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Computer workspace modelling

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In *Evaluation of Human Work: A Practical Ergonomics Methodology*,
Editors J.R. Wilson and E.N. Corlett,
Taylor & Francis, London, pp472-499, 1990

Computer workspace modelling

J. Mark Porter, Keith Case and Maurice C. Bonney

Man-modelling CAD systems*

Computer aided design (CAD) methods are becoming very popular with engineers as they provide considerably more flexibility than conventional techniques. Although they are now commonplace in manufacturing industries the great majority of CAD systems completely ignore the most important component of the human-machine system being designed-humans themselves.

The importance of an ergonomics input to a design is now recognized by many industries as being essential. The increasing complexity of modern systems and the social, economic and legislative pressures for good design have led to the demand for the ergonomics input to be made available as early as possible in the design programme, starting preferably at the concept stage. Traditionally, ergonomists have had to wait until the mock-up stage before being able to perform a detailed evaluation of a prototype design. This delay has several consequences, which will be discussed later in this chapter, all of which are detrimental to the design process.

Clearly, the optimum solution is to provide a means of supplying the ergonomics input in a complementary fashion to the engineering input; the logical conclusion being to develop CAD systems with facilities to model both equipment and people. Recognizing the potential of this solution, in some cases as early as the late 1960s, several research teams have developed man-modelling CAD systems. These have met with varying degrees of success but, essentially, they are design tools which enable evaluations of postural comfort and the assessment of clearances, reach and vision to be conducted on the earliest designs, and even from sketches. In order to achieve these predictions, the systems need: three-dimensional modelling of equipment and workplaces which can be displayed on a computer graphics screen; three-

• *Editors Note:* 'Man' is used in this chapter as a generic term in preference to human or people in the context of modelling systems, since this is the terminology employed in the area.

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dimensional man models (representations of the human form which can be varied in size, shape and posture for a variety of populations); evaluative techniques, based around the man model, to assess reach, vision, fit and posture; and a highly interactive user interface which allows the user to tailor design evaluations to their own requirements.

Existing systems

Existing man-modelling CAD systems show considerable differences in the extent to which the above facilities have been developed, and the breadth of their potential applications. Brief descriptions of the most established man-modelling systems are given below.

BOEMAN
Developed by the Boeing Corporation, Washington in 1969 for use in checking cockpit layout (see Figure 19.1), the system was complex to use and it was not designed for interactive use as graphics terminals were not commonly in use at that time.

BUFORD
Developed by Rockwell International, California (see Figure 19.2), it offers a simple model of an astronaut, with or without a space suit. Body segments can be selected separately and assembled to construct any desired model, although these segments must be moved individually to simulate working postures. The model does not predict reach but a reach envelope of two-

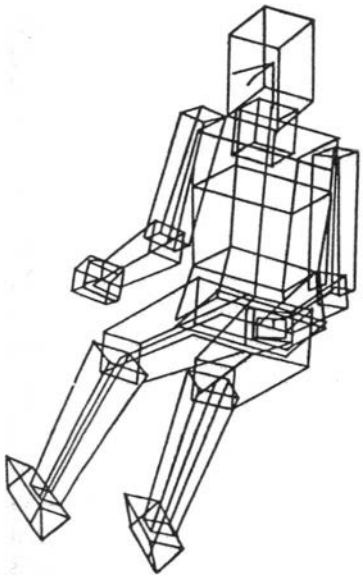


Figure 19.1. BOEMAN (reproduced from Dooley, 1982).

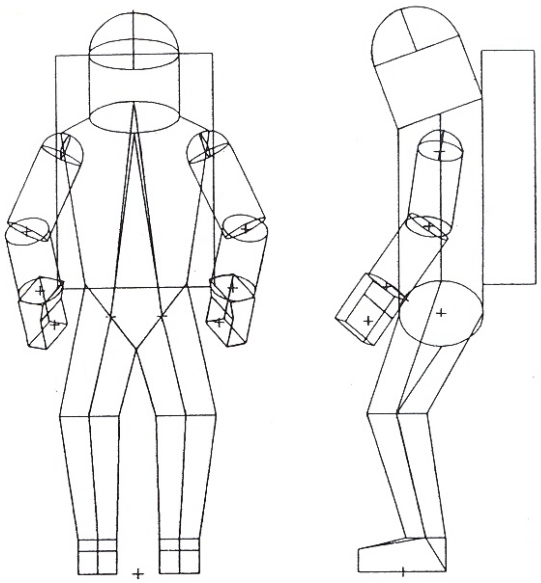


Figure 19.2. BUFORD (reproduced from Doo1ey, 1982).

handed functional reach can be defined and displayed around the arms. It is not generally available.

CAR (*C*rew *A*ssessment of *R*each)
Developed by Boeing Aerospace Corporation for use by the Naval Air Development Centre in the USA, the system is designed to estimate the percentage of users (i.e. aircrew) who will be able to be accommodated physically in a particular workstation. The analysis is purely mathematical and the system has no graphical display. It is only available for in-house assessment of reach in aircraft crew stations.

COMBIMAN (*Com*puterized *Bi*omechanical *Man* Model)
Developed by the University of Dayton for the US Air Force in 1973 to assist in the design and evaluation of aircraft crew stations (see Figure 19.3), the equipment modelling assumes that the work space is made up of panels and controls and the model is only available in the seated position. The use of this system is mainly limited to the prediction of vision and hand reach, and is anyway restricted to in-house users.

CYBERMAN *(Cyber*netic *Man* Model)
Developed by the Chrysler Corporation in 1974 for use in design studies of car interiors (see Figure 19.4). There are no constraints on the choice of joint angles so the man model's usefulness for in-depth ergonomics evaluations is rather limited. This system is also not generally available.

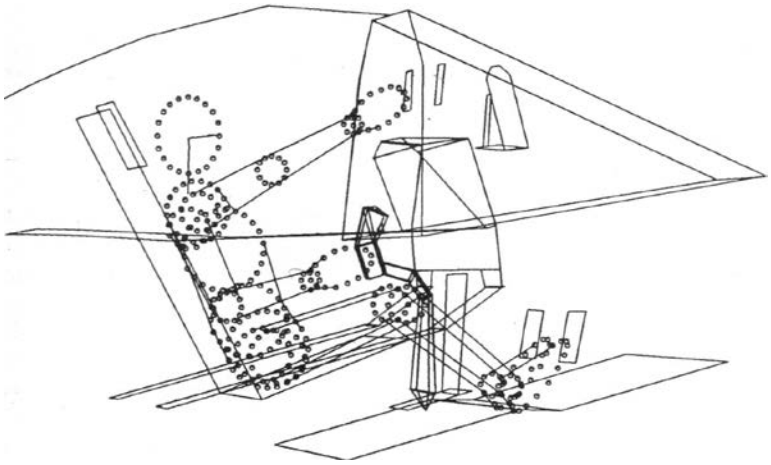


Figure 19.3. COMBIMAN (reproduced from Dooley. 1982).

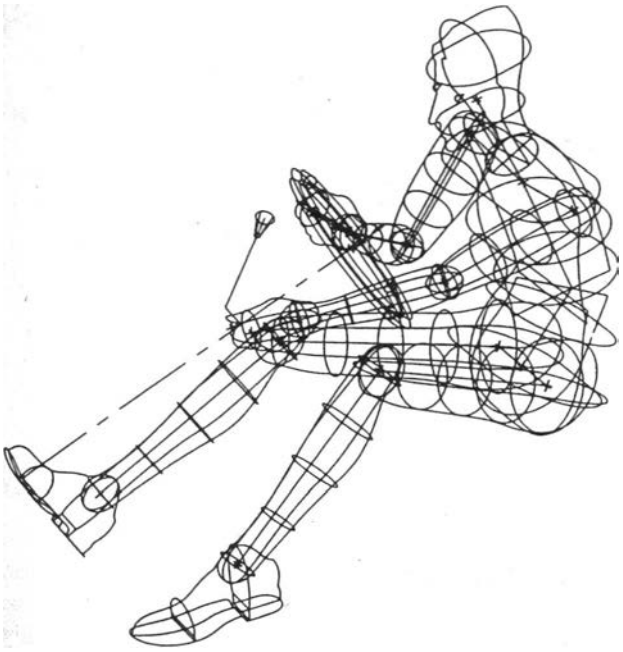


Figure 19.4. CYBERMAN (reproduced from Dooley. 1982).

FRANKY
Recently developed by Gesellschaft fur Ingenieur-Tecnick (GIT) mbH in Essen, it has a very similar (and comprehensive) suite of facilities to SAMMIE (which is described below). However FRANKY is not presently commercially available (see Figure 19.5).

OSCAR
Recently developed by the Hungarian Design Council in Budapest, it has been adapted for use in Western Europe by the SOMACAD team of the Fachhochschule Darmstadt (see Figure 19.6). Although this system can be run on a personal computer, its usefulness is limited as only very simple workplace models can be constructed. This West German team have subsequently developed and are marketing a '3D ergonomic template' called ANYBODY for use as a module in the widely available CADKEY software (see Figure 19.7).

SAMMIE (System for Aiding Man-Machine Interaction Evaluation)
Developed originally at Nottingham University in the late 1960s, and more recently at Loughborough University of Technology (see Figure 19.8), the general purpose nature of the system makes it suitable for a wide range of applications (described later in this chapter). In addition, the system permits the modelling of any special or logical relationships between components of the models, allowing the models to be functional; for example, the operational

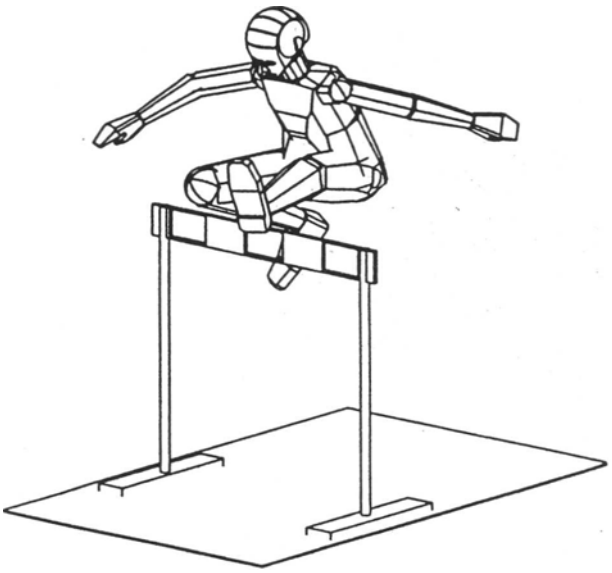


Figure 19.5. FRANKY (reproduced from Bias and Lux, 1986).

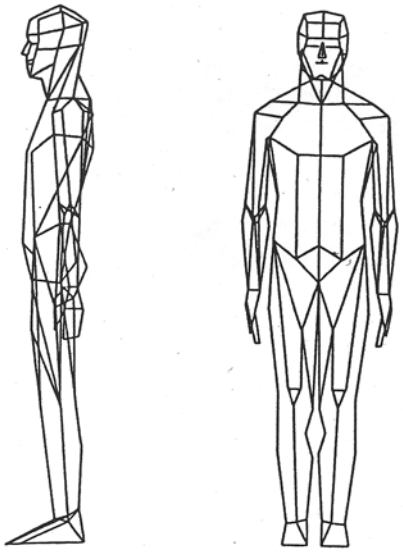


Figure 19.6. OSCAR (reproduced from Lippmann, 1986).

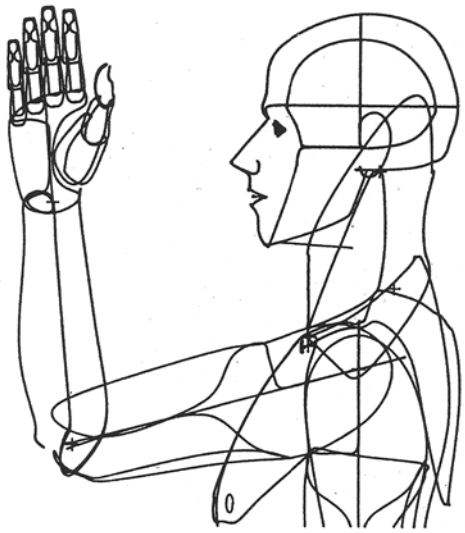


Figure 19.7. ANYBODY.

movements of pedals, doors, seats or levers can be easily specified and executed. SAMMIE is currently the only system being marketed world-wide which provides sophisticated ergonomics facilities and a powerful work place modelling system.

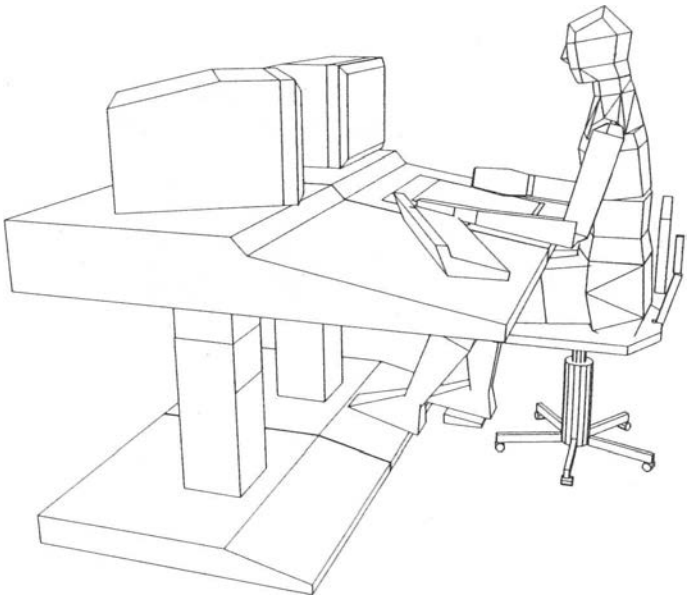


Figure 19.8. SAMMIE.

Further information

Dooley (1982) and Rothwell (1985) both present surveys of man-modelling systems, including most of the above systems. Other sources include: McDaniel (1976) (COMBIMAN); Elias and Lux (1986) (FRANKY); Lippmann (1986) (OSCAR); and Porter and Freer (1987) (SAMMIE).

A man-modelling CAD system

The SAMMIE system will now be described in more detail to demonstrate how a man-modelling CAD system can be used as an extremely effective ergonomics tool.

Equipment and workplace modelling

The workplace modelling system is used to generate full-size 3D geometric representations of a working environment and specific items of equipment. A boundary representation form of solid modelling is used to enable the system to be highly interactive whilst maintaining a sufficiently accurate 3D model. This method requires that solid shapes are constructed from a description of the location of their vertices, a knowledge of which vertices are joined together to form edges and which edges form plane polygon faces. Models of

considerable complexity can be quickly built from the range of parametrically defined primitive shapes available such as cuboids, prisms and cylinders (see Figure 19.9). These primitives require only a brief specification

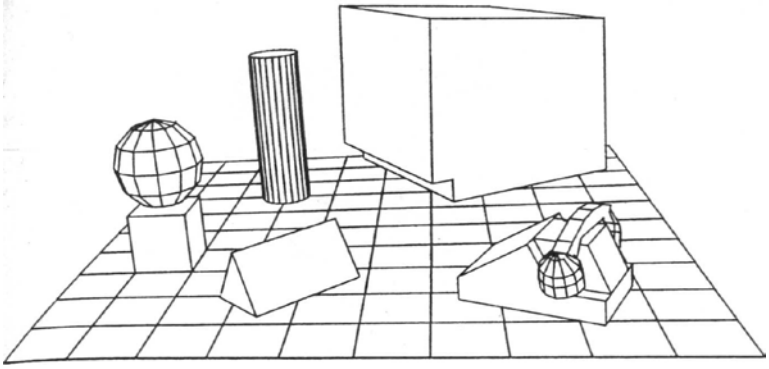


Figure 19.9. Examples of simple model types available in the SAMMIE system. The telephone is an example of how models are formed from these basic types.

[i.e. cuboid name, width (mm), depth (mm), height (mm)). whereas non-regular solids need the complete description of vertices, edges and faces. Solids of revolution (e.g. a sphere) can be created by defining the axis of revolution and the desired profile. Although truly curved surfaces are not available, this has never been a cause for concern from an ergonomics point of view, as sufficient accuracy can be obtained from a suitably configured faceted model. A reflection facility is also available so that mirror images of solids can be constructed automatically; for example, only one side of a car needs to be defined manually.

As mentioned earlier, the SAMMIE modeller is particularly strong in its ability to specify logical or functional relationships between items in the model. This is achieved using a hierarchical data structure, an example of which is shown in Figure 19.10. This hierarchy allows the designer to move the whole car as one unit or to open individual doors or the boot (see Figure 19.11), to rotate the steering wheel or to adjust the tilt of the driver's seat cushion. To achieve this selectivity, users need to travel across and up or down the data structure until they reach the level which will control the particular item(s) to be adjusted.

The data describing the 3D models are normally prepared away from the computer terminal using engineering drawings or sketches, although it is possible to create models interactively at the graphics screen during a design session. Another important feature of the system is its ability to interactively modify the geometry of an item in ways relevant to the design situation. For

example, if a table was modelled as a top and four legs, then increasing the width of the table would automatically reposition the legs to maintain a valid model.

Man modelling

The man model is a 3D representation of the human body with articulation at all the major body joints. Limits to joint movement can be specified and

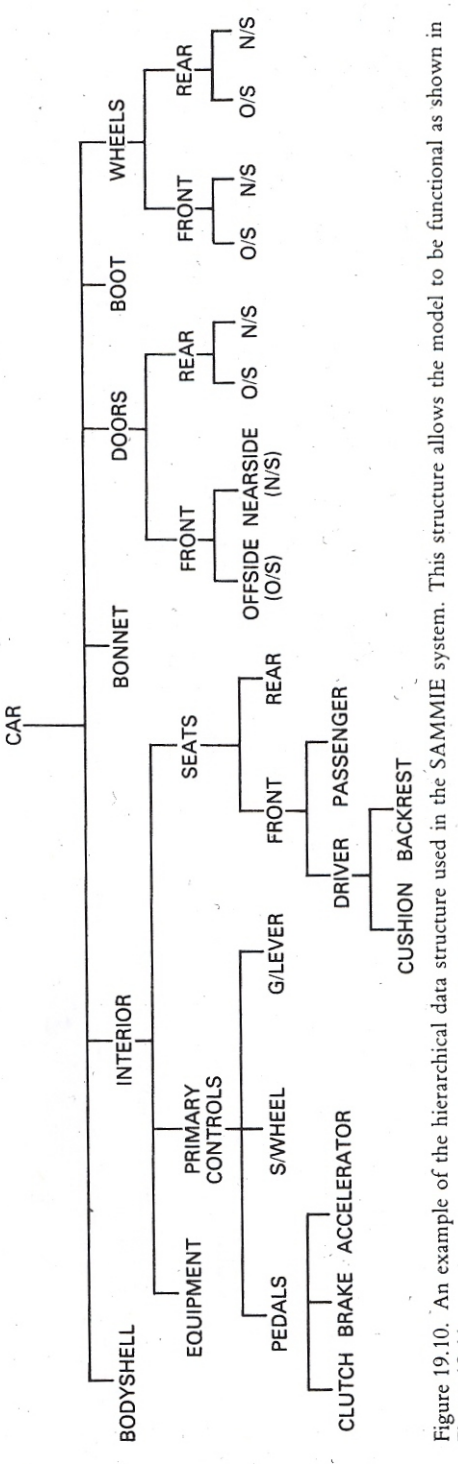


Figure 19.10. An example of the hierarchical data structure used in the SAMMIE system. This structure allows the model to be functional as shown in Figure 19.11.

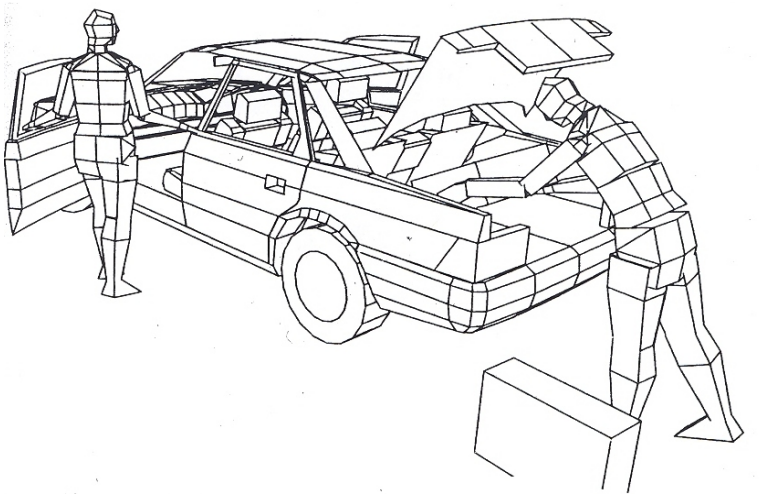


Figure 19.11. A complex car model. SAMM1E's hierarchical data structure enables functional as well as geometric relationships to be modelled, thus all moving parts of the model can be made to function. For example the car's doors, bonnet and boot can be made to open and close. Inside the car it is possible to adjust the seat and steering wheel within the design specification.

the dimensions and body shape of the man model can be varied to reflect the ranges of size and shape in the relevant national and/or occupational populations (see Figure 19.12).

The man model is displayed as a set of 17 pin joints and 21 straight rigid links structured hierarchically to represent the major points of articulation and the body segment dimensions (see Figure 19.13). The hierarchical structure is similar to that shown for the car, so that when the man model's right upper arm is raised, then the right forearm and hand follow accordingly. By dropping down the hierarchy users can control just the forearm and hand together or just the hand, at their discretion.

The size, shape and range of postures permitted are a function of the anthropometric and biomechanical data bases chosen by the user. The data required consist of the linear dimensions between adjacent joints (e.g. from elbow to wrist), the body segment parameters of weight and centre of gravity, and the absolute and 'normal' limits for each joint in each of the three degrees of freedom (i.e. flexion-extension, abduction-adduction and medial-lateral rotation).

The limb length data can be stored as either a set of mean dimensions together with standard deviations, or as a set of dimensions explicitly defining the anthropometry of an individual. The displayed man model can be interactively amended by changing the overall body percentile, individual link

percentile, explicit link dimension and the use of correlation equations to relate internal link dimensions to external anthropometric dimensions.

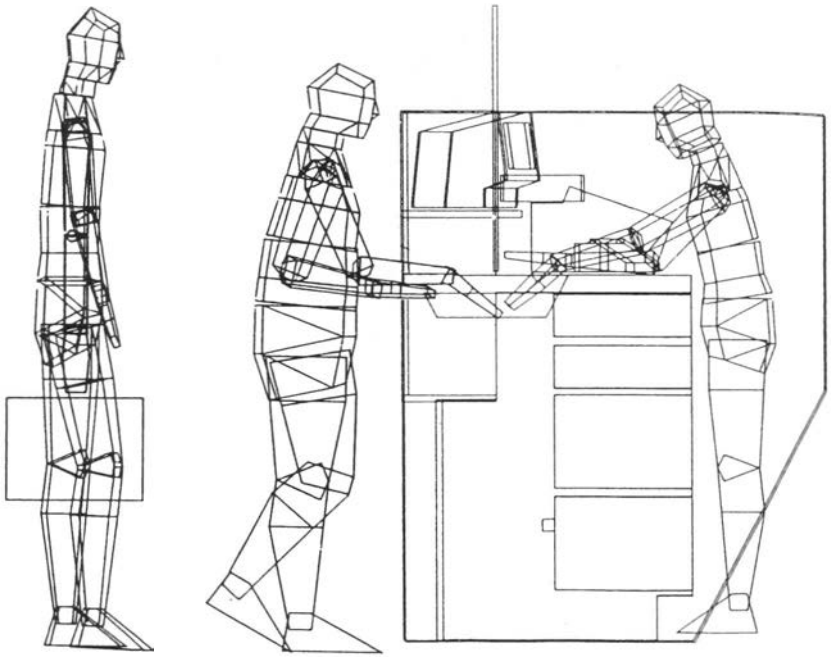
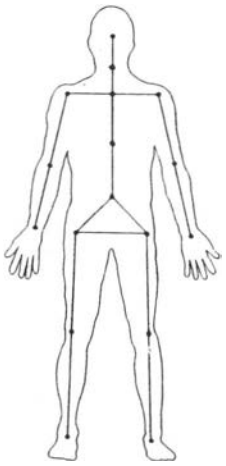


Figure 19.12. Shown, from left to right, are male models of 95th, 50th and 5th percentile stature from a chosen population. The system also enables changes to be made to individual limbs allowing representation of specific users or groups of users. The shape of the models' flesh envelope can be varied in accordance with somatotypes providing a useful evaluative technique for situations involving work in confined spaces.



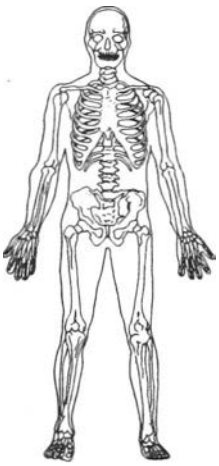


Figure 19.13. The link structure of the man model is a simplification of the human skeletal frame, with pin-joints suitably constrained to simulate human movement capabilities. The rigid links between the joint centres are defined by use of anthropometric data and are usually displayed with 3D flesh shapes.

The flesh shape is controlled by a classification system known as somatotyping (Sheldon, 1940) which enables the extent of endomorphy, (plumpness), mesomorphy (muscularity) and ectomorphy (leanness) to be specified; the somatotype number and the height and weight enables 17 body dimensions to be obtained from Sheldon's experimental data.

The joint constraints prevent the man model being positioned in an unattainable posture. For example, it is impossible to abduct the elbow. The system indicates whether a selected joint angle is within the 'normal' range of movement, 'within the maximum range, or infeasible. The limb dimensions and somatotype can be interactively altered to construct 3D man models to the user's unique specification if desired. Additionally, the joint constraints can be limited to represent disability, the effects of bulky clothing or unusual working conditions, for example where high gravity forces may severely limit arm movement.

The variable anthropometry of the man model is clearly advantageous for the evaluation of body clearances (fit) and reach. In addition, the 'man's view' facility allows the user to display the man model's field of view on the graphics screen. These facilities allow the user to predict the likely work postures that a given design will enforce. For example, a tall and fat model of a driver might be shown to adopt a slouched posture to gain sufficient headroom with arms at full stretch to the steering wheel under which the thighs are trapped. The view to the main driving displays may be obscured by the steering wheel, causing the driver to slouch to an even greater extent. This posture can be visualized by the designer and specified in terms of joint angles which can be compared with recommended angles in the literature (e.g. Rebiffe, 1966 for the driving task). The ergonomist would be able to comment upon such a posture saying that tall drivers of that particular car would suffer considerable discomfort in the neck, shoulders, lower back and thighs. Furthermore, the design can then be interactively modified by lowering the seat or raising the roof-line, and re-positioning or providing adjustment to the steering wheel.

Ergonomics facilities

The system has several facilities to help the user assess the ergonomics of a particular design.

A clasher routine

This facility automatically detects whether two solids are intersecting and, if this is the case, it flashes the appropriate items to attract the user's attention. This feature can be used to check clearances with the man model set to an appropriate size and shape, say 99th percentile limb lengths and an extreme endomorph. Alternatively, visual inspection from a variety of angles will achieve the same result.

Reach algorithms

Reach can be assessed simply by positioning the arms or legs so that the hands or feet either contact, or fail to contact, a specified control or point in space (see Figure 19.12). This method could become tedious for a large number of controls so an algorithm has been developed which predicts a feasible posture for the arms or legs given a specified model item or coordinates to be reached. Generally, there will be a large number of feasible postures for any successful reach attempt. The algorithm selects the limb posture to be displayed by attempting to minimize the extension of the joints away from their neutral positions and by preferring the greater extension of distal links to those that are more proximal. This feature does not ensure that the displayed limb posture is the likely posture adopted by a human, but it does confirm whether or not the reach attempt will be successful. If a reach attempt fails, the system displays this fact together with the distance by which it failed.

There are two other automated methods to define reach: reach areas and reach volumes. Both methods are especially suited to concept design as they are generated without specifying control locations or co-ordinates. The first method enables envelopes of reach areas to be overlaid on any surface of the design as an aid to assessing suitable positions for control locations. The second method is an extension of this whereby reach is assessed over a number of imaginary surfaces parallel to either the frontal, saggital or transverse planes of the man model. An example of a reach volume in the transverse plane is shown in Figure 19.14; such information is particularly useful for locating controls above head height. A major study was conducted using this facility to determine both hand and foot reach zones for drivers of agricultural tractors (Reid *et aI., 1985).*

Vision tests

The view 'seen' by the man model (man's view) is under the full control of the user (see Figure 19.15). For example, one can select left, right or a mean eye position, 60 or 120^0 cone of vision and specify the angle of vision using the

eyes and/or head as appropriate. Constraints limit the maximum angles of vision from the eyes. As with reach, the testing of vision can be achieved manually by directing the head and eyes or else the user can specify the model item or co-ordinates to be viewed; the resulting view, together with the visual angle and viewing distance, will be displayed automatically.

Further developments include 2D visibility plots whereby vision can be determined at any given surface (e.g. checking vision of the fascia of the vehicle and, in particular, through the steering wheel) and 3D visibility charts which describe all-round visibility (e.g. checking external visibility from a vehicle through all the windows). Simple calculations allow one to calculate the maximum vertical visibility at any given point on the ground so, for

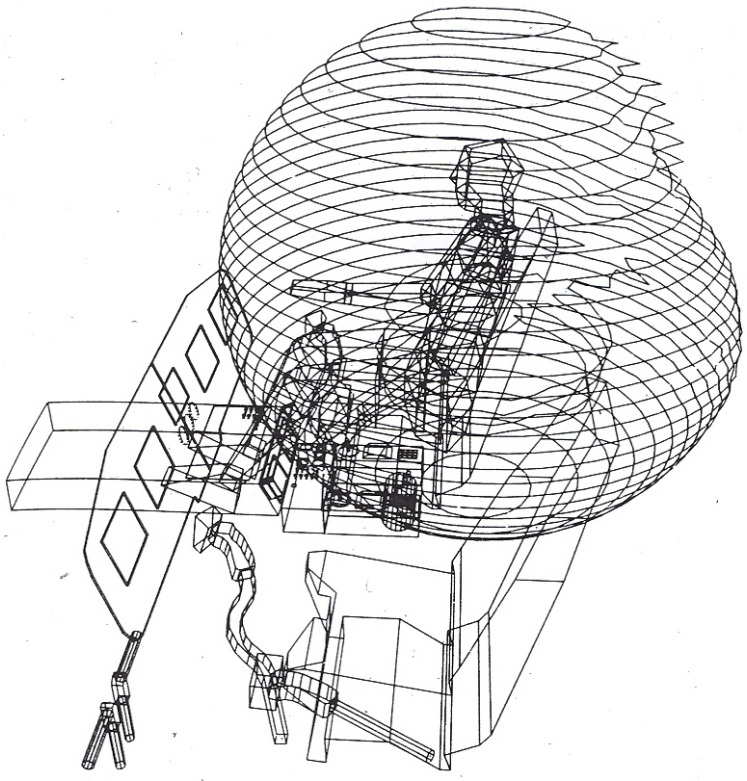


Figure 19.14. This plot illustrates volumetric reach facility (available for both hands and feet). In this example the right hand reach for a 50th percentile male helicopter pilot is being assessed.

example, the user can check whether a tall driver would be able to see signposts and traffic lights without leaning forward. These charts are described in detail in Porter *et al.* (1980).

Mirrors and reflections

The mirror modelling facility can be used to design mirrors for vehicles (see Figure 19.15) or to determine whether reflections will be a problem in windscreens or computer screens. The mirror parameters of focal length, convexity/concavity, size and orientation are all variable and can be interactively adjusted to provide the required field of view displayed on the mirror surface, as seen by the man model.

Saving postures

Having selected an appropriate size and shape of man model and adjusted his/her posture to suit the task demands and physical constraints of the

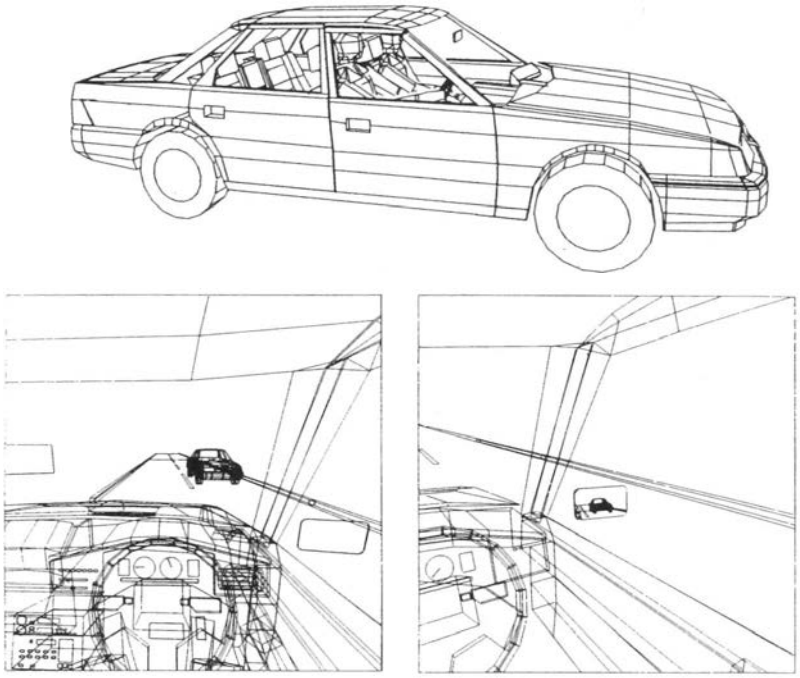


Figure 19.15. SAMMIE's viewing facilities enable the evaluation of the visual field for the full range of operator sizes. Left shows a 95th percentile male driver's view of the car controls and displays and the road through the windscreen. Right shows a 95th percentile male driver's view in his off-side exterior mirror. Reflections in the windscreen at night due to unshielded illuminated displays can also be identified at an early stage in the design.

workplace, it is important that this posture can be stored and recalled at a later date. This facility exists and it enables the user to run through a sequence of typical work postures in rapid succession, for example driving forwards, depressing the clutch and engaging first gear, depressing the clutch, engaging reverse gear and looking rearwards (see Figure 19.16).

User dialogue

The system is highly interactive and allows designers to proceed through the design process in a manner determined by their own requirements rather than in a predetermined manner. The user communicates with the system via a menu based dialogue using either keyboard, light pen, or mouse. Each menu, of which there are nearly 40, contains commands grouped according to their functions. A brief description of the main menus is given below.

View menu

The status of the graphics display is governed by four main parameters. The first is the centre of interest, basically what the user is looking at, either

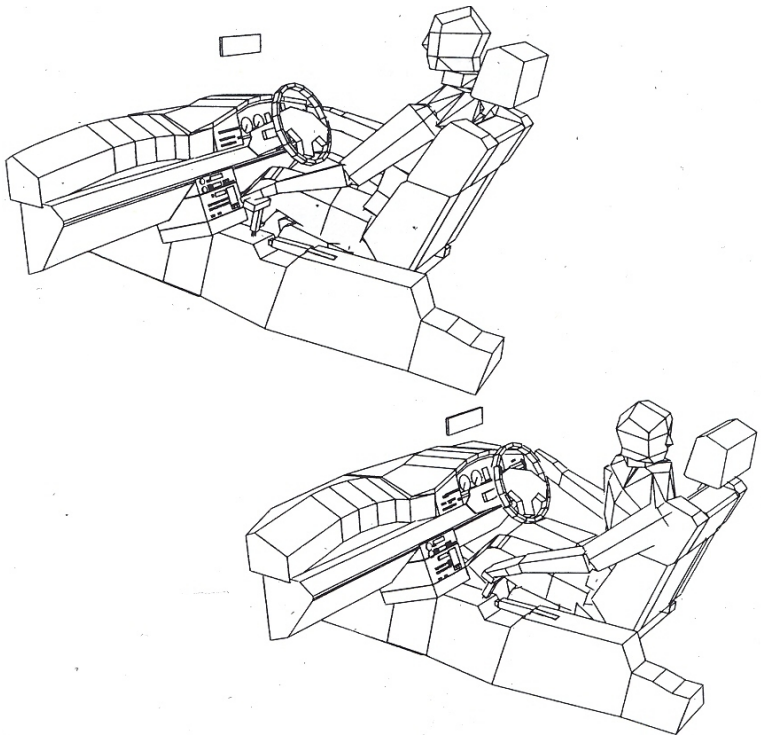


Figure 19.16. SAMMIE can be used to evaluate fit, postural comfort (by reference to joint angle data) and reach to controls in the car interior. As well as the appraisal of static reach and comfort it is also possible to consider use sequences.

directly or through the man's view. The second is the viewing point, which can be set at the man model's eyes or any other point in 3D space around or inside the models that have been constructed. The third parameter is the choice between displaying view in plane parallel projection (e.g. engineering drawing style) or in perspective and the fourth is the size of the displayed model, which is set by the scale factor in plane parallel projection and by the acceptance angle (i.e. the viewing angle) in perspective. The 'view menu' contains a variety of ways of interactively changing these parameters and it also provides a directory of 'saved views' which the user has set up for future use.

Workplace menu

These commands allow the interactive positioning of models or component parts of models in the workplace. Items can be shifted or rotated about either their own (local) axis system or the global axis system. An example of this important distinction is illustrated in Figure 19.17.

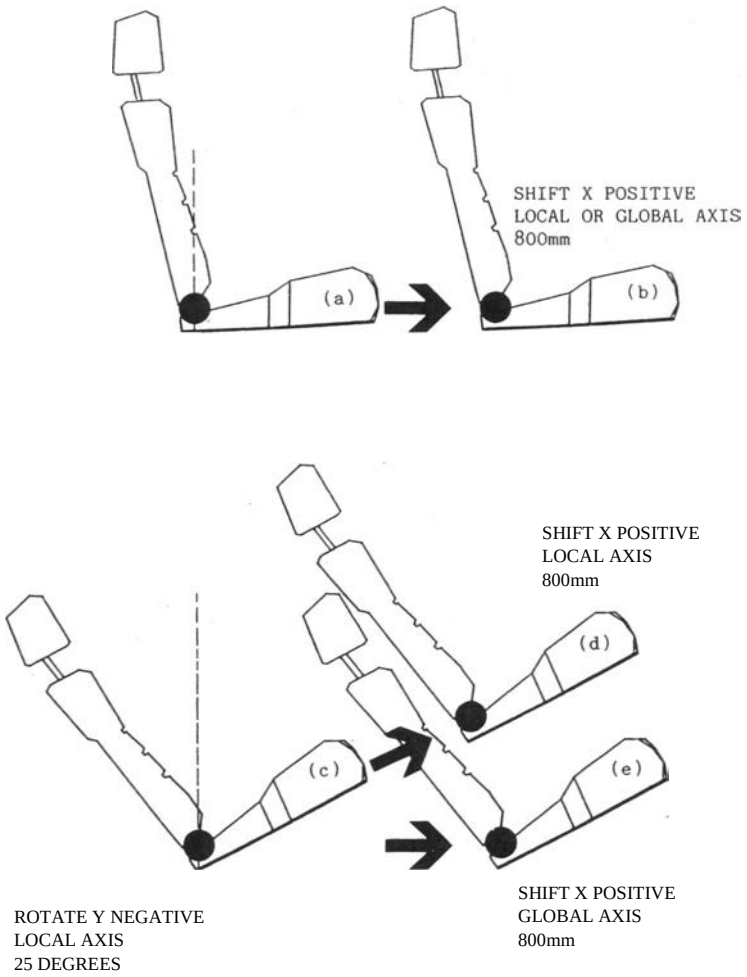


Figure 19.17. An example of the use of the local and global axis systems available in the SAMMIE system. In some orientations these axis systems are identical, as shown in (a) and (b) where the seat is shifted 800mm along the global or local X axis. In (c) the car seat has been rotated about its local Y axis to produce seat tilt. (If it had been rotated about the global Y axis then it would have pivoted around the centre of the available workspace.) Examples (d) and (e) show how a subsequent 800 mm shift along the local and global axis systems, respectively. can produce different results. If the intended movement is to simulate fore and aft adjustment of the seat, then only (e) is appropriate.

A commonly used alternative to specifying the shift distance in millimetres is to 'drag' the chosen item(s) to a desired location on the

screen using the light pen, keyboard cursor keys or mouse. This method can be faster because the location can be changed in two axes simultaneously and the accuracy can be maintained by increasing the scale of the model.

Display menu

Complex models take longer to be drawn on the graphics screen and sometimes these models appear confusing. The 'display menu' allows the user to select which items need to be displayed as required.

Man menu

This menu contains a variety of sub-menus including the 'anthropometry menu' for changing the anthropometry of the man model, the 'joint movement menu' for postural changes, the 'man's view menu' for displaying the view seen by the man model and the 'reach menu' for producing reach areas and reach volumes.

Geometry editor menu

When evaluating a design it is useful to be able to expand or shrink the dimensions of some items. This menu enables the X, Y or Z dimensions (width, depth and height) to be modified in isolation or concert. This feature is very useful at the concept stage because a large number of small cubes can be built and interactively edited to form appropriate sized building blocks for the construction of the early models.

Hidden lines menu

Models are usually displayed on the graphics screen in wire frame form (see Figure 19.14) so that all the edges of the model are visible, even though some in reality would be totally or partially obscured by solid objects. This type of display is easily interpreted by an experienced user although, for extra clarity or presentations, the 'hidden lines' can be automatically removed (e.g. Figures 19.8, 19.11 and 19.16).

Plot menu

The end result of a design and/or evaluation will usually be in the form of a variety of views taken from the graphics screen and drawn on a pen plotter. The 'plot menu' provides a standard format for these views with the option of including a title and several lines of comments.

*Case studies using **SAMMIE***

Two projects carried out using SAMMIE are described here to give the reader an insight into the way in which such systems are used; the typical length of a project using SAMMIE is around ten days.

Computer workstation design

The aim of this project was to design an integrated workstation to be used in the computer aided design of printed circuit boards. The original workstation was purely a grouping together of the hardware needed to perform the required functions, which resulted in a three-sided configuration, comprising an alphanumeric VDT on the left, an AO digitizer board in the centre and a graphics VDT on the right. Not unexpectedly, this arrangement was far from satisfactory with a high incidence of physical discomfort reported by the users. The manufacturers then designed two prototype integrated workstations where the graphics VDT and a much reduced digitizer, which was sunk into the worksurface, were placed directly in front of the user. However, both these designs were found to cause problems for the user for several reasons, including lack of thigh clearance, forward leaning over the worksurface, difficult reach to the keyboard and an excessive viewing distance to the graphics VDT. The manufacturers were both surprised and disappointed when these problems came to light within the first few days of testing, as they had invested considerable time and expense to produce the prototypes. However, most of their attention had been directed at the engineering problems and the interface design had suffered as a consequence.

Following initial discussions with the manufacturers, it was decided to develop three alternative designs using SAMMIE, covering a range of manufacturing costs. These designs are illustrated in Figure 19.18 and are now briefly described:

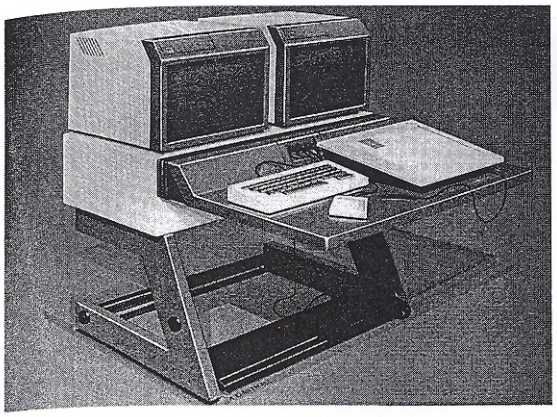
(a) This was the cheapest design with all the components free standing on the fixed height worksurface. Whilst this option may appear satisfactory as a paper specification, the visualization of the workstation clearly shows its shortcomings, such as the lack of space for paperwork, the likely wrist and arm discomfort arising from the raised digitizer board, and the generally clumsy layout.

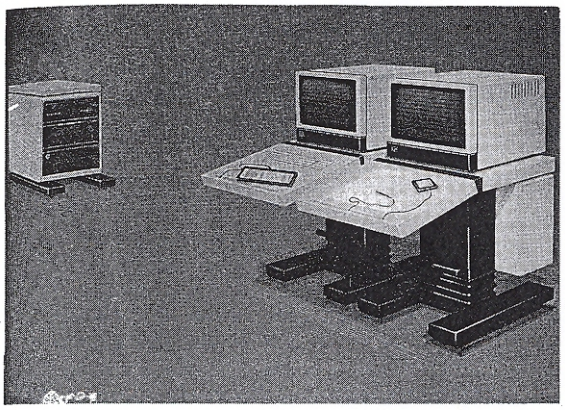
(b) This was the most expensive design as it offered both worksurface height and tilt adjustment. The digitizer was sunk into the worksurface and the workstation could be set up for either left- or right-handed use as it was divided into two modules; this feature also made it considerably more portable.

(c) This was the medium cost design which had all of the features of (b) above except the adjustable tilt angle. The VDTs were adjustable. An evaluation using a man model is shown in Figure 19.8.

These designs were presented to the manufacturers in the form of slides, as

reproduced here. The SAMMIE plots were visually enhanced by an industrial designer who was closely involved in the project. The manufacturers were able to visualize accurately the concept workstations knowing that the SAMMIE system had been used to evaluate the designs in terms of fit, reach, vision and posture. The chosen design was (c) because of several factors, namely its aesthetic appeal, ease of manufacture, cost and sound ergonomics.





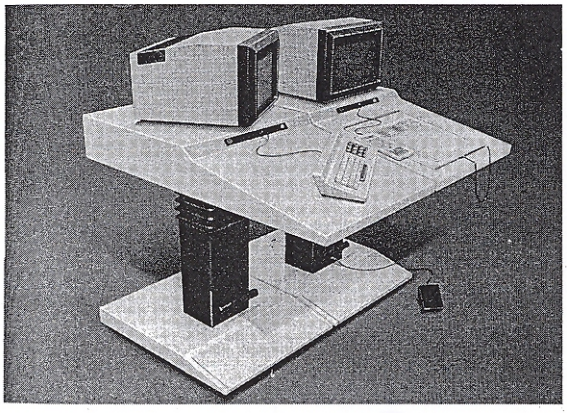


Figure 19.18. Three alternative designs of computer workstations; (a), (b) and (c) were the low cost, expensive and medium cost alternatives respectively (alternative (c) is the same design as shown in Figure 19.7). The SAMMIE plots were enhanced by an industrial designer.

This workstation was manufactured successfully and the product was nominated for a design award the following year.

Train driver's workstation

This project was conducted on behalf of London Underground and it arose because of their policy to change some trains to OPO (one person_driver-operation). The guard's main function had been to open and close the passenger doors at stations, having checked that it was safe to do so. In order for drivers to take on this extra responsibility, it was necessary for them to leave the driving workstation (desk) and walk to the appropriate side of the cab to open the door and check that it was safe to open the passenger doors. The drivers would then wait for all the passengers to disembark or embark before closing passenger doors, then their door, and return to the desk, before pulling out of the station. This additional workload delayed the train from leaving each stop by about 8 s which was considered unacceptable by London Underground's management.

The proposed solution to this problem was to modify the driver's desk by adding a set of passenger door controls to the front edge (see Figure 19.19). In order for this to be a satisfactory solution it was necessary to check that the reduced clearance did not make the workstation too cramped, particularly when getting in and out of the seat. This was assessed using a 95th percentile male man model with an extreme endomorph somatotype and was found not to be a problem as long as the seat cushion was reduced in length by 2 cm. This was achieved by moving the pivot point (the cushion was able to pivot vertically for when the driver wished to stand whilst driving) forwards by 2 cm and cutting off 2 cm of the seat frame at the rear of the cushion. This recommendation was checked for sitting comfort using a full-size mock-up with human subjects; in fact the majority of subjects preferred it to the original design.

One other aspect of the workstation needed investigation before recommending the fitting of new door controls to the desk and this was to ensure that the driver could clearly see the passengers leaving and entering the train without moving from the desk. Obviously, it would be impossible for the driver to see the passengers by direct vision, so underground stations are now fitted with mirrors or video monitors situated on the platform just in front of the train when it is stationary. These displays enable the driver to see the complete length of the train, but only if the displays are completely visible through the driver's windscreen. This was assessed by defining a 3D volume within which all the displays would appear for all the underground stations. These boxes are shown in Figure 19.20 for a 95th percentile male driver. The views show the driver's view of the desk, incorporating the new door controls,

the windscreen, the track and the nearside and offside display boxes. The windscreen is shown with a mesh superimposed over it to allow recommendations to be made regarding the swept area of the wiper blade.

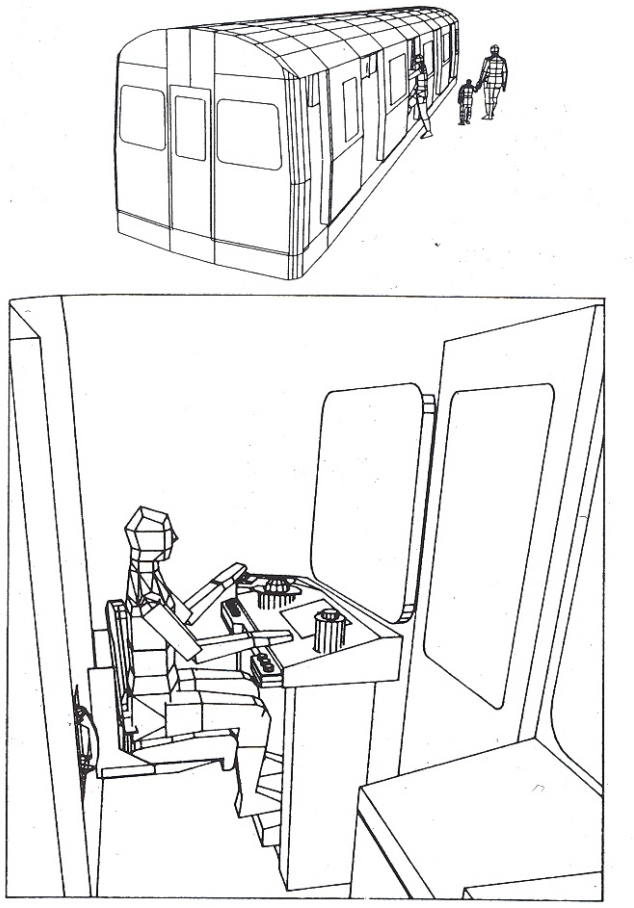


Figure 19.19. A model of a London Underground train; the principal evaluations carried out were concerned with the driver's workstation which was evaluated for ease of access, reach of controls and vision.

The top plot shows the poor view that the driver has when sitting upright; only half of the nearside box is visible and very little of the offside box. The left hand plot shows the view with the driver adopting a 40° forwards lean, whereupon the nearside box becomes completely visible as the driver's eyes are closer to the windscreen enabling a wider angle of view. A further lean of

20° to the left permits the clear view of the offside box. Clearly, any new cab design should enable the driver to see the displays without any leaning at all. However, these postures were considered to be acceptable in the existing cab as they will be fairly infrequent and maintained for short periods of time, and then only when the train is stationary.

The SAMMIE work showed clearly that the proposed modification to the driver's desk was acceptable in terms of both fit and vision, subject to the

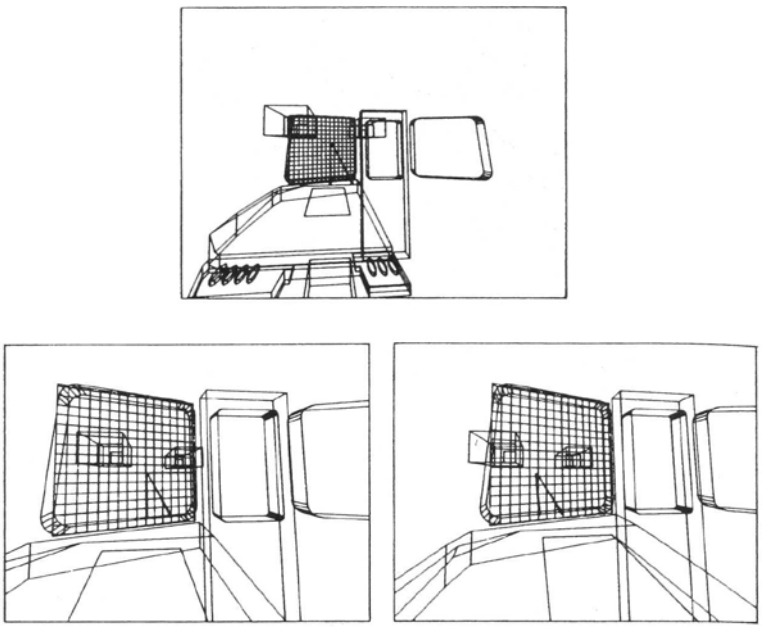


Figure 19.20. Selected views for a 95th percentile male driver in an underground train cab. Vision through the windscreen was evaluated to determine whether the mirrors or video monitors mounted on the platform were obscured by the bodywork of the cab. The top plot shows the view, when sitting upright, of the control panel, windscreens, track and two cuboids depicting the envelopes of possible display locations for all stations. Clearly, the display envelopes are only partly visible .However, if the man model is instructed to lean forward by 40° (bottom left) then the left hand envelope becomes completely visible; the right hand envelope becomes visible (bottom right) when the man model leans to the left in addition (20°). These infrequent postures arc considered satisfactory when the train is stationary.

minor alteration to the seat cushion length. This project highlights the value of CAD in assessing compromises in design.

Details of the above two projects can be'found in Porter (1981) and Porter and Porter (1987). Other projects have been described in Bonney *et al.* (1979a,b), Case and Porter (1980), Levis *et al.* (1980), and Porter and Case (1980).

The advantages of using CAD

There are several important advantages to using 3D man-modelling CAD systems in design and these are now briefly discussed.

Reduced timescale

This clearly can be a major factor and it may often decide whether or not the

project receives any ergonomics input at all. Time can be saved in several

areas. For example, the construction of a computer-based mock-up might take between 1 (simple) to 5 (complex and large) days compared to as many months using wood, glass fibre or other materials. Subject selection can be a time consuming process when conducting user trials, whereas the anthropometric database of the computer system can be used to select the required man models in seconds. For example, when designing driving packages it is important to consider people with long legs and short arms because they will have a personal conflict between positioning the seat rearwards for good leg posture, whilst having the steering wheel at full stretch, or having the seat further forwards for good arm posture at the sacrifice of leg posture. The best solution is to provide steering wheel adjustment but this requirement may not be apparent if user trials are rushed using only a small handful of subjects who may have similar percentile reach with their hands and feet. Another saving is made at the evaluation stage as only a few man models are examined compared to 20-30 subjects, with the ensuing lengthy data analysis.

Early input of ergonomics expertise

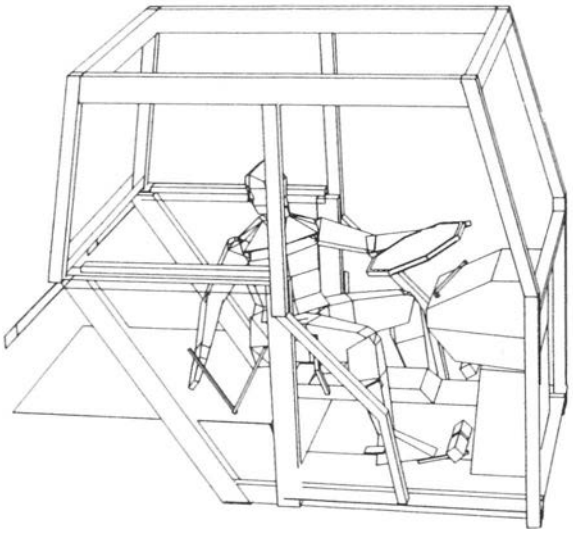
Because of the rapid modelling facilities it is possible to start the ergonomics input right at the beginning of the project. This is particularly necessary as engineers are using CAD systems themselves and the design might be virtually finished from their point of view by the time the first full size mock-ups are ready for traditional user trials.

Iterative design

Early commencement coupled with reduced timescale make it very easy to establish an iterative design programme and to promote the exploration of a wide range of design solutions. Compromises are an essential feature of design and the above features are important ingredients in developing the optimum trade off between, for example, cost and the ergonomics specification.

3D analysis

Apart from user trials, other traditional techniques involve using anthropometric data or 2D manikins. Both of these methods are unsatisfactory for complex tasks, for example driving a tractor and



ploughing a field (see Figure 19.21). The driver will have both feet operating foot controls, one hand will be on the steering wheel and the other will be on a hydraulic control lever to adjust the height of the plough. The driver will be looking both in front and, twisting the spine, over the right shoulder to the furrows behind. This posture cannot be assessed without using 3D analysis.

Figure 19.21. Being three-dimensional, the man models can assume complex postures. For example, the tractor driver shown above must be able to reach the hydraulic control and watch the plough as well as operating the normal driving controls.

Improved communication

Computer graphics provide an excellent means of presenting ergonomics input to design committees. The visual impact of the ergonomics specifications is far stronger and easier to grasp than numerous recommendations in a report. Additional realism can easily be supplied using the services of an industrial designer or stylist (see Fig. 19.22) and this collaboration improves communication within the design team.

Cost effective ergonomics

The use of CAD is cost effective because of the advantages described above. If the ergonomics input lags behind the engineering, then the end result is often last minute modifications which take time and money to implement or a product that does not meet the full ergonomics specification. Both of these are undesirable; the first because it increases the development and production costs, whilst the second is likely to reduce the success of the product or service.

There are few disadvantages, and these are more to do with restricting the potential advantages. One problem is that CAD is a powerful tool and, like any tool, it can be dangerous in the wrong hands. The selection of relevant and accurate data bases and decisions concerning workstation design and posture require the skills of an experienced ergonomist or a designer/engineer with suitable training. The systems arc designed to supplement an ergonomist's skills, not replace them. It would be short-sighted to think that such systems

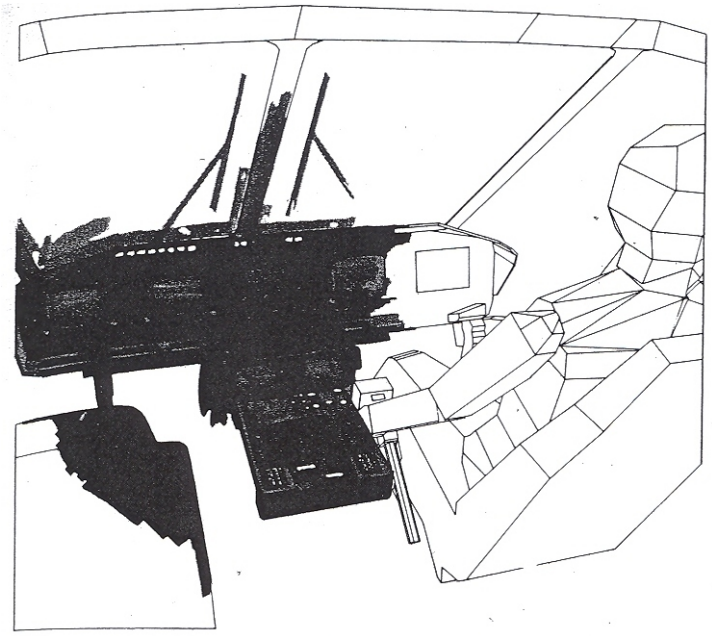


Figure 19.22. A concept model of a helicopter cockpit interior. The combined strengths of the ergonomist and stylist are clearly shown in the above photograph. The ergonomics contribution to the design can be communicated powerfully using 3D graphics.

can replace totally user trials; they should only be used to explore alternative designs, to eliminate the poor ones and select and, if possible, improve upon, the promising ones. The results of the CAD evaluation should lead straight to an in-depth user trial with working prototypes, especially if the tasks are complex and performed under adverse conditions.

Future developments

The future of man-modelling CAD systems looks very promlsmg as manufacturing organizations are always looking for ways to reduce development times and costs, whilst producing good quality design for the increasingly 'design aware' public. With regard to the development of SAMMIE, the following useful enhancements to the system are being considered.

Control of the man-model's posture

The current methods for setting the posture are limited by the fact that it is often difficult to predict the actual posture that people would adopt in some

circumstances. For example, could you specify exactly how you would get

out of a car without taking mental notes as you do it? Even if you do this it would be quite tedious to set up such complex postures for the man model:
One interesting solution to this problem, currently being investigated, is the use of a catsuit worn by the user with strain gauges at the major body joints. This device enables the user's posture to be recorded in the form of voltages which could be linked directly to the control of the man model's posture Another use of the catsuit would be to collect postural data from a sample of people performing a variety of tasks and use the findings as a database for SAMMIE.

Anthropometric database

Very few anthropometric surveys take sufficient measurements to define an accurate 3D model of people. In addition both external dimensions and the location of joint centres, including ranges of movement, are required. It has been suggested (Bonney *et al.,* 1980) that surveys should take into account these requirements and take more comprehensive measurements to maximize the potential applications of their data. The major problem with this request is the time and cost required. However, developments in recording methods may allow the automated collection of thousands of measurements that define points all over the body in seconds.

Other areas of future interest include the implementation of a static strength modeller and the development of a SAMMIE 'expert' system.

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