. The role of the humans statement should define what functions humans are expected to play in the workplace whether as operators, maintainers, managers (ie commanders), or users of the workplace product.

Function Allocation

13.2.2 The process of function allocation can be defined as a five step procedure for embedding the allocation of decisions within workplace design. The allocation of decisions will require the application of four principal rules (see (c) below and Price 1985). The procedure is as follows:

(a) prepare for workplace design by organizing the design teams, clarifying requirements, and planning a design documentation base;

(b) identify functions by categorizing whether or not they are either primary functions in terms of their inputs and outputs, or if they are of a secondary nature to the function of the workplace system. Return to this step later to reorganize into smaller functions;

(c) propose/produce workplace design solutions. This is the major step in the workplace design cycle where interaction takes place between engineering, allocation and human factors decisions. Four rules can be applied for developing the allocation hypothesis. They are by:

(1) Mandatory allocation (ie there are mandatory reasons for allocating a function, or portions of it, to either humans or machines).

(2) Balancing the values by determining the hypothetical allocation between humans and machines as performers of the intended function.

(3) Allocating on a utilitarian and or cost basis. For utilitarian allocation, a function may be allocated to humans simply because their presence is required, and there is a compelling reason why they should perform the work. Otherwise, consider the relative cost of human and machine performance and allocate on the basis of least cost. However, this may not be straightforward to determine since one must consider the relative efficiency and effectiveness of human versus machine execution of a function.

13.2.2 (Contd)

(4) Allocating functions for affective and cognitive support. Humans should be treated as different to machines in two qualitative respects. Affective support refers to the emotional requirements of humans, such as their need to know that their work is recognized for its value, to feel personally secure, and to feel that they are in control. Cognitive support refers to the human need for information, in order to be ready for actions and decisions that may be required.

NOTE: Where adequate information for allocation is not available, human factors judgments based on partial information will result in better design decisions. These judgments should be made by those whose professional training and experience put them in the class of experts, whether in the field of night vision, physical anthropometry, hearing disorders, perception, heat stress, acceleration, learning, decision making, or otherwise.

(d) inevitably, this will require trading off certain advantages for others. Balancing out these advantages and disadvantages will generally need to take account of a variety of considerations, eg. engineering feasibility, human considerations, economic considerations, and others. However, the general objective or aim of the workplace system must not be lost sight of (ie that trade-offs should be made on the basis of the stated or implied system objectives and the accompanying performance requirements).

(e) test and evaluate the allocation hypothesis. It is during this step that the training and experience of the human factors team will be of significant value in locating and interpreting relevant data on human performance.

(f) iterate the workplace design cycle in order to correct subsequent errors, optimize the workplace design and complete the workplace to an acceptable level of detail.

13.2.3 In conclusion it would seem that the most effective approach to this procedure is by a trial and error technique using demonstrators to illustrate, by example, possible workplace design solutions.

13.3 Checklist method

13.3.1 A method for designers approaching the human factors implications of workplace design is to consider by means of checklists, whether demands on the human can be classified in broad terms as being either organizational, mental, physical or environmental.

Organizational demands

13.3.2 Organizational (both functional and managerial) demands, can be defined as the need to promote and enhance operator performance, for example by correctly allocating functions according to human capabilities and limitations, by selection and training and hence improvement of the skill levels of the operators. In contrast, the need to prevent work overload and performance degradation for example, by the organization of shift work, task significance, variety, distribution and realistic timescales of work schedules, will thereby enable operators to complete the various mental and physical demands of the workplace.

Mental Workload

13.3.3 Mental workload can be defined as the differences between the capacities of the information processing system that are required for task performance to satisfy performance expectations, and the capacity available at any given time.

13.3.4 Mental demands are often overlooked (or inadequately defined), during the workplace design process, because they are transparent/latent and not part of hardware and equipment design. Designers should know that operators require designed equipment which avoids or reduces operator mental overload, so that the means of processing information, solving problems, aiding the operator to make decisions, and allowing communication between people, both within and between workplace(s) can be carried out in a tolerable working environment.

Physical Demands

13.3.5 Physical demands can be defined as the material requirements that a person needs in order to carry out static, dynamic and motor processes when either acting on or reacting to a machine/equipment. For example, with respect to the motor processes, by the completion of either simple discrete tasks, or complex continuous tasks. Motor and visual processes should be readily apparent to equipment designers, because they physically and visually link, (or couple) the operator to the machine interface.

Environmental Demands

13.3.6 Environmental demands can be identified with respect to their location as being either external or internal to the workplace. The external environment can in broad terms be classified as being from either an atmospheric or mechanical source. The designer requires to control the effects of these sources on the internal workplace environment, in order to promote the life support, health, safety and physical/mental well-being of the operators, by either reducing their internal effects, or protecting operators from these sources to within tolerable limits, so that the physical and mental demands of the workplace can be met.

13.4 Systems appoach to human factors operations

13.4.1 The application of human factors data to design processes does not (at least yet), lend itself to the formulation of a completely routine, objective set of procedures and solutions. However, systematic consideration towards the human factors aspects of a workplace system will at least focus attention on features which should be designed with human beings in mind. In this connection, it will be useful to list at least some reminders that are appropriate when approaching a design problem. These reminders are presented in the form of a series of questions (with occasional supplementary comments). Some points should be made about them. Not all of the questions are pertinent to the design of some workplace items, nor are they intended to be an all-inclusive list of questions. Also, the fulfillment of one objective may of necessity be at the cost of another. Nevertheless, these lists of questions should serve as a good start in the workplace design process, by deleting and adding questions to fit the specific situation. Human factors considerations relating to the questions are provided under comments. The checklist questions in this Section of this Defence Standard are cross referenced to this Part and other Parts of Defence Standard 00-25 Human Factors for Designers of Equipment. It must also be appreciated that a human factors specialist will be required to answer some of the questions.

13.4.2 Organization demands

13.4.2.1 Functional requirements

QUESTIONS	COMMENTS
1. What are the functions that need to be carried out to fulfil the workplace system objectives?	1. Choose a coupling approach that maximizes total system effectiveness; do not choose on the basis of whether it is easy or hard to automate a function.
2. If there are any reasonable options available, which of these should be performed by human beings? a. Is the existing equipment the result of tradition - or has it been planned from the start with the operator in mind? b. What role is the operator expected to play? c. How will the equipment fit the operator?	2. Select the human sensor link which makes the best use of human capacity, sensitivity, and reliability. Avoid coupling via a particular link merely on the basis of tradition or because it may appear that a particular hardware implementation is less expensive, easier to design, or already available. Fatigue. Human capacity and functional capabilities are subject to short and long-term fatigue effects, whereas machines can be designed to be almost fatigue-resistant.
3. Are the information inputs collectively within the optimum bounds of human information-receiving capacities, or will humans be called upon to undertake functions which they cannot do very well?	3. Speed and Accuracy. Human response cannot compete with the capacity of a machine in terms of speed and accuracy, thus, functional allocations to humans must be made on the basis of their capacity. Use hardware to aid the human, do not use the human to complement a predetermined hardware concept. Select coupling methods that do not require humans to make frequent, laborious, and lengthy calculations where accuracy is critical. (See also physical and mental demands.)

QUESTIONS	COMMENTS
a. Can any of these functions be transferred to the equipment? (Ie can reversionary modes of operation be employed to enable the workplace to function?)	a. Couple humans with machines in such a way that they are not compelled to work at peak limits all or most of the time.
4. Is there provision for adequate redundancy in the workplace, especially of critical functions? (Ie can reversionary modes of operation be employed to enable the workplace to function?)	4. Redundancy can be provided in the form of backup or parallel components (either persons or machines).
5. In any evaluation or test of the workplace system (or components), does the workplace system performance meet the desired, managerial performance requirements?	(See managerial requirements sections).

13.4.2.2 Managerial requirements

QUESTIONS	COMMENTS
1. Are the various tasks to be done grouped appropriately into jobs? a. To what extent should the job be broken down? b. How can knowledge of results be given and targets set? c. What should be the size of the working group and the physical spacing between members of the group?	
2. Do the tasks which require time sharing avoid over-burdening any individual in the system?	Overload. Humans are fairly limited compared with machines in terms of how much information they can absorb and handle at one time, how many things they can monitor or control at one time and how effectively they can maintain cognizance of a situation for extended periods, and when under severe physiological and psychological stress conditions. Task overload will cause physical and/or mental fatigue, degrade operator performance, and generally reduce workplace system efficiency. Particular attention must be given to the possibility of overburdening in emergencies.
3. Assessing human workload a. What is the main occupation of the operator? b. What is the secondary occupation?	To prevent work overload a. Sequence tasks rather than creating overlaps. b. Make individual tasks short. c. Minimize task precision requirements. (See also mental and physical demands)

QUESTIONS	COMMENTS
4. Is the work made harder by the way it is organised?	
a. <u>Shift work</u>	
(1) Are there day and night shifts? (2) Does the existing shift system permit only short periods on night shift? (3) How many free periods are there per duty cycle? (4) Are conditions favourable for daytime sleep? (5) Would flexible hours be advantageous or permissible within an operational context? (6) What is the maximum intended unbroken working spell? (7) What is the total intended worktime in each 24 hr period?	
b. <u>Pauses (breaks) and the preparation and eating of food</u>	
(1) If physical work is involved, how long should be allowed for recovery? (2) How should these recovery periods be spaced? (3) Are the timing and lengths of these periods reasonable?	
(4) If there is a heat load or cold load on the operator, how long should the operator be allowed for recovery?	(See also Workplace environmental demands.)
(5) How long should light work continue before a pause is given and how long should this be? (6) Should there be more than one pause in a working period and what is the maximum intended unbroken working spell? (7) Would additional short breaks be desirable and what is the total intended worktime in each 24 hour period.	

QUESTIONS	COMMENTS
(8) Should pauses be spaced by management (ie official breaks), or left to the will of the operator? (9) Is there adequate provision for food (snacks) and non-alcoholic drinks during breaks? (10) Should some change in activity be introduced during a pause? (11) Is the main break long enough? (12) Have facilities for the collection and disposal of human biological waste been provided?	
c. Tasking (Prevention of Boredom (1) How much time is allowed for each task? (2) Does the machine (equipment) speed during paced work bear the optimum relationship to the performance and variability of the operator(s) employed on the job? (3) Is the machine (equipment) being run for the optimum length of time? (4) Does repetitive work create a bad body posture? (5) Is the variability of the people it is proposed to employ on repetitive work within limits which can be accommodated by the process and can uniform performance be maintained which is normal for the process? (6) Is it possible to make the work less monotonous by broadening the tasks or by the rotation of jobs? (7) Should the operator be kept on the same job all the time, or should jobs be undertaken in rotation?	c. To prevent boredom (1) Provide task variety. (2) Distribute tasks equally. (3) Assign the operator only significant tasks, and make it clearly evident that the operator rather than the machine is in control. Humans can become just as fatigued by boredom as by overwork. (See also mental demands.)

QUESTIONS	COMMENTS
(8) Does the organization of the work allow for social contacts? (9) Does the work in its entirety provide reasonable opportunity for the individuals involved to experience some form and degree of self-fulfilment.	Couple the humans with machines in such a way that they can recognize or feel that their contribution is meaningful and important. Avoid giving humans machine-serving responsibilities.
(10) Does the work in its entirety contribute generally to the fulfillment of reasonable human values?	In the case of work with identifiable outputs of goods and services, this consideration would apply to those goods and services.
5. <u>Training</u> a. Are the jobs of such a nature that the personnel to perform them can be trained to do them? b. If so, is the training period expected to be within reasonable time limits? c. Do the work aids and training complement each other? d. If training simulators are used, do they achieve a reasonable balance between transfer of training and costs?	b. <u>Learning.</u> Humans generally require some finite learning period to perform a new function. A machine begins its operation immediately and theoretically requires neither initial training nor proficiency refreshment.

13.4.3 Mental workload

13.4.3.1 Mental work including mental stress and fatigue

QUESTIONS	COMMENTS
1. Will the mental demands of the task be such as to overload the operator? a. If yes, what steps can be taken to reduce this?	1. Individuals have been able to summon some mental reserve during a crisis, and thus there is a tendency to believe that, with the proper stimulation, most people can continue mental activity indefinitely. Considerable evidence to the contrary, however, has shown that when an individual works too near to mental capacity for long periods, almost any emergency that suddenly occurs may push the individual beyond his or her capacity to cope, the result often being a complete collapse or disorientation. Mental fatigue is further confounded by the fact that an individual's threshold may be stressed to within a few degrees of tolerance by pre-operating conditions (prior activities), with the result that he or she has no tolerance to cope with an overly demanding mental task or situations.
2. Does the work and workplace environment make heavy demands on: a. Skill? (1) Is the skilled work performed under visual control?) See also managerial requirements, Question 5. (2) Does it require a long training period?)	Equipment design and operating features known to contribute to mental fatigue. a. Skill demands are greater when: (1) Overly precise control adjustments are required. (2) Poor control dynamics, in terms of force-displacement, control-display, direction of motion, and or movement ratio incompatibilities, are present.

QUESTIONS		COMMENTS
(3) Has every facility been given to acquire an automatic skill	)See also)managerial)requirements,)Question 5.	(3) Continuous manual monitoring or control tasks are required that could just as well be automatic, with periodic operator alerting.
(4) Do the directions and sequence of movements follow a stereotyed pattern?	)See also)clause)13.4.4.2)Question 5.))	
b. Memory?		b. Memory demands (feedback) are increased when:
(1) Short term?		(1) There are long delays in informational feedback, ie long periods between signals or changes in equipment status.
(2) Long term?		(2) There is a lack of timely indication of whether the equipment is functioning properly.
c. Vigilance?		c. Vigilance demands are inhibited when:
(1) Is vigilance disturbed by noise?	)See also)workplace)environmental)demands)clause	(1) Simultaneous audio communications and/or excessive background noise is present.
(2) Is vigilance impaired by other people's activities?	)13.4.5.2)Questions 1,)2 and 3	
(3) Is vigilance impaired by what is going on at the same workplace?	))))	
d. Perception?		d. Perception demands are increased when:
(1) Is the lighting good?	))	(1) Too many separate visual displays have to be monitored simultaneously.
(2) Are the instruments well arranged and appropriate to the task?	))))	(2) Visual display formats require extrapolation rather than providing directly usable information. When the display format is too clutt--ered with information and when too many coded information elements are used.

QUESTIONS	COMMENTS
(3) Are numbers, words, symbols and scale divisions of a size to suit the reading distance?	(3) Visual display detail is considerably greater than required eg there are more scale marks than are warranted by the inherent accuracy of the instrumentation and/or task objective.
(4) Are instruments, components and labels in full view, so as to avoid mistakes?	(4) The legibility of visual display details is borderline, requiring unnecessarily close scrutiny in order to detect, recognize and interpret what is being displayed.
(5) Are any magnifying devices necessary?) See also workplace environmental demands, clause 13.4.5.1 Question 5	(5) Visual displays vibrate because they are not properly shock-mounted.
(6) Are instruments and controls properly placed in relation to each other?	(6) Visual displays are not adequately illuminated, or there are uncontrolled glare sources within the critical viewing envelope.
(7) Can any audible signals be heard clearly and without danger of missing one?	(7) There is a lack of standardization among various similarly operated pieces of equipment, thus requiring operators to shift their point of reference.
	(8) The control panel layout is poorly organized, making it necessary for the operator to search for appropriate panel elements.
e. <u>Overall habitability?</u>	e. <u>Overall habitability demands are increased when:</u>
(1) Is the working environment controlled to provide tolerable (bearable) conditions for the operator?	(1) The workplace environment is inadequately controlled in terms of: (a) Lighting, temperature, humidity, ventilation, noise, vibration, acceleration, pressure, etc.

QUESTIONS	COMMENTS
	(b) Support furnishings (standing platform, seating, writing surface, reference storage, restraint system, etc). (c) Space, eg clearance. (See also clause 13.4.5 Workplace environmental demands.)

13.4.3.2 Informational requirements

QUESTIONS	COMMENTS
1. For a given function, what information external to the Individual is required?	Couple humans with machines so that information flow and information processing are natural; this minimizes learning time and the probability of confusion and/or errors. Storage Capacity. Human capacity to store large amounts of information over the long term is extremely great, but their ability to retrieve information quickly is sometimes extremely limited and unreliable. A computer information processor however, can store almost any amount of data and recall it almost immediately. On the other hand, the machine's capacity to store and retrieve is entirely limited to what is designed into it.
a. What information does the operator need in order to do the task? b. In what form is the operator to receive the information? c. Can information be adequately received directly from the environment? d. What information should be presented through the use of displays? e. How can it best be displayed? f. Do the various information sources avoid excessive time sharing?	Overload. (See Managerial requirements, clause 2). Human-Machine Performance Surveillance. Machines are also affected by environmental and operational distortions, especially computers
2. For information to be presented by displays, what sensory modality should be used? a. Should this be a visual, auditory of tactual display?	Consideration should be given to the relative advantages and disadvantages of the various sensory modalities for receiving the type of information in question. Select the human sensor link which makes the best use of capacity, sensitivity and reliability.

QUESTIONS	COMMENTS
b. Which type of display will give information most quickly and with the minimum of ambiguity?	Avoid coupling via a particular link merely on the basis of tradition or because it may appear that a particular hardware implementation is less expensive, easier to design, or be already available. Sensory Isolation. To perform useful tasks within a controlled environment, humans must be able to receive information at levels commensurate with their inherent sensory channel threshold capabilities; eg there are limits to visual activity and auditory perception and these senses are easily degraded by noise in the environment. In fact, sensory inputs may be distorted, causing humans to make perceptual errors, ie to misinterpret what they see, hear, or feel. (See Part 7 of this Defence Standard and also consider the operator's perceptual processes, clause **13.4.3.1d).**
3. Are the various visual displays arranged for optimum use? a. Which displays are essential for the efficient operation of the workplace, and which can be relegated to a minor position?	Displays should provide the information when and where it is needed. These considerations should take into account the general type of display, the stimulus dimension and codes to be used and the specific features of the display. The display should provide for adequate sensory discrimination of the minimum differences that are required. (See Part 7 of this Defence Standard).
4. Can different parts, control knobs and tools be easily recognized by position and touch?	Logical positioning and tactile feedback aid in recognition of location. (See Part 10 of this Defence Standard.)

QUESTIONS	COMMENTS
5. Are the decision making and adaptive abilities of human beings being appropriately utilized?	5. Interpretation of, and response to, unexpected events. Humans possess the unique capability to constantly re-evaluate a situation, change their approach, and invent new ideas on the basis of unexpected events and operating conditions. The can often continue with either an alternative or less-than-perfect procedure, whereas a machine may stop operating completely. A machine does only what it is designed to do; ie , its capability is limited to anticipate all events and conditions of operation.
6. Are the decisions to be made at any given time within the reasonable capability limits of human beings?	
7. In the case of automated systems or components, do individual operators have basic control, or do they feel that their behaviour is being controlled by the workplace system?	Couple humans with machines as though humans might at some time have to assume control (even though the nominal mode may be automatic).
8. What form of communication will have to take place between operators?	
9. Has this communication to be verbal and if so, will there be interference from noise? a. If interference from noise is expected, can information between operators be transmitted by means of instruments?	(See also workplace environmental demands, clause **13.4.5.2**, Question 3.) (See comments for Question 2c and d.)
10. If there is a communication network, will the communication flow avoid overburdening the individuals involved?	(See also comments concerning mental work clause **13.4.3.1**, Question 1.)
11. Does the task require high auditory demands?	(See Part 8 of this Defence Standard and also comments concerning vigilance demands, clause **13.4.3.1c.)**

13.4.4 Physical demands

13.4.4.1 Physical work including physical strain and fatigue

QUESTIONS	COMMENTS
1. Will the physical demands of the task be such as to overload the operator? a. If yes, what steps can be taken to reduce this?	Overload. Task overload will cause physical fatigue, degrade operator performance, and generally reduce workplace system efficiency.
2. What physical work will the operator be required to do? a. Is the work physically arduous? b. Will it be within the operator's physical capacity? c. Will some form of mechanical assistance be required?	Physical Strength. Humans are extremely limited compared with machines in terms of how much force they can apply, and for how long. See Parts 2 and 3 of this Defence Standard.
3. Questions relating to physical strain a. Bodily posture: (Sitting, standing, stooping) (1) Can the operator sit or must he stand? In either case will his posture be satisfactory? (2) Does the required posture involve much static muscular effort? (3) Is a favourable work posture promoted by the location of instruments, workplaces and controls?	Design implications relative to minimizing potential muscle fatigue a. Avoid design features that: (1) Require operators to apply near maximum force capacities over many cycles and for long periods of time. (2) Require continuous, rapid, repetitive muscle contractions for long periods, eg pounding, tapping, cranking, or push-pull cycling. (3) Force operators to hold some device in a fixed position for long periods without rest periods.

QUESTIONS	COMMENTS
(4) Is the working height correct?	(4) Require operators to maintain an upright posture for long periods without adequate body support (as in the case of a seat).
(5) Is the range of movement of grips and handles automatically correct?	(5) Require operators to make very long reaches, frequently, and for extended periods of time.
(6) Is there enough room for the operator to move about?	(6) Require operators to stand or sit in awkward positions, and to hold their arms above their heads for long periods.
(7) Can the work be seen clearly and any displays be read with the body in a natural position?	(7) Require operators to work in a bent-over or squatting position, or in a position on their stomachs or backs, with the accom-panying stress of holding the head and arms in a strained position.
(8) Does the body have to take up an unnatural posture when pedals are operated?	(8) Require operators to bend over and straighten up frequently, and over long periods.
(9) If the operator is standing, can foot control be dispensed with?	
(10) What force will the operator be called upon to exert and will some form of servo assistance be required?	
(11) Is the height of the work surface adapted to the posture, and correct in regard to viewing distance?	
(12) Is the work surface correct with regard to: (a) Height? (b) Width? (c) Colour tones and contrast?	

QUESTIONS	COMMENTS
(13) Are chairs and supports available to obviate necessary standing? (14) Is a support for elbows, forearms, and back necessary.	
b. <u>Sedentary work:</u> (1) Is sitting promoted by the location of instruments, workplaces and controls? (2) Is the seat correctly adjusted to the working height? (3) Does the seat cause discomfort? (4) Is a foot rest necessary? (5) Are the controls set out so that bodily postures are natural? (6) Is much effort needed to operate manual controls? (7) Are the controls adequate for their purpose?	b. Avoid workplace layouts that: (1) Require repeated iterations over long periods. (2) Require operators to sit askew (in a twisted position) in order to watch a display and simultaneously operate some control (especially a foot control). (3) Require operators to hold a foot above a foot control (between pedal depressions) for long periods. (4) Require operators to continuously move their heads from side to side or up and down. (5) Require operators to step up and down frequently for long periods. c. Avoid tool designs: (1) That require operators to hold and push a tool against a work surface or component in order to maintain contact pressure. (2) That require operators to hold a very heavy tool in a precise position for long periods. (3) That require operators to maintain a very tight grip in order to keep the tool in place (especially if the grip must be maintained for long periods).
c. <u>Muscular Work</u> (1) Is the muscular effort predominantly static or dynamic?	

QUESTIONS	COMMENTS
(2) Is any form of strenuous static work involved? (3) If so, can this be avoided by providing clamps or supports for the work? (4) Can the work be made easier by supporting hands and/or elbows? (5) Must loads be lifted? (6) Are the weights of these loads acceptable? (7) Is there some more suitable method of lifting and transporting these loads? (8) Is strenuous dynamic work required? (9) Is the average heart rate below the limits? (10) Is the work performed with a high enough degree of efficiency?	

13.4.4.2 Material requirements

Physical control and control devices

QUESTIONS	COMMENTS
1. When physical control is to be exercised by the operator: a. What controls will be needed? b. What type of control device should be used? c. Which controls are essential for the efficient operation of the equipment? d. Which controls can be relegated to a secondary position?	Select coupling methods that do not require: a. Extremely precise manipulations. b. Continuous, repetitive movements. c. Physical contributions that demand reaching a human's upper strength limits.
2. Is each control device easily identifiable?	
3. Are the controls correctly designed in terms of shape, size, surface and material with regard to the required forces?	(See also Parts 3 and 10 of this Defence Standard)
4. Are the operating requirements of any given control (as well as of the controls generally), within reasonable bounds?	The requirements for force, speed, precision, etc, should be within the limits of virtually all persons who are to use the system. The man-machine dynamics should capitalise on human abilities so that, in operation, the devices meet the specified system requirements.
5. Is the operation of each control device compatible: a. With any corresponding display? b. With common human stereotype response tendencies? c. With the location of instruments and workpieces?	(See also Part 10 of this Defence Standard)
6. Are the control devices arranged conveniently and for reasonably optimum use? a. Is correct control by hand or feet promoted by the location of instruments, workplaces and controls?	

Workspace and User Population

QUESTIONS	COMMENTS
1. Is the workspace satisfactory for the range of operators who will use the facility? a. Is the equipment likely to be operated partly or exclusively by females? If so, what population of females must be provided for?	Select the appropriate target population.
2. Are the various components and other features of the facility arranged in a satisfactory manner for ease of use and safety?	(See also workplace environmental demands.)
3. When relevant, is the visibility from the workstation satisfactory? 4. Are the controls and displays located in front of the operator within optimal reach, visual area and arranged for optimum use? 5. Are warning lights/panels placed in the central part of the visual field?	Blanking arcs and blind spots should be checked using a field of vision test. Ensure controls are within the 5th percentile maximum and 95th percentile minimum reach envelopes, important displays are within primary visual field, and their layout is logically arranged. (See also Part 7 of this Defence Standard.)
Maintenance Requirements 1. What are the expected maintenance requirements? 2. Is the workplace system or item adequately designed for convenient maintenance and repair, including individual components? a. Is there adequate clearance for reaching individual parts that need to be maintained, repaired or replaced? Note: Does the machine construction allow for this in terms of: (1) Accessibility? (2) Avoiding accidents? (3) Lighting requirements? (4) Tracing technical faults? b. Are proper tools and diagnostic aids available?	 (See also Part 11 of this Defence Standard.)

QUESTIONS	COMMENTS
3. Has the equipment been: a. Designed to make the diagnosis of faults easy? b. Planned so that probable repairs can be carried out with the minimum of delay? c. Supplied with adequate instructions for maintenance and repair?	

13.4.5 Workplace environmental demands

13.4.5.1 Atmospheric sources

QUESTIONS	COMMENTS
1. Are the environmental conditions such that they: a. Permit satisfactory levels of human performance? b. Provide for the well-being of individuals?	Environmental Constraints. The human's physiological tolerance to certain operating environments is limited. Therefore, an early decision is required regarding costs and complexity necessary to protect and support the human under severe environmental demands (ie extreme atmospheric pressure, acceleration, temperature, noise, vibration, radiation, and/or potential emergency situations produced by explosive blasts, fire, atmospheric or chemical contamination, etc).
2. What are the ambient atmospheric conditions likely to be? (a) Will the air contain contaminants and toxic substances such as nuclear, biological and chemical agents? (b) Will there be a non-standard air mixture? (ie oxygen deficiency, carbon dioxide and/or carbon monoxide excesses). (c) Will air circulation and ventilation be provided? (d) Will there be altitude and sudden barometric pressure changes to affect the operator? (ie altitude sickness, breathing and hearing difficulties). (e) Will there be heat and/or humidity conditions which will require refrigeration for cooling and dehumidification, to reduce the water vapour content? (f) Will there be cold conditions which require heating? (g) What lighting (illumination) is likely to be required for working in daylight and artificial light? (See also Question 5 below.)	The environmental life support system shall be part of workplace design.

QUESTIONS	COMMENTS
Will there be radiation and ionization hazards, or any other harmful waves/rays in the electro-magnetic spectrum, which requires protection for the operators?	
3. Health Safeguards a. Does the air in the room contain any toxic substances? b. Can the spread of toxic substances be stopped at source? c. Can ventilation equipment be installed? d. Is there contact with any substance that may cause skin irritations such as dermatitis?	
4. Questions Relating to the Working Environment	
a. Light and Colour (1) Is the lighting bright enough during daytime? (2) Is the artificial lighting bright enough? (3) Are excessive contrasts present in the workstation? (4) Must the operator keep looking from a bright to a dark area, and vice versa? (5) Are there reflective surfaces in the workstation? (6) Are the light sources properly arranged? (7) Is the lighting steady? (ie no flickering fluorescent tubes; tubes out of phase with each other; no strobo-scopic effects from moving machinery). (8) Is there excessive brightness contrast between different colours? (9) Are attention getters sensibly used?	(Refer also to comments on perception demands clause **13.4.3.1** Question 2d.)

QUESTIONS	COMMENTS
(10) Does the colour scheme in the workplace avoid visual strain?	
(11) Will the task require high visual demands?	(See Part 7 of this Defence Standard)
(12) Does the workspace require a high illumination level?	)
(13) Is general artificial illumination necessary?	)(See Part 6 of this Defence
(14) Will the workspace layout be exposed to different illumination levels?	)Standard)
(15) Is there any glare from the workspace or surroundings?	)
b. Indoor climate	
(1) Is the air temperature comfortable?	
(2) Are the surrounding surfaces at approximately the same temperature as the air?	
(3) Are there any perceptible draughts?	
(4) Is the relative humidity physiologically suitable?	
(5) Are the heating appliances placed correctly?	
(6) Is the air changed as frequently as required?	
c. Questions Relating to Work Under Hot Conditions	
(1) Is the heat load acceptable?	
(2) Are the operators suitably clothed?	
(3) Is the supply of liquids sufficient?	
(4) Can the heat load be reduced by protective devices?	

13.4.5.2 Mechanical sources

QUESTIONS	COMMENTS
1. What are the ambient and range of mechanical conditions likely to be? a. Will there be high impulsive and/or continuous noise levels above safe levels from which operators will require protection? (See also Question 3 below.) b. Will there be vibration of mechanical origin, shock loading, and ride motion due to movement across uneven terrain; wave, swell and wind effects from water; wind-shear, clear and storm air turbulence from which operators will require protection? c. Will there be high acceleration, G-forces and weightlessness experienced by operators from which they require protection? d. Are any parts of the body exposed to undue constant or intermittent mechanical pressure? e. Does the machine/equipment cause significant vibration and if so, how will this effect the operator's performance?	(See also Parts 5, 8 and 9 of this Defence Standard.)
2. Do external factors listed in Question 1 above make the work harder such that operator performance is degraded?	
3. a. Protection against noise (1) Does the noise disturb vigilance or mental effort? (2) Does the noise interfere with conversation? (3) Is the noise level so high that there is a danger of damage to hearing? (4) Can the noise level be reduced? (5) Is there a danger of hearing damage because of the intensity or long-term presence of noise?	(See also mental workload clause **13.4.3**).

QUESTIONS	COMMENTS
b. Health safeguards (1) Does the layout of the workplace make accidents possible? (2) Does the performance of the work involve risk of accidents? (3) An accident is unpredictable hence perhaps it is better to talk about making the workspace safer than whether accidents may occur. (4) Is there any risk of burns or explosion?	It is suggested that the designer prepares a list of potential injury modes (cuts, bruises, fractures, amputations, burns, internal ruptures, eye penetration, asphyxiation, etc). This should be used as a checklist to evaluate the proposed human-machine allocation decisions.

Table A

Anthropometric Data for Common Working Positions

	Percentile values (mm)			
	5th percentile		95th percentile	
	Male	Female	Male	Female
1 Weight (including combat clothing)	62 kg	48 kg	96 kg	84 kg
2 Stature (clothed, including shoes)	1705	1570	1915	1770
3 Functional reach (back of shoulder to thumbtip in pinch-grip)	720	665	855	785
4 Dynamic forward reach (including forward shoulder movement)	840	785	975	905
5 Vertical functional reach - standing (one-handed, including shoes)	2085	1915	2375	2210
6 Vertical functional reach - sitting (one-handed)	1285	1175	1460	1345

Related Documents

The documents and publications referred to in this Part of the Standard are as follows:

BS 5940 Part 1 1980 - Design and dimensions of office workstations, desks, tables and chairs
Def Stan 00-25 Part 2 - Body Size
Def Stan 00-25 Part 3 - Body Strength and Stamina
Def Stan 00-25 Part 5 - The Physical Environment: Stresses and Hazards
Def Stan 00-25 Part 6 - Vision and Lighting
Def Stan 00-25 Part 7 - Visual Displays
Def Stan 00-25 Part 8 - Auditory Information
Def Stan 00-25 Part 9 - Voice Communication
Def Stan 00-25 Part 10 - Controls
Def Stan 00-25 Part 11 - Design for Maintainability
Def Stan 00-25 Part 12 - Systems

A J Metric Handbook (3rd Edition), 1970

The Architectural Press: London 1969

Bailey R W (1982)

Human Performance Engineering. A guide for System Designers.
Prentice-Hall, Inc.

Barnes R M (1963)

Motion and Time Study (5th edition).
New York: Wiley, 1963.

Flowers K, (1975)

Handedness and Controlled Movement.
British Journal of Psychology, 66, 39-52.

Grandjean E (1980)

Fitting the Task to the Man.
Taylor and Francis Ltd, London.

Kantowitz B H and Sorkin R D (1983)

Human Factors. Understanding People-System Relationships.
J Wiley and Sons Inc

McCormick, E J & Sanders, MS (1982)

Human Factors in Engineering and Design (5th Edition).

Morgan C T and Chapanis A, (1963)

Human Engineering Guide to Equipment Design.
McGraw-Hill Book Company.

Oborne, D J (1982)

Ergonomics at Work.
J Wiley and Sons Ltd.

Pheasant S, (1986)

Bodyspace. Anthropometry, Ergonomics and Design.
Taylor and Francis.

Porter J M, Case K and Bonney MC (1986)

SAMMIE: An Ergonomics CAD System for Vehicle Design and Evaluation, BODITEK 1986, Institute of British Carriage and Automobile Manufacturers, University of Keele.

Price H E

The Allocation of Functions in Systems.
From Human Factors, 1985, 27(1) 33-45.

RARDE, (1988)

VERDI (Proposal for a Vetronics Demonstrator Programme).
The Wessex Press.

Rebiffe P R (1969)

Le Siege du Conducteur: Son Adaptation Aux Exigences Functionnelles et Anthropometriques. Ergonomics, 1969. (From McCormick and Sanders 1982, page 341).

Van Cott H P, Kinkade R G (1972)

Human Engineering Guide to Equipment Design.
Joint Army - Navy - Air Force Steering Committee.

Woodson W E, (1981)

Human Factors Design Handbook.
McGraw–Hill Book Company.

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