

# INTERACTIVE GRAPHICS PACKAGE FOR HUMAN ENGINEERING AND

## LAYOUT OF VEHICLE WORKSPACE

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**ABSTRACT** - The problem of vehicle workspace design is solved by use of an interactive graphics package. The package consists of an optimization programme (WOLAP), a biokinematic - anthropometric model and the use of a 3-D graphics display system. It is hoped that by use of this package the designer would have a more comprehensive tool by which to design and configure both the basic dimensions of workspaces for seated operators and the required controls and displays therein.

### INTRODUCTION

#### Background

Previously-documented studies (e.g., Kilpatrick, 1970, Evershed, 1970, Kraemer, 1973) have indicated a need for a systematic approach to the man-workspace design layout problem. Until relatively recently (the last 5 to 7 years) traditional approaches were employed in workspace design, i.e., qualitative design criteria such as the various "guiding principles of arrangement" as outlined in McCormick (1970) were applied by designers to initially configure given man-machine workspaces.

Traditional approaches would typically yield several alternative workspace configurations. The designer would then choose the one he subjectively judged to be optimal, and this layout sometimes would be subject to static evaluation by means of a mock-up of the workspace. Only by means of such crude simulation (done at considerable cost in man-hours and dollars) could one identify the man-machine interface problems inherent in the design.

In the above model, minor problems usually were not dealt with by means of costly design and mock-up iteration, since the designer would assume that operators are capable of adjusting behaviourally in such a way as to overcome potentially adverse effects of minor workspace design deficiencies. Only if the problems were major in scope and in terms of their effects, would the cost of design changes in mechanics or layout of the man-machine interfaces be authorized. Even today, one may still find such designs implemented in this classical manner. It is pertinent therefore to ask whether it is possible to develop some inexpensive, interactive design process, by which the designer could continually get feedback as to the utility of the design.

#### Purpose

The purpose of the current study is to develop an interactive design package to be used as a tool for the layout and design of vehicle workspaces. Vehicle workspaces have been chosen for two reasons: first, the man-instrument display interface in vehicles are of direct interest to the research sponsor, and second, it is believed that any results gained from this study could be applied to other types of system workspaces which possess man-machine interface problems similar to those of vehicle control stations.

The "design package" will consist of two portions. The first is a program to optimize the layout of instruments and displays in the workspace. The second is a biokinematic-anthropometric model of a man. The developmental research is laid out as is shown in Figure 1, a flow chart of research progress. First, the man-model and optimization program are being developed in parallel. The man-model has been initially developed

in a non-graphic seated operator format, followed by development of a computerized version of this man-model. Concurrently the WOLAP optimization program is being modified from its initial 2-D (two dimensional) graphic format into a 3-D graphic version. At this point, both models will converge, the optimization program linking with the man-model. This will give the designer a complete package with which to design the man-workspace problem in any seated situation. The next step would be to generalize the model such that one could design for the man in any position in a workspace, i.e., either sitting, standing or any position in between.

### METHODOLOGY

In developing this interactive design package, a three-part philosophy must be kept in mind for the workspace. First, when the workspace envelope and geometry are not constraints and the vehicle operator can make all reaches required, the workspace layout optimization becomes the most important single design problem. Second, when the workspace envelope and geometry are tightly constrained, the human body geometry becomes the most important single design problem. Third, when only moderate constraints are exerted on the vehicle workspace envelope and geometry, both workspace layout and human body geometry become equally important design problems, and the design method must take both into consideration.

The interactive design package which is being developed will handle the vehicle control-display layout problem, when reaches are of no concern, by means of an optimization program. Second, when reaches are of concern, a biokinematic model of the human operator will be utilized to test reaches and to make changes in a previously-dimensioned workspace. However, this model can also be used in conjunction with the optimization program even when no tentative dimensions have yet been determined for the workspace design. In such a case, the optimization program will provide the location coordinates for individual controls and displays, while the biokinematic model will test their reach feasibility. Finally, to make this package interactive, the results will be displayed on a CRT screen with 3-D figures representing the man and the vehicle workspace parameters.

### THE ALGORITHMS

#### WOLAP

According to Rabideau and Luk (1975) a "Monte Carlo Method" is a general term used to describe any computational method or program execution routine using random (or pseudo-random) numbers". This was the first method used by the WOLAP (Workspace Optimization and Layout Program) optimization technique. It involves the random assignment of instrument locations on given panels or in a given workspace. Then a cost figure is calculated for the given layout. Next a new layout is randomly generated and a cost figure is again calculated. The three best (or most optimum) are saved, and, after the required number of iterations, they are printed out with a figure for cost for each layout.

The algorithm for calculating cost is taken from the well known "Utility Cost" procedure and is docu-

mented in most texts on linear programming. The formula used for calculating the cost of any randomized workspace is as follows:

$$\text{Cost} = \sum \bar{X}_i Y_i Z_i \quad \text{where}$$

$X_i$  = distance over which transition is made

$Y_i$  = priority, or importance, weighting of an instrument or control component which is accessed

$Z_i$  = probability of transition x 100 (to convert to percentage), and

$i$  = all possible transitions.

One defines a transition in this case as a movement of a hand or an eye from either its null position to an instrument or from one instrument to another.

The weighting given each of the instrument and control components are relative. Rabideau and Luk (1975) assert that each weighting is designated by a quantitative cost coefficient which should be defined by the designer according to his subjective experience and/or design preference with respect to the component. However, "potentially bad" effects of designers' judgement bias in determining such weightings can be minimized in large part if system mission analysis and task analysis data are available and if an analysis of eye and hand movement links has been conducted (see Haygood et al, 1964, also Freund and Sadosky, 1967). Even ratings of importance, e.g., to mission success, to safety, can be standardized and based upon independent ratings.

WOLAP is a Fortran-based algorithm, developed within the Department of Systems Design, University of Waterloo, (Rabideau and Luk, 1975). Its major purpose is to handle general workplace optimization and layout planning problems with the aid of a Monte Carlo method. The flow chart of the algorithm used is given in Figure 2.

#### IA Optimization Program

- 1) Literature Search
- 2) Development of Optimization Technique and Algorithms
- 3) 2-D Non-Graphic Version of WOLAP
- 4) 3-D Non-Graphic Version of WOLAP
- 5) 3-D Graphic Version of WOLAP

#### 1E Man-Model

- 1) Literature Search
- 2) Link and Math Models of Man in Seated Position
- 3) Non-Graphic Computer Model (Seated Man)
- 4) 3-D Graphic Version of Seated Man

#### II 3-D Graphic Link up of WOLAP and Man-Model (Seated)

#### III 3-D Graphics of WOLAP and Man-Model (any position)

Figure 1: Flow Chart of Research Progress

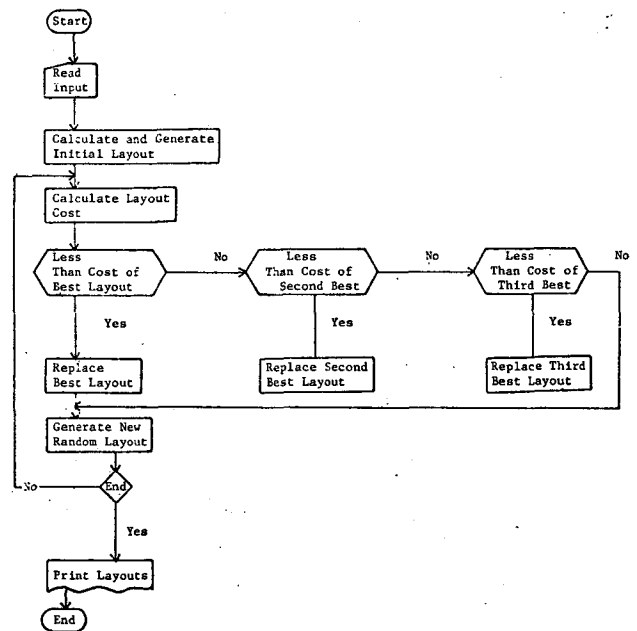


Figure 2: General Flow Chart of WOLAP

Basically the WOLAP algorithm takes the inputs of information about the workspace in a 3-D sense. However, each of the instrument and control panels within the three-dimensional workspace are only two-dimensional, i.e., the panels are planar representations of surfaces of the real 3-D panels. Once all information has been inputted the program generates an initial layout and calculates the cost of this layout. After this initialization, the program randomly generates new layouts, with a cost figure for each new layout. The cost of the new layout is compared to the previous "best" solution. If it is better it replaces it. If not, the program tests whether it is better than either the second or third best layouts. In either case if it is better than the previous layout, it replaces it. The ranks of all other layouts in the hierarchy are then readjusted accordingly. The program continues to generate new layouts until the required number of iterations are completed. At this point the program stops and prints the three best layouts.

#### Man-Model

This model tests operator limb reaches and/or displacements with respect to contact with and manipulation of controls within a workspace using a biokinematic or anthropometric model of the human body developed at the University of Waterloo. The model basically consists of two parts, one is a body link model and the other a mathematical model of the human body and its movements which are viewed as interactions of moments about the various links. The mathematical model provides the basis for a computer algorithm to facilitate rapid calculation of the pertinent equations of human body movement during a specific limb displacement in space required to accomplish a given control reach.

A link is defined as the distance from one joint center in the body to the next. In devising a link model it was decided that it should contain only the minimal number of links needed to make the mechanics feasible and the model relatively realistic. (Because the human skeletal system's joints are loosely jointed with ligaments which permit considerable joint displacement, one should view it as an "open chain of links" rather than a

series of pin-centered linkages). Hence a model which has been developed consists of eighteen links and nineteen joint centers. It is presented in Figure 3.

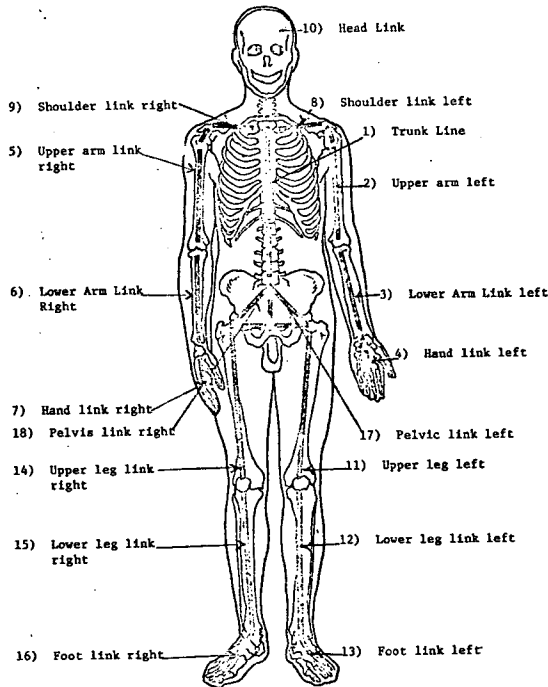


Figure 3  
Link System for Model

One should realize that it contains only one link for neck plus head and only one link for the spine. This simplifies the mechanics without greatly detracting from the validity of the model. The mathematical model represents a sequential introduction of links for an operator in the seated position. The man-model is divided into three segments; the head, the upper torso (body above the pelvis) and the lower torso (body below the pelvis including the legs). Each segment operates separately and utilizes somewhat separate mathematical modelling techniques. In each step one must test to see if there is an object to be reached and if there is, test to see if the required reach is feasible.

With respect to the upper torso, either a one or two-arm reach is possible. (Description of the mathematics is briefly presented herein; details are available in Farnady, 1976). To calculate the coordinates of the body when a two-arm reach is to be made one assumes that the upper torso forms a tripod. (For a detailed description of the tripod concept see Evershed, 1970). Hence the points for left hand (coordinates  $X_5, Y_5, Z_5$ ), right hand ( $X_3, Y_3, Z_3$ ), and pelvis ( $0,0,0$ ) and the link lengths of trunk ( $R_1$ ), right arm ( $R_2$ ) and left arm ( $R_3$ ) are known. All that remains is to solve for the top of spine ( $X,Y,Z$ ). This is done by solving the following three equations for three unknowns:

$$(X-X_0)^2 + (Y-Y_0)^2 + (Z-Z_0)^2 = R_1^2 \quad \text{.....(1)}$$

$$(X-X_3)^2 + (Y-Y_3)^2 + (Z-Z_3)^2 = R_2^2 \quad \text{.....(2)}$$

$$(X-X_5)^2 + (Y-Y_5)^2 + (Z-Z_5)^2 = R_3^2 \quad \text{.....(3)}$$

To perform a one arm reach, two steps have to be performed. First, the shoulder and/or top of spine must be optimally located (if needed), and then the arm must be moved to make the reach. The procedure to locate shoulder and/or top of spine is as follows:

1) X-Y rotation of shoulder only

$$\text{TAN } \theta = \frac{S_y - Q_y}{S_x - Q_x} = H \quad \text{.....(1)}$$

$$\text{and } \theta = \text{ARCTAN}(H) \quad \text{.....(2)}$$

where:  $S_y$  = shoulder Y coordinates

$S_x$  = shoulder X coordinates

$Q_y$  = object's Y coordinates

$Q_x$  = object's X coordinates

$\theta$  = angle of rotation of shoulder from X-axis

2) X-Y (shoulder) rotation followed by Y-Z (top of spine) rotation.

a) Equations 1 and 2 give rotation of shoulder in X-Y plane

$$b) \phi = \frac{X'}{R}$$

where:  $X'$  is distance from pelvis to object minus distance from top of spine to knuckle.

$R$  is the distance from pelvis to top of spine.

$\phi$  is angle of rotation of top of spine from Z-axis.

Once the shoulder and/or top of spine is located, one moves the arm to make the reach. This is done in two steps: First, the arm is rotated up to have some Z value as the target object and at the same time contracting the arm such that the distance from shoulder to hand equals the distance from shoulder to object; and second, the arm is rotated in the X-Y plane to make the reach. (The underlying philosophy of this method is similar to that described by Kilpatrick, 1970, and the method is described in detail in Farnady, 1976). The notations used in Figure 3 follow basic human body movement geometry; hence the present work does not employ a matrix notation scheme such as that developed by Denavit and Hartenberg (1955).

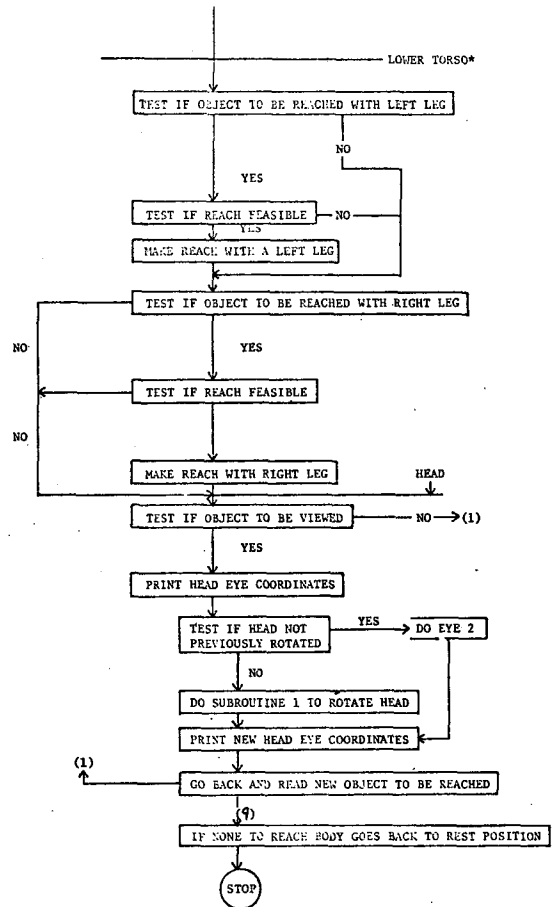
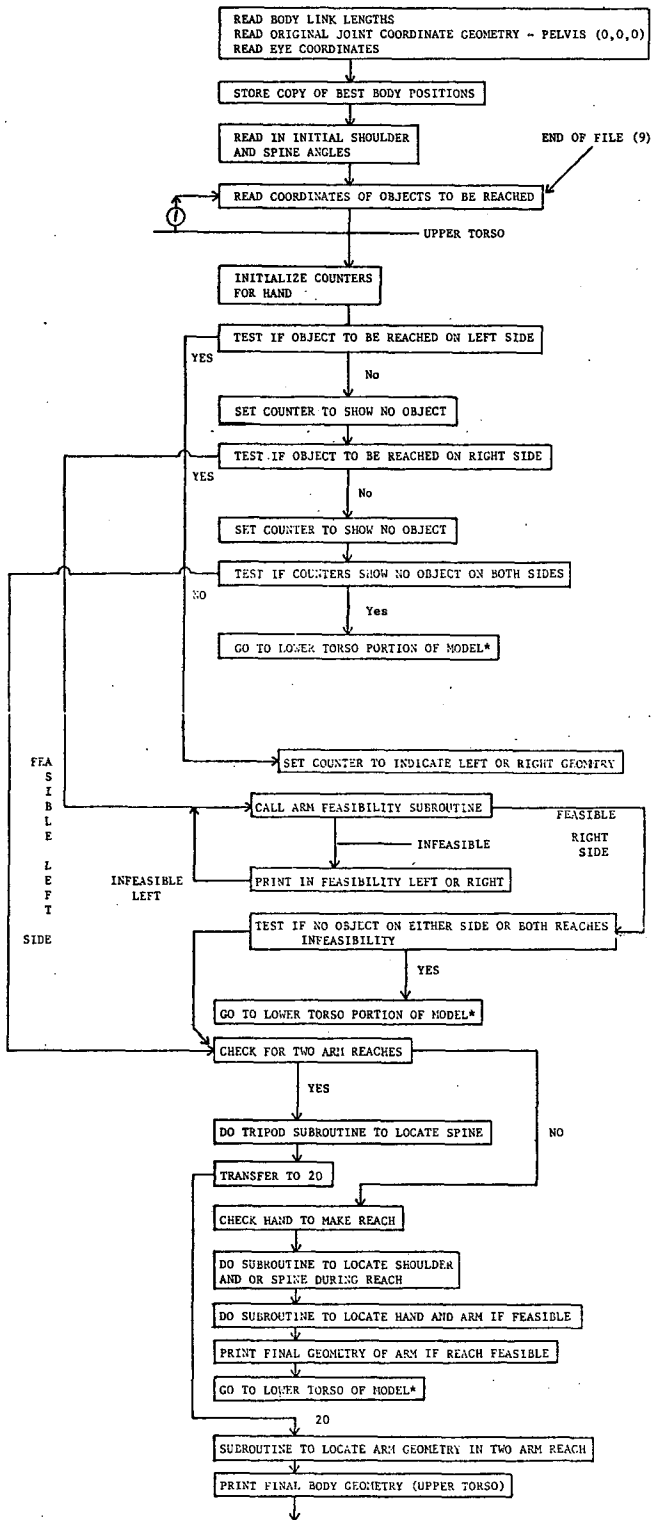
The "mechanics" for the lower torso are the same as for a one arm reach, except that, in a seated format, the legs are fixed at the pelvis. This means there is no need to optimize the pelvis position when making a reach with either leg.

The head involves slightly different mechanics than the other two segments. This is because to make a sighting, one must transform the eye's coordinates to a point where it can view the object in question. A direct reach is never made because only an unobstructed line-of-sight contact with the target is needed. If  $A$  represents the matrix for the eye's coordinates originally, and  $T$  represents the matrix of orthogonal transformation, then to effect rotation to view the object,  $A' = TA$  where  $A'$  represents the new coordinates of the eye.

In performing the mathematics to test if a reach is feasible and to make the reach, for many different objects, it becomes noticeable that the computations are lengthy and time-consuming. In order to minimize delays, thereby allowing a designer to rapidly test successive reaches with virtually instantaneous feedback of results, a computer package has been developed. The structure of the main-line program for a computer model of a man is shown in Figure 4. This model involves a Fortran-based program

and is also utilized for the graphics package of the man for designing the workspace.

FIGURE 4: COMPUTERIZED MAN-MODEL



## THE GRAPHICS PACKAGE

Because the graphics package has been developed at the University of Waterloo, the graphics facilities at this institution were utilized, consisting of a Digital Equipment Corporation PDP-9 computer and 340 Precision Display. Also, a data link between the IBM 360 and this PDP-9 is available as required.

To perform 3-D graphics on this 2-D display one transforms a 6 by  $n$  matrix into a 4 by  $n$  matrix. All rotations of the object are done before one makes this transformation. Rotations are done by using the  $T$  matrix of transformation along the  $X, Y$ , or  $Z$ -axis. To make an object move or spin, one simply does a series of rotations, pausing to display the object after each rotation. To make the display simulate real-time movement, one must employ the same principle as is used in motion pictures, i.e., the display must be run in fast-time at rate commensurate with the rate of body movement which is being simulated.

## The Interactive Graphics Package

As stated earlier, the graphics package is composed of several parts. Each part can therefore be used either separately or in combination as part of the design process.

Using the WOLAP Portion of the Graphics Package  
Only. In workspace design problems in which dimensional constraints are unimportant, e.g., all reaches are feasible, configuration of the required controls and displays represents the single most important workspace design problem, as previously noted. Therefore, the designer need only call up WOLAP to provide the desired configuration alternatives. He or she presumably would

input the data on the initial layout and start the WOLAP program. (A complete description of data inputting procedure is given in Rabideau and Luk, 1975). Figure 5 presents an example of inputted data. Once this is done, the program generates layouts according to the previously-described algorithm. After the number of iterations specified by the designer have been completed the program displays the best three layouts one at a time on the 340 display, and the designer receives a hard copy print of these layouts, as illustrated by Figures 6, 7, and 8 representing the best, second best and the third best solutions to the layout problem. At this point, the designer can interact with the system again if he desires to change any parameters or if he wishes to have additional alternative layouts generated.

FREQ	LN	HM	1	2	3	4	5	6	7	8	9	10	
EYES	0	0	0	0	0	10	0	20	0	0	20	0	0
LN	0	0	0	0	0	0	20	0	2	1	1	5	1 CONTROL/DISPLAY
HM	0	0	0	20	0	0	0	0	0	0	0	0	HEIGHT
1	0	0	10	0	20	0	0	0	0	0	0	0	5.0
2	0	0	0	20	0	0	0	0	0	0	0	0	5.0
3	10	0	0	0	0	0	20	0	0	0	0	0	5.0
4	0	20	0	0	0	20	0	0	0	0	0	0	5.0
5	20	0	0	0	0	0	0	0	0	0	0	0	10.0
6	0	0	0	0	0	0	0	0	0	0	0	0	10.0
7	0	0	0	0	0	0	0	0	0	0	0	0	10.0
8	20	0	0	0	0	0	0	0	0	0	0	0	10.0
9	0	0	0	0	0	0	0	0	0	0	0	0	20.0
10	0	0	0	0	0	0	0	0	0	0	0	0	20.0

Figure 5 (a) Example of Input Data for WOLAP:  
Table of Frequencies of Use of Controls and Displays

TOTAL COST = 4746.54900												
1	1	1	1	1	2	2	2	2	2	3	3	3
1	1	1	1	1	2	2	2	2	2	3	3	3
1	1	1	1	1	2	2	2	2	2	3	3	3
1	1	1	1	1	2	2	2	2	2	3	3	3
1	1	1	1	1	2	2	2	2	2	3	3	3
5	5	5	5	5	6	6	6	6	6	7	7	7
5	5	5	5	5	6	6	6	6	6	7	7	7
5	5	5	5	5	6	6	6	6	6	7	7	7
5	5	5	5	5	6	6	6	6	6	7	7	7
5	5	5	5	5	6	6	6	6	6	7	7	7
9	9	9	9	9	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0

Figure 5 (b): Example of Input Data For WOLAP:  
Initial Layout

Figure 6  
Best Solution, Total Cost = 3773.67100

2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 7  
Second Best Solution, Total Cost = 3778.65000

2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
6	6	6	6	6	8	8	8	8	8	5	5	5	5	7	7	7	7
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8  
Third Best Solution, Total Cost = 3787.43200

2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
2	2	2	2	2	1	1	1	1	1	4	4	4	4	3	3	3	3
6	6	6	6	6	5	5	5	5	5	8	8	8	8	7	7	7	7
6	6	6	6	6	5	5	5	5	5	8	8	8	8	7	7	7	7
6	6	6	6	6	5	5	5	5	5	8	8	8	8	7	7	7	7
6	6	6	6	6	5	5	5	5	5	8	8	8	8	7	7	7	7
6	6	6	6	6	5	5	5	5	5	8	8	8	8	7	7	7	7
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0

Using Only the Man-Model Portion of the Graphics Package. If constraints are the principle design problem, e.g., the control-display layout having been previously determined, the designer need only call up the man-model section of the graphics package to use the biokinematics of body movement as a design tool. In utilizing this man-model, the designer must select which percentile-rank of body dimensions he wishes to consider, e.g., 50th, 5th, or 95th percentile. Next he inputs data on the link length for this man, the initial location of the subject joint centers. This being defined as the man's resting position. Figure 9(a) gives input data on link lengths for a 50th percentile person as described in Damon et al (1966). Figure 9(b) gives the rest position of joint centers for this man in a seated

position. Then the designer inputs the pertinent workspace dimensions, including length, with height of workspace plus seat dimensions. Next it is necessary to input data on the shoulder angle for the rest position. Finally, the coordinates of different objects to be either reached or sighted are read in for each series of limb and/or visual reaches.

In this man-model mode the model then determines if reaches are feasible, displaying a status message to the designer. After each series of reaches is tested the man-model displays the man in a new position on the 340 display screen, also providing hard copy data on reaches and body geometry via a computer typewriter terminal. Figure 10 shows the man as displayed on the 340 display in a resting position. Figure 11(a) shows a two-arm reach on the 340 display, and Figure 11(b) illustrates the associated hard copy data. To make the system interactive, the designer can change the input coordinates of the object to be reached and then observe the effects of this change on body geometry.

Figure 9 (b): Rest Position of Joint Centers (In Inches) for 50th Percentile Man

<u>Right Leg</u>		<u>Left Leg</u>	
Foot -	(-6.6, 34.1, -21.7)	Foot -	( 6.6, 34.1, -21.7)
Ankle -	(-6.6, 23.6, -21.7)	Ankle -	( 6.6, 23.6, -21.7)
Knee -	(-6.6, 23.6 0)	Knee -	( 6.6, 23.6, 0.0)
Thigh joint	( 6.6, 0.0, 0.0)	Thigh joint	( 6.6, 0.0, 0.0)
<u>Pelvis</u>		<u>Top of Spine</u>	
		(0.0, 0.0, 23.0)	
<u>Eye</u>			
(0.0, 0.0, 30.3)			
<u>Right Shoulder</u>		<u>Left shoulder</u>	
(-8.95, 0.0, 23.3)		(8.95, 0.0, 23.3)	
<u>Right Arm</u>		<u>Left Arm</u>	
Elbow -	(-8.95, 0.0, 9.0)	Elbow -	(8.95, 0.0, 9.0)
Wrist -	(-9.95, 11.4, 9.0)	Wrist -	(8.95, 11.4, 9.0)
Hand -	(-8.95, 18.9, 9.0)	Hand -	(8.95, 18.9, 9.0)

Figure 9 (a): Link Lengths (in Inches) Used as Inputs for Computer Model Based on 50th Percentile Man

T(1) = 12.5	T(7) = 14.3	T(13) = 23.6
T(2) = 8.95	T(8) = 11.4	T(14) = 21.7
T(3) = 14.3	T(9) = 7.5	T(15) = 10.5
T(4) = 11.4	T(10) = 23.3	T(16) = 23.6
T(5) = 7.5	T(11) = 6.6	T(17) = 21.7
T(6) = 8.95	T(12) = 6.6	T(18) = 10.5

Key to Identify of Above Links:

T(1) = Head link length	T(10) = Torso link length
T(2) = Shoulder link length (right)	T(11) = Pelvis link length (left)
T(3) = Upper arm link length (right)	T(12) = Pelvis link length (right)
T(4) = Forearm link length (right)	T(13) = Upper leg length (left)
T(5) = Hand link length (right)	T(14) = Lower leg link length (left)
T(6) = Shoulder link length (left)	T(15) = Foot link length (left)
T(7) = Upper Arm link length (left)	T(16) = Upper leg link length (right)
T(8) = Forearm link length (left)	T(17) = Lower leg link length (right)
T(9) = Hand link length (left)	T(18) = Foot link length (right)

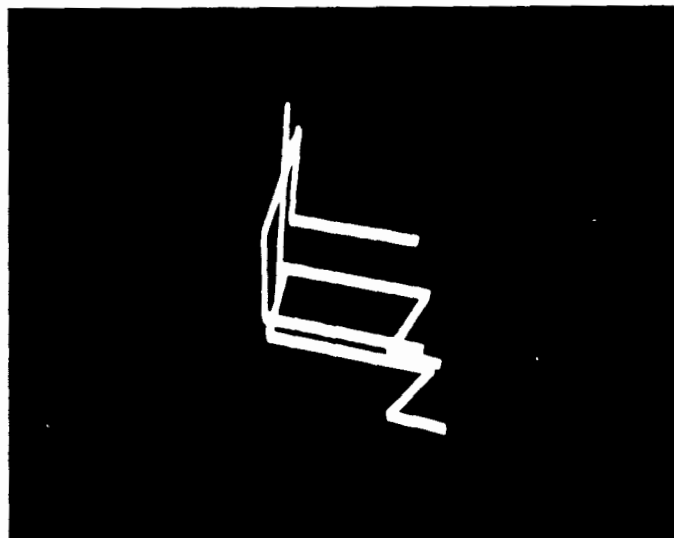


Figure 10: Seated Man (Rest Position)

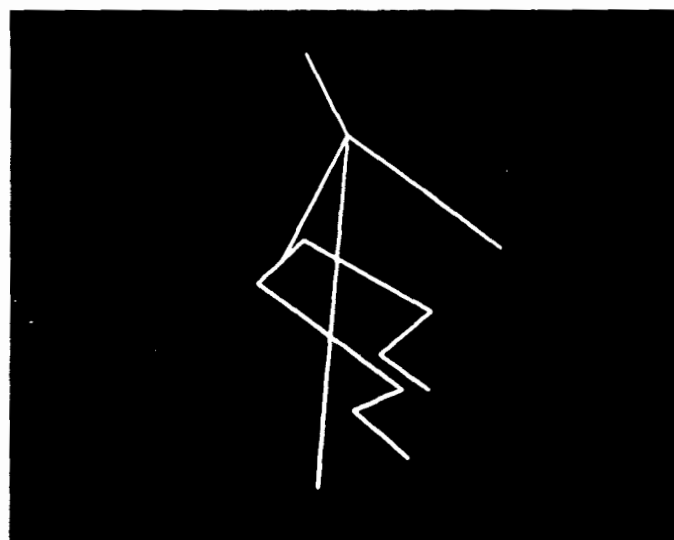


Figure 11(a): Two-Arm Reach from Seated Position

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REACH# 1 - Two Arm Reach
FEASIBLE LEFT SIDE
FEASIBLE RIGHT SIDE

TOP OF SPINE X=      Y=      Z=
          -1.14  0.18  22.44

      RIGHT HOOY GEOMETRY
X=      Y=      Z=
-6.630  11.240  14.096 - Shoulder
X=      Y=      Z=
-15.404  14.321  11.163 - Elbow
X=      Y=      Z=
-22.394  25.762  5.630 - Wrist
X=      Y=      Z=
-27.000  30.000  2.000 - Hand

      LEFT HOOY GEOMETRY
X=      Y=      Z=
 6.323  10.391  14.734 - Shoulder
X=      Y=      Z=
 18.244  17.114  12.818 - Elbow
X=      Y=      Z=
 27.748  22.474  8.102 - Wrist
X=      Y=      Z=
 34.000  26.000  5.000 - Hand

```

Figure 11(b): Print Out For Two Arm Reach

Using the Combined Graphics Package. Both WOLAP and the man-model may be employed simultaneously if the designer has not finalized the control-display configuration within the workspace and reach (or visual access) capability is critical to the completion of the configuration. To accomplish their interactive use, the optimization program (WOLAP) is run first as previously described and the output is stored to be used as input for the man-model. Then the man-model is run as before, with the exception that no object locations are given manually. Instead the input of objects to be reached is supplied by the stored output of WOLAP, e.g., the coordinates of specific controls/displays in the first-ranked configuration. Then both models are simultaneously displayed in graphic format. The designer can observe all outputs and make changes as he/she deems appropriate to solution of the workspace design problem.

#### DISCUSSION AND CONCLUSIONS

##### Limitations of Package

The graphics package as it now stands is limited in two respects. First, the optimization program - WOLAP, although it projects a 3-D simulation of a workspace is still only a 2-D approximation of three dimensional space, i.e., although the panels are laid out in any 3-D configuration around the man which the designer may desire, each panel is still only 2-D. In examining a WOLAP panel configuration, one immediately notices that the controls and displays shown represent only flat approximations of the real items, providing no information concerning protrusion or recession from the plane represented by the panel. This makes testing for reaches only an approximation of the real reaches. Second, the man-model has been developed in a seated format only. Therefore only vehicle or other workplaces for seated operators can be handled with the present model.

Even in workspace configurational problems for which neither protrusion nor recession of equipment features, i.e., controls and displays present potential operational use difficulties, it has been deemed desirable to attempt to upgrade WOLAP so that it can handle multiple panels located on different planes in the work-

space. This was recently attempted at the University of Waterloo. The results, however, indicate that the efficiency of the program is adversely affected, suggesting that it would be wiser to utilize the basic program in two or more iterations, one for each of the planes, or panels under consideration.

##### Further Research Needs

Further research is merited in order to alleviate the limitations described above. A suggested first step would be to generalize the man-model to make reaches and test for displacements in any postural position. That would give the designer the opportunity to optimize and test layouts were the operator to be in a standing, stooping, or kneeling or prone position rather than a seated position.

It would also be highly desirable to modify WOLAP in such a way that display instruments and controls on panels in the workspace are given some 3-D shape. This would mean the man-model reaches would not necessarily be tested to the center of some point on a plane surface but, instead, could test the effects of protruberance and recessing on both limb reaches and need for unobstructed visual line of sight.

One might ask why a random starting method such as Monte Carlo has been used to optimize panel layouts. Indeed several colleagues at Waterloo and elsewhere have raised this question. The answer is quite simple: it is more efficient than others when a large number of discrete locations, e.g., 30 or more, are involved than are some logical competitors such as the complex and simplex methods (see Beveridge and Schechter, 1970). For instance, a branch and bound method was recently tried out, and it was found that its efficiency (in terms of computer time) was less than that of the Monte Carlo for 15 or more discrete locations. If there is a more efficient patterned technique suitable for such an interactive workplace layout task it has yet to be discovered.

#### CONCLUSIONS

Even in light of the limitations mentioned above, however, it is reasonable to conclude that the work already done potentially provides designers with a comprehensive interactive design tool for workspace design layout, one which is relatively economical in terms of cost and time involved in analyzing the physical man-machine interface problems concerned with workspace design for seated operators. Nevertheless, one may conclude that additional work - both with respect to development of an improved method and with respect to still other operator postures is merited.

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