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DEVELOPMENT OF DESIGN STANDARDS FOR GROUND SUPPORT CONSOLES

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Foreword

The work presented in this report was accomplished under Project 7184, "Human Performance in Advanced Systems," Task 718404, "Advanced Systems Human Engineering Design Criteria," and Task 718408, "Anthropology for Design." It was a joint effort of the Anthropology Branch and the Performance Requirements Branch, Human Engineering Division, Aerospace Medical Research Laboratories.

The authors are indebted to Dr. M. J. Warrick, Assistant Chief, Human Engineering Division and to Mr. C. E. Clauser and Mr. H. T. E. Hertzberg, Anthropology Branch, for their comments and criticisms; and to Mr. S. A. Heckart of the Performance Requirements Branch for his many helpful suggestions. The original attempt to standardize console configuration on WS 131-B owes much of its success to the efforts of Mr. Paul E. Beck, Chief of the Training and Checkout Division, Research and Technology Division, Wright-Patterson Air Force Base, Ohio. He not only contributed significantly to the console design but also played an important role in its implementation in the Hound Dog Program.

This technical report has been reviewed and is approved.

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Abstract

Experience gained in using a single standardized ground-support console configuration in the WS 131-B, Hound Dog, is discussed. Other ground console designs for possible standardization in future systems are described in detail. All designs are derived from a basic sit-stand configuration and will accommodate approximately 95% of the USAF male population and approximately 60% of the USAF female population. Each of the consoles can be made from five standard subassemblies. The suggested standard configurations permit engineering design freedom, yet restrict certain dimensional characteristics of the consoles to assure accommodation to the requirements and capabilities of the operator.

Table of Contents

Section		Page
I	INTRODUCTION	1
II	THE BASIC SIT-STAND CONSOLE	6
III	DERIVED CONSOLES	15
	The Stand Console with Vision Over	15
	The Sit Console without Vision Over (High Variation)	15
	The Sit Console without Vision Over (Low Variation)	16
	The Sit Console with Vision Over (High Variation)	16
	The Sit Console with Vision Over (Low Variation)	17
	The Stand Console without Vision Over	17
IV	ACCOMMODATION OF THE CONSOLES TO THE CAPABILITIES OF THE OPERATOR	20
V	COMPONENTS	37
VI	INTER-CONSOLE COMPATIBILITY AND CONSOLE GROUPING	42
VII	RECOMMENDATIONS	43
VIII	SUMMARY	44
	REFERENCES	45

List of Illustrations

Figure		Page
1	WS 131-B Standardized Console Configuration (Three-Bay Unit)	2
2	Standing and Seated Operator's Eyes Adjusted to the Same Level	7
3	The Positions of the Eyes of Men with 5th Percentile, Mean, and 95th Percentile Eye Heights (Standing) and Eye Heights, Sitting	9
4	Preliminary Evaluation of Reach and Visual Capabilities Over Surfaces Set at 5°, 10°, 15°, 20°, and 25° from Vertical	11
5	Dimensions of the Sit-Stand Console Profile	13
6	The Effect Panel Angle has on the Display Space within 30° Below Horizontal	14
7	Dimensions of the Sit Console without Vision Over (Low Variation)	15
8	Dimensions of the Sit Console with Vision Over (High Variation)	16
9	Dimensions of the Sit Console with Vision Over (Low Variation)	17
10	Dimensions of the Stand Console without Vision Over	18
11	Side View of a Composite of All Console Display Panels Superimposed onto the Side View of a Sector of the 5th Percentile Grasping-Reach Envelope of the Seated Operator	22
12	Composite Representation of Visual Capability and Reach with the Right Hand Over the Surfaces of All Console Display Panels	23
13	True Composite Representation of Reach and Visual Capabilities Over the Surfaces of All Console Display Panels	24
14	Reach and Visual Capabilities Over the Surface of the Sit-Stand Console Display Panel	25
15	Reach and Visual Capabilities Over the Surface of the Display Panel of the Stand Console with Vision Over	27
16	Reach and Visual Capabilities Over the Surfaces of the Display Panels of the Sit Consoles without Vision Over (High and Low Variations)	29
17	Reach and Visual Capabilities Over the Surfaces of the Display Panels of the Sit Consoles with Vision Over (High and Low Variations)	29
18	Reach and Visual Capabilities Over the Surface of the Display Panel of the Stand Console without Vision Over	32
19	Mock-up of the Sit-Stand Console with Standing Operator of Relatively Small Size	33
20	Mock-up of the Sit-Stand Console with Seated Operator of Relatively Large Size	34
21	Mock-up of the Sit Console with Vision Over (High Variation) with Seated Operator of Relatively Small Size	35
22	Mock-up of the Sit Console with Vision Over (Low Variation) with Seated Operator of Relatively Large Size	36
23	Console Components: Series 1	38
24	Console Components: Series 2	39
25	The Five Standard Consoles	42

List of Tables

Table		Page
I	Console Cost Comparison	3
II	Standard Console Dimensions	19
III	Dimensions of the 5th Percentile, Right Hand, Grasping-Reach Envelope for the Seated Operator	21
IV	Reach and Visual Capabilities Over the Surface of the Display Panel of the Sit-Stand Console	26
V	Reach and Visual Capabilities Over the Surface of the Display Panel of the Stand Console with Vision Over	28
VI	Reach and Visual Capabilities Over the Surfaces of the Display Panels of All Sit Consoles without Vision Over	30
VII	Reach and Visual Capabilities Over the Surfaces of the Display Panels of All Sit Consoles with Vision Over	31
VIII	Reach and Visual Capabilities Over the Surface of the Display Panel of the Stand Console with Vision Over	32

SECTION I

Introduction

Complex missile and aircraft systems require extensive ground support systems to control, operate, checkout, and maintain them. The cost of these ground support systems generally accounts for approximately half of the total system cost and in some instances may account for as much as 80 percent of the total cost. Coupled with the Real Property Installed Equipment (RPIE) of a fixed base system and/or the specialized equipment, such as trucks and vans, required in mobile systems, support equipment represents a major design activity in system development.

Generally, ground support equipment is designed to accomplish one or more of four system functions. One class of equipment is designed to accomplish countdown, preflight checkout, launch, etc., of the system. Another class of equipment is designed to accomplish checkout to a subsystem or modular level. A third class of equipment is designed for detailed checkout and troubleshooting within the modular level. A fourth class of equipment is designed to operate and maintain such system facilities as power generation equipment and heating plants. This equipment is generally of unique, special purpose design in the launch-preflight case, and progresses to general purpose or standard off-the-shelf equipment for detailed maintenance and housekeeping functions.

The scope and diffuse nature of this design problem has often forced the human engineer to attack the design of Ground Support Equipment (GSE) on an individual basis. A casual inspection of the consoles of most system-complexes will reveal little or no standardization. Indeed, variety is the rule. The standardization, if any, of console configurations that exists is typically the result of the company purchase department's standard parts list. The purchase department standard is generally the 24- by 36- by 72-inch, electronic equipment rack to which some displays and controls are added to make a console. When the human engineer can demonstrate that such a configuration is inadequate, a unique console configuration is designed to fit the specific requirement. This approach results in a wide variety of configurations, ranging from standard equipment racks to wrap-around-and-over configurations built to cockpit criteria.

An obvious solution to this situation is the standardization of console configurations. But this is not a step to be taken thoughtlessly. Standardization can create as many design problems as it solves. Often it costs more to make an item of standardized equipment fit a specific set of requirements than to apply a unique design. But this does not imply that the history of the standardized design approach is all bad. Many standard designs are indispensable to the technical community.

The success of the standardized design approach depends to a large degree on three major factors:

- The ability to predict continuing general need for the design;
- The ability to specify the performance requirements, both present and future, for the design;
- The excellence of the design relative to the current and predicted needs.

With the above requirements in mind, Messrs. Beck, Randack, and Bates of the then Wright Air Development Division, and Mr. Gail Jenson of North American Aviation, Downey, California, designed a standard ground support console, or crew station, for WS 131-B (Hound Dog). The following is a summary of the major requirements:

- Design for sit-stand operation;
- Have a working surface (detachable or folding);
- Ninety-five percent of the AF population able to see over the console while standing;
- Meet military specifications electronic packaging requirements (principal requirement here was for 24-inch console width);
- Meet military specifications in regard to explosion-proofing, structural integrity, mobility, etc;
- Provide maximum accessibility to console interior within structural limits;
- Have built-in leveling capability;
- Appropriate provision for cooling (either self-contained or vented from central system);
- Provision for pedestal mounting when permanently installed.

The resulting design is depicted in Figure 1. It corresponds and is similar to the anthropometric sit-stand console design subsequently derived and presented in Figure 5 herein. With few exceptions,

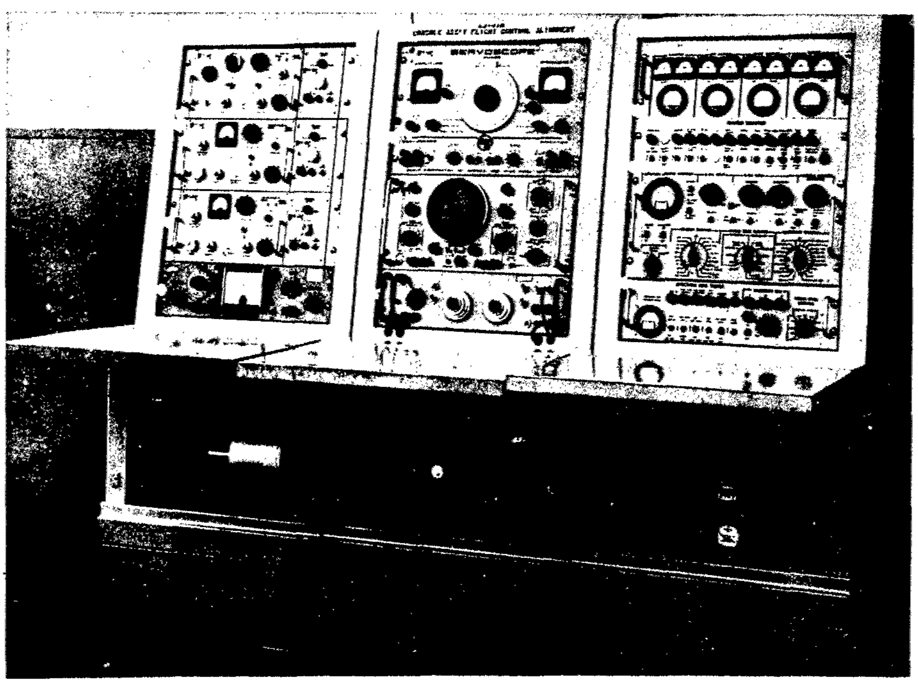

Figure 1. WS 131-B Standardized Console Configuration (three-bay unit)

this configuration could be applied to all ground crew stations required for WS 131-B operation and maintenance.

When the standard design was first introduced to WS 131-B designers, their major complaints were that (1) an individual unit (24 inches wide and 62 inches high) would not provide enough space for the equipment required in a typical console, (2) the cost of making a chassis with a sloping panel would be prohibitive, and (3) the folding workshelf would prevent access to the panel space below it. As experience with the design was gained, it was apparent that the first objection was not a serious handicap to implementing the design. Joining of the units in 2-foot increments could provide all the internal volume and/or panel space required. This space could be provided, as nearly as can be determined, at no significant cost in packaging density. In several informal comparisons of packaging density between the standardized console and the 72- by 24-inch rack, the standardized design was approximately 13 percent more efficient in the utilization of internal volume.

The second objection, also, was not a major problem. All equipment racks (drawers) designed to meet specific system requirements incorporated a sloping panel and were mounted with rails parallel to the floor. Where standard items of test equipment (oscilloscopes, etc.) were incorporated into console design, they were mounted with their rails at right angles to the console panel, providing the necessary panel slope continuity. The loss of usable internal volume resulting from this mounting arrangement was judged to be insignificant.

The third objection to the standardized console, inaccessibility of lower panel space, was solved by permitting the workshelf to rotate through approximately 200° so that in the full up position, access to the lower panel was uninhibited. In addition, only maintenance, calibration, and other secondary and backup controls and displays were located in this space.

Although cost comparisons between weapon systems, developed as they are under different restraints, time periods, and for different missions, must be interpreted with caution, table I demonstrates that excessive cost was not encountered in applying the standardized console approach to WS 131-B:

TABLE I

CONSOLE COST COMPARISON

Weapon System	*Console Design Approach*	*Relative Cost of Console Shell*
131-B	Standardized design all ground crew stations.	1.0
A	Tailored design for critical crew stations — all other stations standard electronic equipment racks.	1.35
B	All ground crew stations of tailored design.	2.25

Systems A and B above are both missile systems and were selected for cost comparisons solely on the basis of availability of cost data to the writers. System A was developed subsequent to WS 131-B; system B was developed prior to WS 131-B. The relative costs represent console structure only. The writers hypothesize that the favorable relative cost position of the standardized console in WS 131-B exists because unique designs manufactured in small quantities as in systems A and B would cost well in excess of any standardized approach employed. In WS 131-B, the standardized console could be applied to nearly all ground crew stations. As favorable a cost comparison might not be possible in another application.

With the experience gained on WS 131-B, the sit-stand console has been modified and presented in this report along with standardized designs for other console configurations designed to meet requirements commonly found in ground support systems. These designs are presented in a building block approach that is believed to facilitate standardization. Should the building block approach be unfeasible, the dimensions presented would be applicable to the construction of a family of standard designs (sit, sit-stand, stand, etc.) to meet a particular set of design requirements. Critical dimensions and relationships between parts of these basic consoles have been utilized in deriving design standards (see table II on page 16). The basic console profiles were designed to make possible: (1) a high percentage of accommodation to the different body sizes and visual and reach capabilities of the using population, in this case the United States Air Force, and (2) a minimization of operator reorientation when duties are transferred from one console type to another.

From an anthropological standpoint, ground support consoles can be grouped into types based on: (1) the posture best suited for monitoring, and (2) whether or not the operator is required to have horizontal vision over the top of and beyond the console. All console types must accommodate the reach capability of at least 95 percent of the using population. The reach requirement, then, does not act as a criterion by which we differentiate a console type. With the postural and visual requirements, however, four console types may be recognized: (1) That for the standing operator requiring vision over the console, (2) that for the standing operator not requiring vision over, (3) that for the seated operator requiring vision over, and (4) that for the seated operator not requiring vision over the console. By combining into the design of one console the requirements of (1) and (4), we can envision a console of great flexibility, a console at which the operator may elect to sit or stand as the situation requires. This is the Sit-Stand Console. This console becomes the basic configuration from which all others are developed.

The general design objectives applicable to each of the different console profiles are:

1. The greatest practicable percentage of the United States Air Force population must be accommodated.

2. Console utility must be emphasized. Emphasis of both personnel accommodation and equipment requirements often results in conflicting design. When this occurs, compromises of both are necessary.

3. Consoles of different types must be compatible with each other when used together in a system of consoles. Operator reorientation must be minimal when duties are transferred from one console type to another.

4. Designs must be developed with an eye toward economy and simplicity. Consoles are expensive. Logistic problems and development cost can be significantly reduced through standardization of console design.

5. Consoles must be provided with a horizontal working surface or writing leaf which has a depth of at least 16 inches. The shelf must fold down, leaving a shelf at the base of the display panel.

Each console profile was developed from anthropometric data (ref 7) that describes accurately the United States Air Force population. Each console was designed to accommodate at least 95 percent of this population. Similar accommodation of other American and north European male military populations is highly probable. Approximately 60 percent of the USAF female population may be adequately accommodated.

The engineering, military, and human engineering requirements that any standardized family of consoles might be required to meet could be satisfied in a number of ways. From a practical standpoint, a Sit-Stand console similar to the WS 131-B console previously discussed will satisfy most of the requirements for a standardized design; however, four additional configurations should meet nearly all requirements for such a design. These four configurations also serve to demonstrate the derivation of alternate designs from the basic anthropological data presented in this report. This family of five standardized configurations with typical requirements for which they were designed are as follows:

Configuration	*Requirement*
1. a. Sit-Stand	Alternately sitting and standing operator with vision over the console when standing.
b. Stand console with vision over	Operator standing with a requirement to see over the console.
c. Sit console without vision over (high variation)	Operator sitting not required to see over the console.
2. Sit console without vision over the top (low variation)	Seated operator without vision over console, height restraint on console.
3. Sit console with vision over (high variation)	Seated operator with vision over, maximum console volume required.
4. Sit console with vision over (low variation)	Seated operator with vision over the console with no large volume requirement and/or console height restraint.
5. Stand console without vision over	Standing operator not required to see over the console — maximum volume required, no height limit, etc.

SECTION II

The Basic Sit-Stand Console

Since the Sit-Stand console must accommodate standing as well as seated operators, it can be considered the central or basic configuration from which the remaining consoles are developed. Furthermore, compatibility among consoles of different types will result from basing their design on a single basic Sit-Stand configuration.

The initial task in designing the Sit-Stand console is the establishment of a critical point or points in space that must, for the sake of good design, be limited in location with respect to the console. Since visual and arm-reach capabilities and limitations are so important in console design, they must receive preferential consideration. With the ready availability of data regarding the height of the eye from the floor and from the seat (ref 7), it is logical and convenient to use the eye position as the first point of reference. A reference point for reach accommodation can then be approximated relative to the eye reference point.

Under ideal conditions, equivalent visual and reach accommodations should be provided at the Sit-Stand console regardless of whether the operator is seated or standing. To lay out a configuration permitting such accommodation, the mean Eye Height, Sitting, and Eye Height (standing) should be adjusted to the same level. This can be accomplished through the use of a chair 34.25 inches high for the seated operator, i.e., mean Eye Height (standing) (65.69 inches*) minus mean Eye Height, Sitting (31.47 inches), rounded off to the nearest 0.25 inch. Figure 2 illustrates the effect on console design that results from adjusting the means for standing Eye Height and Eye Height, Sitting, to the same level.

Since a very large segment of the USAF population must see over the Sit-Stand console when standing, console height is limited to the value for 5th percentile Standing Eye Height plus 1 inch for shoes (62.0 inches). This will insure that 95 percent of this population will be able to see over the console without materially altering their posture.

Since the seated operator's thighs must clear the underside of the writing leaf, all of the space between 5th percentile Eye Height (standing) and the seat cannot be reserved for panel space. Allowing a space equal to 95th percentile Thigh Clearance, 6.5 inches (ref 7, p. 46), and 1 inch for the thickness of the writing leaf, necessitates that the working surface be 7.5 inches above the seat. The space between 5th percentile standing Eye Height and the upper surface of the seat is 27.75 inches: 62 inches (5th percentile Eye Height, standing) minus 34.25 inches (the height of the seat). Subtracting 7.5 inches to permit clearance for the thighs and the thickness of the writing leaf leaves 20.25 inches of vertical space above the writing leaf for the location of the display panel. This is inadequate. Since we must emphasize utility as well as personnel accommodation, operator accommodation must be compromised to a minor extent to gain adequate display space.

Locating the mean eye positions at the same level would permit more than 99 percent of the Air Force population to see over the Sit-Stand console from the seated position and 95 percent to see over it in the standing position. However, the operator need not see over this console when he is seated; when

* Throughout this report, Eye Height (for the standing position) includes 1 inch for shoes.

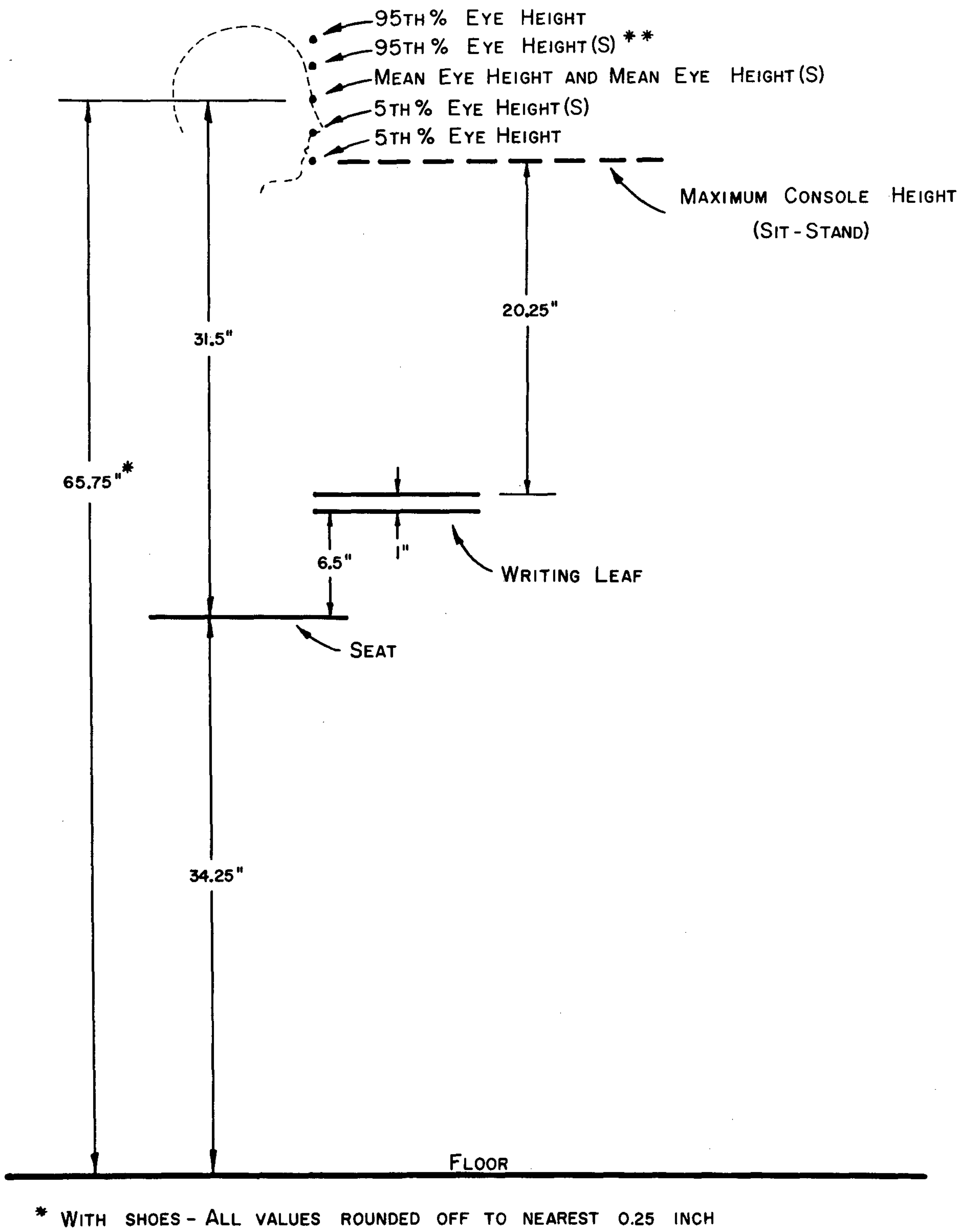

Figure 2. Standing and Seated Operator's Eyes Adjusted to the Same Level. Display panel space is limited to 20.25 inches. Console height is limited to 62 inches, 5th percentile Eye Height (standing).

necessary, he may stand. The level of the mean Eye Height, Sitting, then, may be lowered below the level of the mean standing Eye Height. By so doing, more vertical distance is made available for panel space between the upper surface of the writing leaf and 5th percentile standing Eye Height. Experience with WS 131-B, Hound Dog, consoles indicates that 26 inches of vertical space is adequate for most display purposes. This, then, appears to be suitable space for the Sit-Stand display panel. Adding to this distance the 7.5 inches required for thigh clearance and the thickness of the writing leaf, we have the total (33.5 inches) that must be subtracted from 5th percentile standing Eye Height (62.0 inches) to obtain the necessary height of the seat (28.5 inches). Such a seat will, then, provide us with 26 inches of vertical space within which to locate the display panel. By adding to this seat height the value for mean Eye Height, Sitting (31.5 inches) we find that the mean eye position for the seated operators is 60 inches above the floor. The level of the mean eye position for the seated position is lowered a distance of 5.75 inches below its original position at the level of the mean standing eye position which was 65.75 inches above the floor. By this adjustment, the 95th percentile Eye Height, Sitting, and 5th percentile Eye Height, standing, are for all practical purposes at the same level. Therefore, approximately 5 percent of the USAF male population will be able to see over the Sit-Stand Console when seated; 95 percent will be able to see over it when standing.

The location of the eye for the seated operator conceivably could be lowered farther and thereby release additional space for displays; however, we lose the advantages of having the seated and standing operator's eyes and shoulders at levels reasonably close to each other. Accommodation of a single panel surface to both the seated and standing operators would be more difficult as the space would increase between the locations of the eyes and shoulders in the two operating positions. Figure 3 illustrates the final eye positions and those console parts that we are thus far able to locate.

We can now establish the angle of the display panel. Any angle, however, must satisfy a number of requirements. These are listed below:

1. The operator must have convenient grasping reach capability over most of the display panel surface without materially altering his posture.

2. The operator must have adequate visual capability over the surface of the display panel without materially altering his posture.

a. Most of the display panel should be within 45° of the line-of-sight perpendicular to the panel. The center of this area, then, should be as close as possible to the center of the display panel. Placement of a display within this vision cone will assure a viewing angle* of at least 45°. Error due to parallax will be minimal.

b. It should be possible to locate important and frequently used displays and critical-function warning lights† so that they will be at eye level to about 30° below the standing operator's line-of-sight when he is looking horizontally over the console.

3. The panel angle should permit at least 16 inches of writing surface between the operator and the base of the display panel.

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* The angle formed by a line from the eye to the viewed surface. A right angle is regarded as optimal (ref 6).

† Killer warnings – alerting the operator to some existing dangerous condition requiring immediate attention.

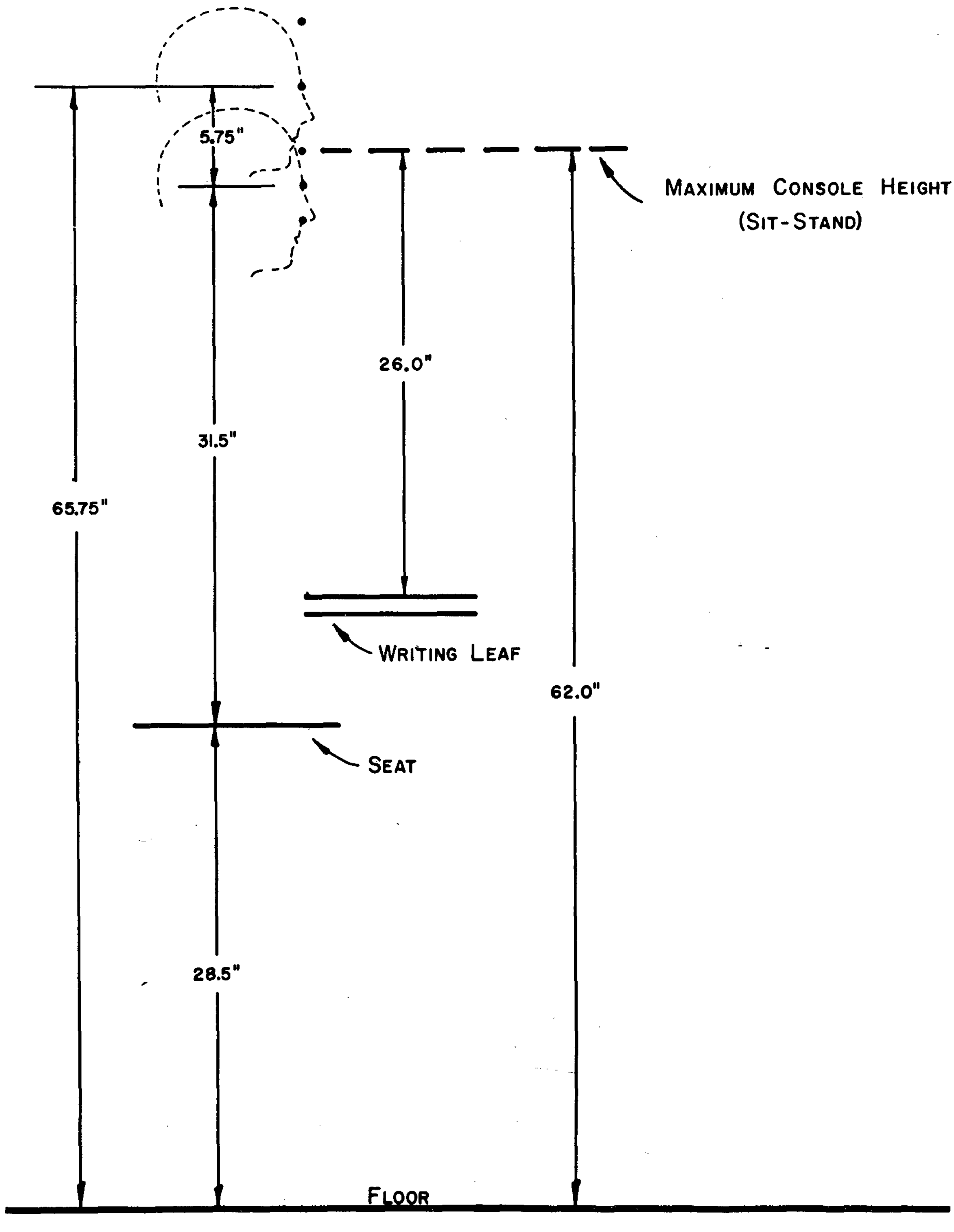

Figure 3. The Positions of the Eyes of Men with 5th Percentile, Mean, and 95th Percentile Eye Heights (standing) and Eye Heights, Sitting. A 28.5 inch high seat permits 26 inches of vertical space to be devoted to the display panel. The eyes of men with 95th percentile Eye Height, Sitting, and 5th percentile standing Eye Height are at the same level.

The initial step in determining the slope of the display panel is to establish a point through which it should pass. This point must be at a location that permits adequate vision and is within convenient grasping-reach of at least 95 percent of the Air Force population. For adequacy of vision, this point should be not less than 13 inches from the eyes and preferably not less than 20 inches (ref 5, p. 46). Assuming appropriate instrument size, Baker and Grether (ref 2, p. 46) indicate that the viewing distance need be limited only if the operator is required to manipulate controls on the panel from the normal seated position. For now, we will assume that the operator does not change his position relative to the console. Such a point can be established by utilizing the value for 5th percentile Functional Reach, and will likely be at an acceptable viewing distance. To establish this point through which the plane of the panel will pass, we need to approximate in space the location of another point, one from which Functional Reach may be measured.* On a series of 10 subjects, it was found that Functional Reach was measured from a point 8.75 inches below the eye and 8.25 inches to the rear. An arc with a radius equal to 5th percentile Functional Reach increased by 4 inches to account for additional reach obtained through shoulder extension (29.7 plus 4 equals 33.7 inches) was drawn, using as its center this point on the back of the operator with 5th percentile Eye Height, Sitting. Where this arc crosses the level of 5th percentile standing Eye Height, a convenient point is established through which the plane of the display panel may pass. The height of the Sit-Stand Console has been defined as being equal to 5th percentile standing Eye Height. This point, in profile, represents the forward, upper edge of the console (see fig. 4) and will be well within the reach of nearly all operators whether standing or sitting.

To determine the most appropriate panel slope, angles at 5° intervals between 5° and 25° from vertical were struck from this point and reach and visual capabilities over each were given preliminary study. Considering all the requirements that should be satisfied, a suitable panel angle will necessarily be relatively small, between 5° and 25° from vertical. Disadvantages of a panel set at more than 25° or less than 5° will become obvious as the discussion proceeds.

Figure 4 shows the various panel angles and preliminary estimates of the effects these have on the position of the operator and on his reach and visual capabilities. As the angle increases, the upper part of the panel is displaced farther away from the operator and becomes less convenient for the smaller operators to reach. At angles greater than 15°, the upper section of the panel becomes inaccessible to the small operator in both the seated and standing position unless he bends forward at the hip [fig. 4 (a) and (c)].

The planes of all panels in this figure originate at the junction (X) of the level of 5th percentile standing Eye Height, which has previously been prescribed as the height of the Sit-Stand console, and 5th percentile Functional Reach increased by 4 inches. The latter is measured in (a) from a point (+) corresponding to the location on the back from which Functional Reach is measured on a subject with 5th percentile Eye Height, Sitting. Point (X) will be well within the reach of larger operators, both standing and sitting. The horizontal rows of crosses (+) illustrate how the operator is displaced away from point (X) as the angle of the panel is increased. In (b), an arc equal to 50th percentile Functional Reach plus 4 inches is struck from the back of the operator having 95th percentile Eye Height, Sitting.

* Functional Reach is a static dimension. To measure it, the subject stands in a corner of a room (or Morant Board) with his shoulders against the rear wall. His right arm and hand are then extended to the horizontal position and his thumb and forefinger opposed (pressed together). Functional Reach is the horizontal distance from the rear wall to the tip of the thumb. The point from which Functional Reach is measured, then, is on the surface of the wall. Since the back and shoulders are against the wall, this point may also be established on the subject's back and its position determined relative to the subject's right eye.

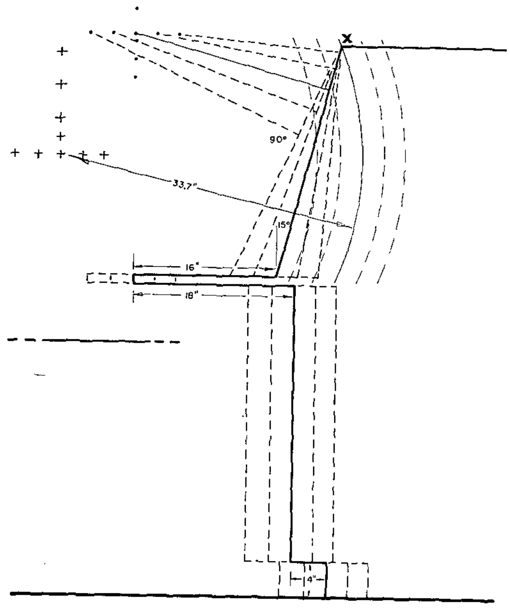

Figure 4(a)

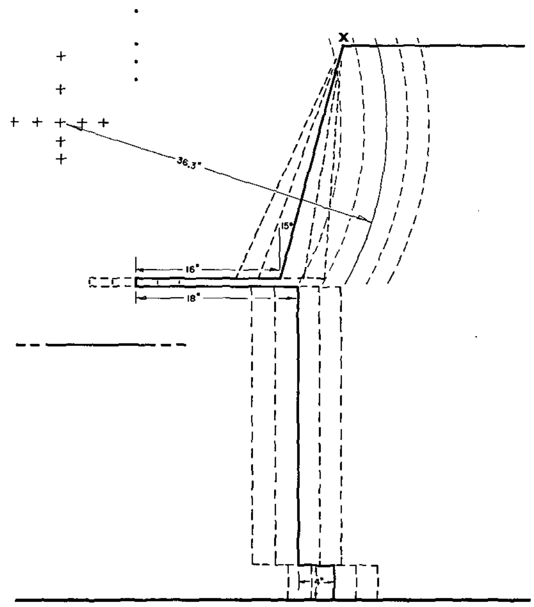

Figure 4(b)

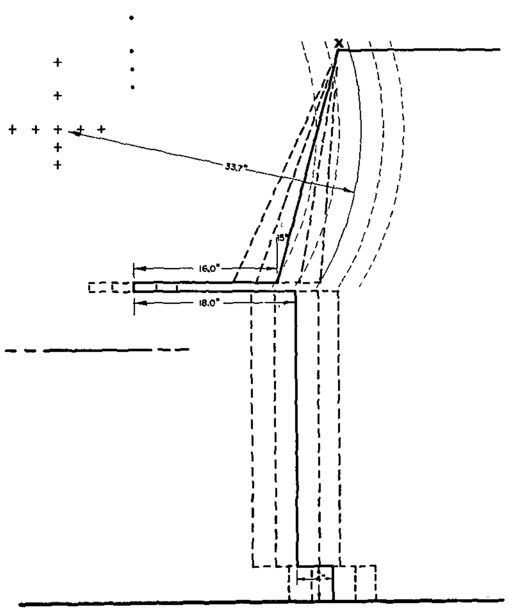

Figure 4(c)

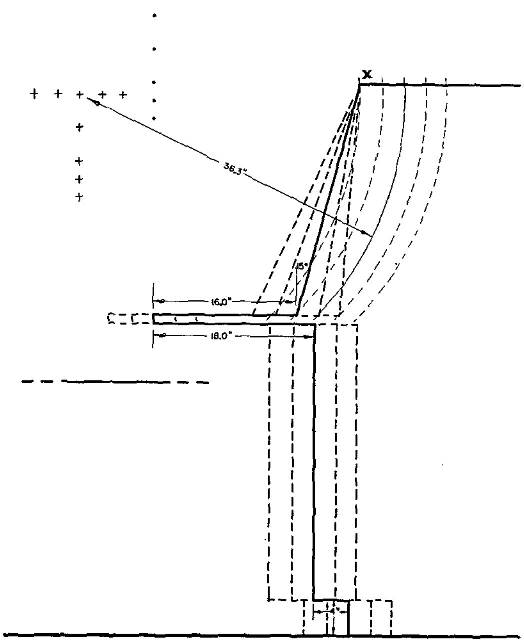

Figure 4(d)

Figure 4. Preliminary Evaluation of Reach and Visual Capabilities Over Surfaces Set at 5°, 10°, 15°, 20°, and 25° from Vertical

In (c), a 5th percentile arc is struck from the back of the operator having 5th percentile standing Eye Height. In (d), a 50th percentile arc is struck from the back of the operator having 95th percentile standing Eye Height. As the angle of the panel increases, the upper part of the panel is displaced farther away from the operator and becomes less convenient to reach, especially for the smaller operator. In (a), the height of the horizontal row of dots (.) is equal to the grand mean of standing Eye Height and the sum of Eye Height (Sitting) and 28.5 inches for chair height. The horizontal arrangement of dots illustrates how the operator's eyes are displaced away from the display panel as the angle of the panel is increased.

In evaluating visual accommodation over the Sit-Stand console display panel, one must consider the different eye levels throughout the range of possible locations in the standing and seated positions. The most convenient approach is to establish the Grand Mean eye position for a population of operators in the seated and the standing positions and evaluate visual accommodation using the mean eye position as the point of reference. For our purpose, the Grand Mean eye position can be considered as lying mid-way between the means for the adjusted seated and standing eye positions. Increasing the panel angle from 5° to 25° has the effect of lowering the level at which the operator's line-of-sight is perpendicular to the panel, thereby increasing the panel space within which a viewing angle of 45° or greater is possible.

Again we are confronted with conflicting design rationale. Whereas a larger panel angle avails more panel space which is acceptable in the visual sense, it also compromises the smaller operator's reach over the upper part of the panel. It is necessary, then, to select the maximum panel angle that permits adequate reach over its surface and allows the line-of-sight of the operator to be perpendicular to the panel at a level as close as possible to the center of the panel.

Excessive compromise of the operator's convenience to manipulate controls at any location on the display panel should not be introduced, especially since the point through which the plane of the panel passes has been established through the use of Functional Reach increased by 4 inches to account for increased reach through arm extension. A 15° angle is the maximum that accommodates adequately to the reach of the smaller operator. A 15° panel also brings the point at which the operator's line-of-sight is perpendicular to the panel to a level that will allow adequate panel space within which the viewing angle is at least 45°.

At this point an undesirable characteristic of the console is observed. Initially it was advisable to consider a minimum writing leaf. At the same time it was necessary to provide enough knee space beneath the writing leaf to accommodate the large operator. The resulting console profile requires that the knee space undercut the panel (see fig. 4). Since the writing surface must swing out of the way, leaving a small shelf, the hinge point must be located about 4 inches from the base of the panel. When the writing surface is swung into the down position, it will be approximately 6 inches from the front of the console. Such a design would be subject to damage in shipping as well as in daily use. Designing a hinge arrangement so that the writing surface would swing down to a position against the front of the console would relieve this problem for the writing leaf, but the remaining shelf would be subject to damage.

The situation can be remedied, however, by displacing the display panel away from the operator a distance of 4 inches. For the small operator now to reach the upper edge of the panel, we must require him to lean forward to a position with his back at an angle of about 5° forward of vertical. This is not excessive. It is, in fact, normal to lean toward the panel when reaching to it. It would be required of the smaller operators only, and then only when actually manipulating controls on the extreme right and left edges of the display panel. The small operator would not have to lean forward to reach the center of the panel. The final Sit-Stand profile is as illustrated in fig. 5.

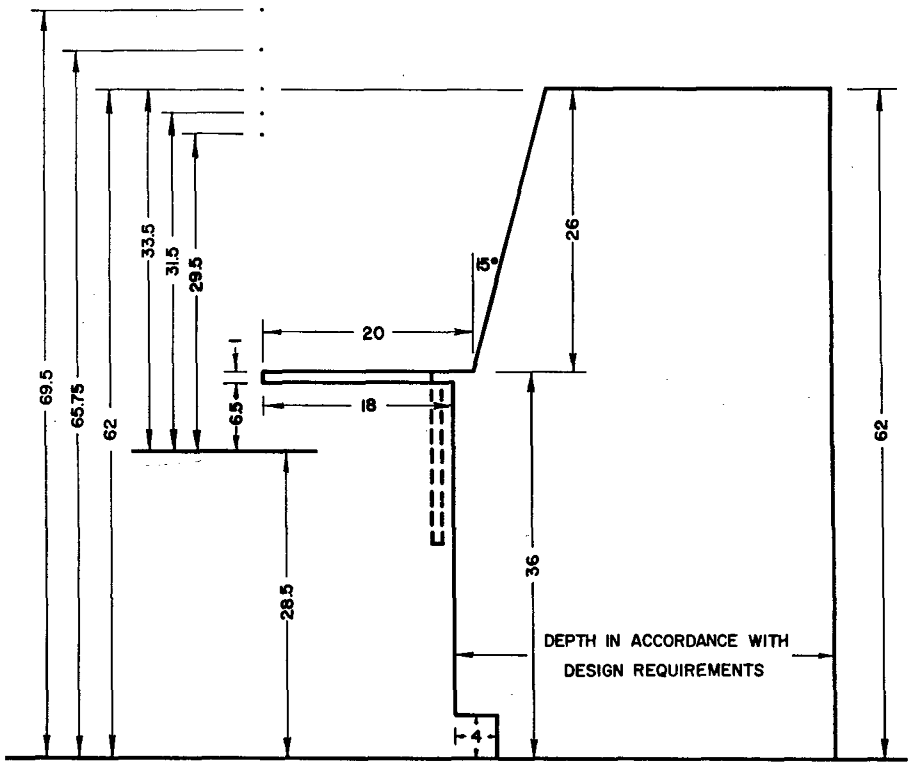

Figure 5. Dimensions of the Sit-Stand Console Profile. Eye positions are illustrated by means of dots (.) and are located directly above the end of the writing leaf. The level of the 95th percentile Eye Height, Sitting (33.5 inches), when using a 28.5-inch chair, coincides with that of the 5th percentile standing Eye Height including shoes (62 inches).

Requirement 2b on page 8 states that it should be possible to so locate important and frequently used displays and critical function warning lights that they will be at eye level to 30° below. Figure 6 illustrates the effect panel angle has on the amount of display space within 30° below horizontal for all standing operators. Note that the 5° panel offers the least such space and that the 25° panel offers the most. On the basis of this one requirement, the 25° panel is somewhat better than the others. However, since all panel angles satisfy this requirement, more or less, there is insufficient reason to influence a change in panel angle.

The primary concern in laying out the console profile below the writing leaf is to assure sufficient leg space for the range of operator sizes. To accomplish this, the minimum distance from Seat Reference Point (SRP) to the front of the console below the working surface must be at least 25 inches to accommodate the 95th percentile Buttock-Knee Length. Since some operators will be as small as 7 inches in the distance between the ventral aspect of their abdomens, which will be against the edge of the writing leaf, and their buttocks, which will be roughly at SRP, the distance necessary to accommodate the thighs of the operator with long legs must be at least 18 inches (25 inches minus 7 inches).

Accommodation to the reach and visual capabilities of the seated operator at the Sit-Stand console cannot be fulfilled without proper seating. A seat 28.5 inches high will assure adequate vertical positioning of the head and shoulders for satisfactory accommodation to most operators. Two inches of vertical adjustability above and below this height is sufficient to provide for the range between the 5th and 95th percentiles for Eye Height, Sitting.

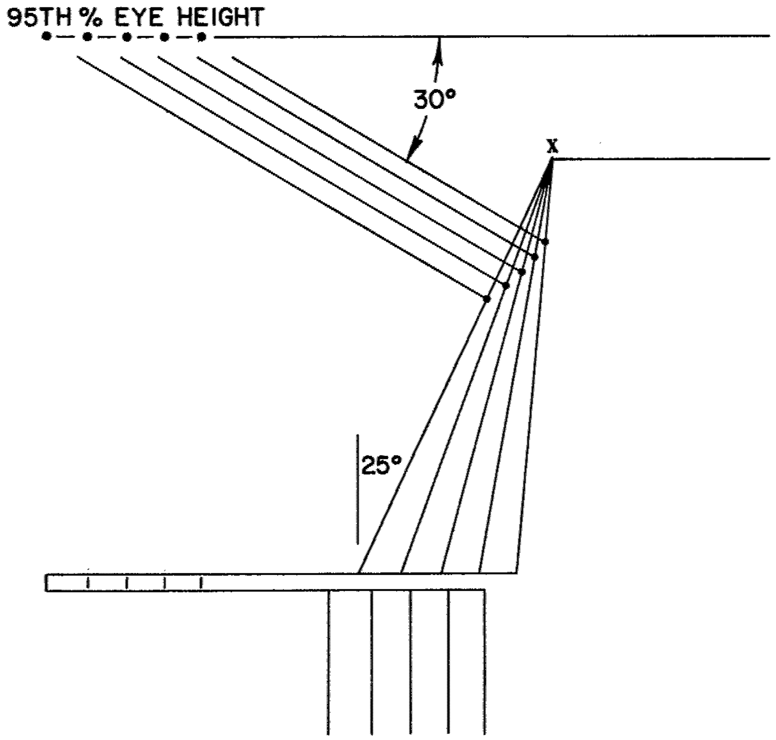

Figure 6. The Effect Panel Angle Has On the Display Space within 30° Below Horizontal Line-of-Sight. As the angle of this display panel increases, the operator is displaced away from point "X". This has the effect of increasing the panel space within 30° below horizontal – between X and the points where the 30° angles strike the different panels.

Note that the Sit-Stand Console is, in a sense, three consoles in one. In addition to its use as a console at which the operator may elect to sit or stand, it can also be used as a console at which the operator always stands or always sits. In the former he has horizontal vision over its top; in the latter he may not. At this point, differentiating between these consoles may appear academic, since their sizes and shapes are identical. As we shall see, however, it is important to consider them separately when treating reach and visual accommodation. In the authors' opinion this configuration would satisfy from 70% to 80% of the console requirements of a typical weapon system.

SECTION III

Derived Consoles

THE STAND CONSOLE WITH VISION OVER

This console is identical to the Sit-Stand Console. The operator may adjust the writing leaf in the horizontal or down position as the demands of the situation require. With the writing leaf down, he may find himself standing closer to the front of the console. Practice in "holding the console-panel at arms' length" when the leaf is down is suggested to avoid compromising visual accommodation.

When considering this as a console which will always be operated from the standing position, there is no need to consider seated reach or visual capabilities.

THE SIT CONSOLE WITHOUT VISION OVER (High Variation)

This console is also identical to the Sit-Stand Console. It is useful when a large amount of electronic or other equipment is required and can be installed below the level of the writing surface. It requires a seat 28.5 inches high. A heel-catch must be provided at 18 inches* below this seat.

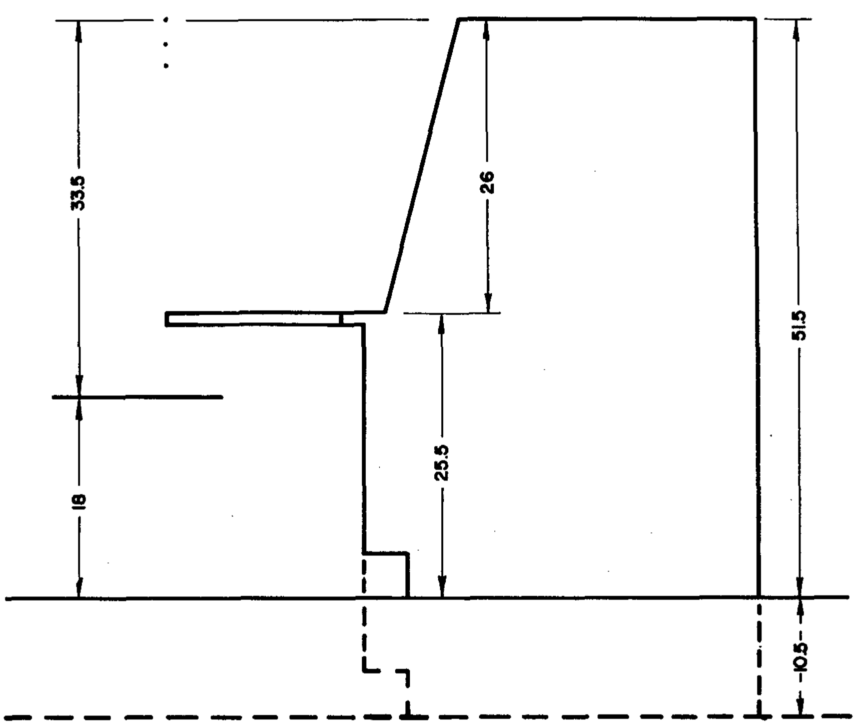

Figure 7. Dimensions of the Sit Console without Vision Over (Low Variation). The height of the seat is reduced by 10.5 inches to 18 inches. A like amount is removed from the base of the Sit-Stand Console so that reach and visual accommodation are not changed.

* The mean value for Popliteal Height, Sitting is 16.97 inches (ref 7). One inch is added for shoes.

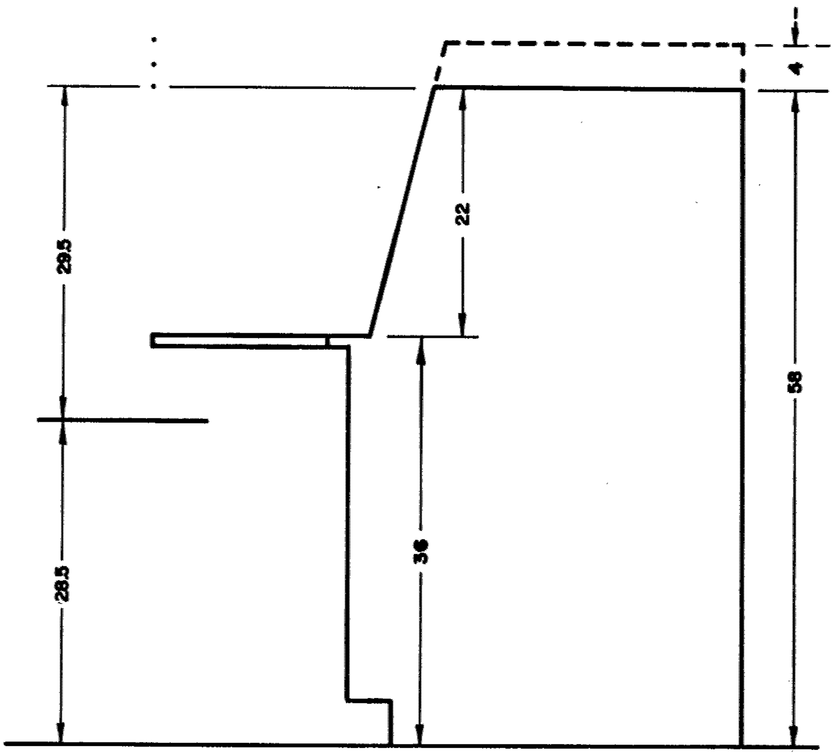

Figure 8. Dimensions of the Sit Console with Vision Over (High Variation). The distance from the seat to the top of the console is reduced from 33.5 inches in the Sit-Stand Console to 29.5 inches in this console. The latter distance is equal to 5th percentile Eye Height, Sitting. Ninety-five percent of the USAF population should be able to see over this console without materially altering their seated posture.

THE SIT CONSOLE WITHOUT VISION OVER (Low Variation)

If space for a large amount of electronic storage or backup equipment is not required, or if for any other reason a smaller console is necessary, the Sit Console without Vision Over (High Variation) may be reduced in height by 10.5 inches, the distance necessary to reduce the midpoint of seat adjustability from 28.5 inches to 18 inches. This will eliminate the need for a heel catch by permitting the operator to rest his feet on the floor. To maintain identical visual and reach accommodation, the size and shape of the display panel and the spatial relationship between the operator and the console panel is not disturbed. The upper half of this console remains identical to that of the Sit-Stand Console. Thus, even though the height of the console is reduuced from 62 inches to 51.5 inches, accommodation to reach and visual capabilities are not altered from those already described for the seated operator at the Sit-Stand Console. See figure 7 for the profile dimensions of this console.

THE SIT CONSOLE WITH VISION OVER (High Variation)

Horizontal vision over the console for the seated operator is made possible by reducing the distance from the seat to the top of the Sit-Stand Console to equal the value for 5th percentile Eye Height, Sitting (29.5 inches). By establishing the height of the console in this manner, 95 percent of the using population is assured adequate vision over its top when in the seated position. This console requires a seat 28.5 inches high when at its midpoint of vertical adjustability. Dimensions may be found in figure 8.

A heel-catch must be installed 18 inches below the seat. This is the same seat used with the Sit-Stand Console.

THE SIT CONSOLE WITH VISION OVER (Low Variation)

The overall height of this console is 10.5 inches less than that of the Sit Console with Vision Over (High Variation). The space within the console below the writing leaf is sufficient to contain a moderate amount of electronic and other equipment. Again, the special relationship between the operator and the display panel are not disturbed. Visual and reach capabilities over the panel surface remain essentially the same as those for the Sit Console with Vision Over (High Variation). A seat 18 inches high is used with this console. See figure 9 for the dimensions of this console.

THE STAND CONSOLE WITHOUT VISION OVER

The maximum height suggested for a Stand Console, for which there is no requirement to see over, should be limited to that height to which the small operator can conveniently reach, or to the highest level on the display panel which is tangent to the area permitting a viewing angle of 45° or greater, whichever is the lowest. In determining an appropriate height, assume, for example, that the standing eye positions are the same as those previously treated for standing operators at the Sit-Stand Console. The highest level on the surface of the display panel at which the operator with 5th percentile standing Eye Height is able to maintain a 45° or greater viewing angle is 84 inches above the standing surface. For the operator with 5th percentile standing Eye Height and Functional Reach, this height on the

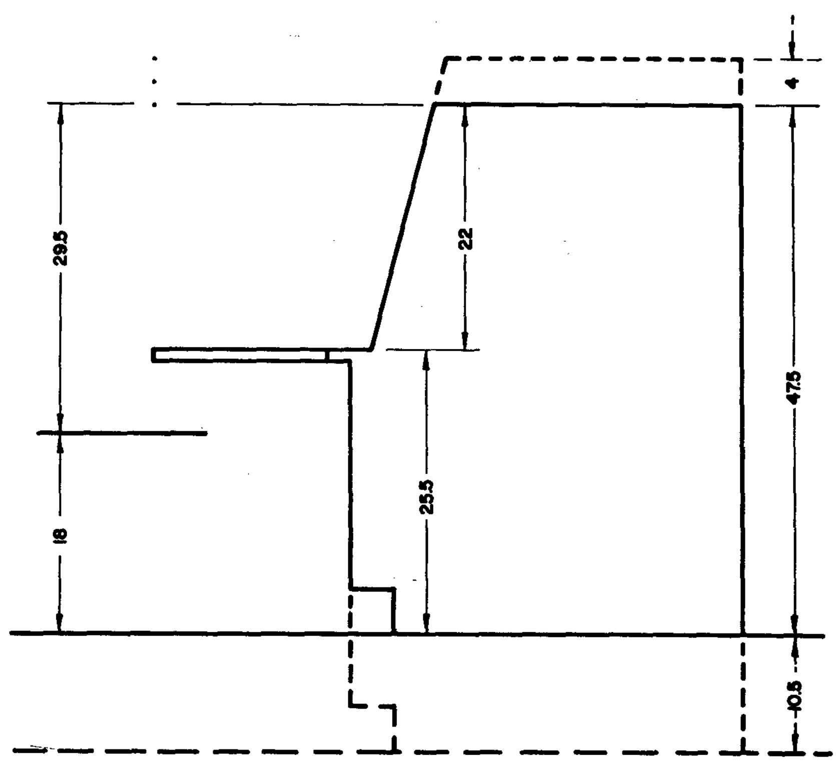

Figure 9. Dimensions of the Sit Console with Vision Over (Low Variation). The 18-inch seat is used. This console is derived by removing 10.5 inches from below the writing leaf of the High Variation of the Sit Console with Vision Over.

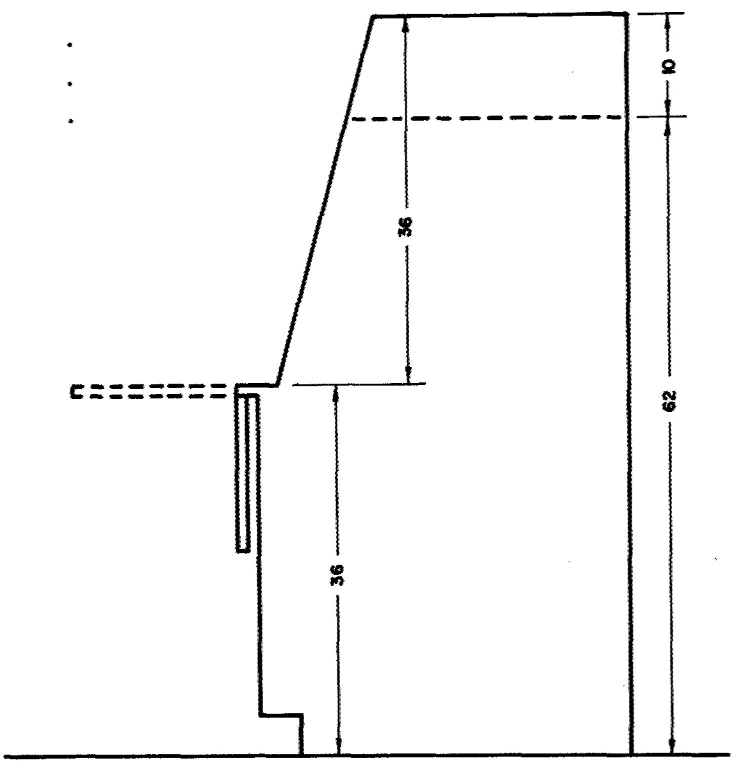

Figure 10. Dimensions of the Stand Console without Vision Over. By increasing the height of the Sit-Stand configuration to 72 inches, we have a console that most operators will not be able to see over, yet will accommodate to the reach and visual capabilities of most.

display panel is too great for convenient reach. By lowering the writing leaf and allowing the operator to move somewhat closer to the front of the console, he is able to reach comfortably to about the 72-inch level on the display panel. In prescribing a 72-inch height, the uppermost part of the display panel is within convenient reach of the shorter operators. The dimensions of this console are found in figure 10.

Dimensional design standards within which the designer should work are specified in table II. Basic relationships between these dimensions should be adhered to if inter-console compatibility and operator accommodation are to be fulfilled. For some dimensions, upper and lower limits are specified. A modified form of this table appears in Military Standard 803 A-1 (USAF), Part 1, "Aerospace System Ground Equipment" (ref 10).

TABLE II

STANDARD CONSOLE DIMENSIONS

	Maximum Console Height from Standing Surface	Console Depth at Base	Suggested Vertical Dimension of Panel, Including Sills	Console Panel Angle – from Vertical	Minimum Pencil-Shelf Depth	Minimum Writing Surface Depth – Including Pencil Shelf	Minimum Knee Clearance	Seat to Heel Catch[1]	Minimum Seat Adjustability	Minimum Thigh Clearance at Midpoint of "I"	Writing Surface Height from Standing Surface	Seat Height at Midpoint of "I"[1]	Maximum Console Panel Breadth
TYPE OF CONSOLE	A	B	C	D	E	F	G	H	I	J	K	L	M
1. Sit-Stand	62.0	Opt.	26	15°	4	16	18	18	4	6.5	36.0	28.5	36
2. Sit (w/vision over top)	47.5* to 58.0	Opt.	22	15°	4	16	18	18	4	6.5	25.5 to 36.0	18.0 to 28.5	44
3. Sit (w/o vision over top)	51.5** to 62.0	Opt.	26	15°	4	16	18	18	4	6.5	25.5 to 36.0	18.0 to 28.5	36
4. Stand (w/vision over top)	62.0	Opt.	26	15°	4	16	NA	NA	NA	NA	36.0	NA	44
5. Stand (w/o vision over top)	72.0	Opt.	36	15°	4	16	NA	NA	NA	NA	36.0	NA	36

* "A" must never be more than 29.5 inches greater than "L".

** "A" must never be more than 33.5 inches greater than "L".

[1] When Seat-to-Standing Surface exceeds 18", a heel catch should be provided.

SECTION IV

Accommodation of the Consoles to the Capabilities of the Operator

It is worthwhile to examine in greater detail the extent to which the 15° panel accommodates to the grasping reach and visual capabilities of different operators. We are primarily interested in visual capability when the operator's back is vertical (the alert position) and reach capability when his back is 5° forward of vertical (the operating position). Kennedy (ref 9) has ascertained the Minimum, 5th, 50th, and 95th percentile, shirt-sleeved, grasping reach envelopes on a series of subjects representative of the USAF population.

The 5th percentile reach envelope is that within which an estimated 95 percent of the Air Force population can reach when in a standard seated position. The data regarding this envelope are presented in table III. Although specifically ascertained for the seated operator, this envelope can be utilized to ascertain the extent to which the Sit-Stand configuration accommodates to the grasping reach capability of both the sitting and standing operators with 5th percentile reach. Since the grasping reach envelopes in ref 7 were determined utilizing a rearward back angle of 13°, the reach envelope must be rotated 18° forward so as to coincide with the back angle in the operating position at 5° forward of vertical. Also, all dimensions of the reach envelope were measured from a vertical line through SRP. This line, then, is also rotated 18° forward and is used in reconstructing the sector of the reach envelope found in figure 11. Ninety-five percent of the USAF population will have grasping reach in excess of the 5th percentile envelope, and, consequently, will not have to lean forward as far to have equivalent reach over the surface of the panel. To simulate the increase in reach capability that results from extending the shoulder, the reach envelope was displaced forward a distance of 4 inches.

Side views of the 5th percentile envelope and the console were then superimposed so that the extent of accommodation to reach could be examined (see fig. 11). To simulate the change in the relative position of the console when the operator changes from the sitting to the standing position, the console is illustrated in both positions relative ~~to~~ the operater's eyes. Thus, it is possible to evaluate reach and visual capabilities through the use of a single eye position. After constructing a top view of the console display area (not shown), a composite, primary auxiliary view (fig. 12) was drawn to reveal the nature of the operator's reach and visual capabilities over the surface of all panels. To avoid an overly complex illustration, only the reach capability of the right hand is portrayed.

As a result of the manner in which we simulated the positions of the standing and seated operator relative to the console panel, the lower edge of the panels of the Stand consoles do not coincide with those of the Sit consoles. It is necessary to adjust them until they do coincide.

The true composite, including reach capability for the left hand, is presented in fig. 13. Illustrated are the sections of the panels that are within grasping reach and within which viewing angles of 45° and 60° are conveniently attainable. The areas of these sections were ascertained with a polar planimeter and compared with the total area of the panel. The diagram of reach and visual capabilities over the surface of the Sit-Stand display panel is derived from fig. 13 and illustrated in fig. 14. Data regarding these capabilities for different panel breadths are found in table IV.

TABLE III

DIMENSIONS OF THE 5th PERCENTILE, RIGHT HAND, GRASPING-REACH ENVELOPE FOR THE SEATED OPERATOR*

Dimensions are in inches and are measured from a vertical line through SRP (Seat Reference Point). 0° is forward and in the median plane. Only the boxed-in part of the table was required in the evaluation of reach accommodation at the Sit-Stand Console. The grasping-reach envelope for the left hand is assumed to be a mirror image of that for the right hand.

	Inches Above SRP									
Angle†	*0*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
L165°										10.5
L150										8.75
L135										7.75
L120								10.75	11.25	7.5
L105								12.25	11.75	7.25
L 90								13.75	12.25	7.25
L 75								15	12.5	7.5
L 60					17.5	18.25	17.25	16	13.25	7.75
L 45				19	19.5	20	19	17.25	14	8.5
L 30				21.75	21.5	22.5	21.5	19.25	15.5	9.5
L 15				23.25	23.5	24	23.75	21	17	11
0°				24.75	25.5	26.25	25.5	22.25	19	12.75
R 15				26.5	28	28.25	27.25	24.75	21	15.5
R 30	17.5	23.75	27	28.5	30	30.25	29	26.75	22.75	17.5
R 45	19.5	25.25	28.25	30	31	31	30.25	28.25	24.75	19
R 60	20.5	25.75	29	31	32	31.5	31	29	25.5	20.5
R 75	20	25.75	29.25	31.5	32.25	32	31.25	29.5	26	20.5
R 90	19.5	25.75	29.25	31	32.25	32.25	31.25	29.75	26.25	21
R105	18.75	25.25	28.75	30.75	31.75	31.5	31	29.75	26.75	21.5
R120	18.25	24.5	27.75	29.5	30.5	30.5	30.25	29	26.25	21.25
R135	16.5	22.75	26.25							20
R150	14									15.5
R165										14.75
180°										12.75

* From Kennedy (ref 9).

† L, Left of Median Plane.
R, Right of Median Plane.

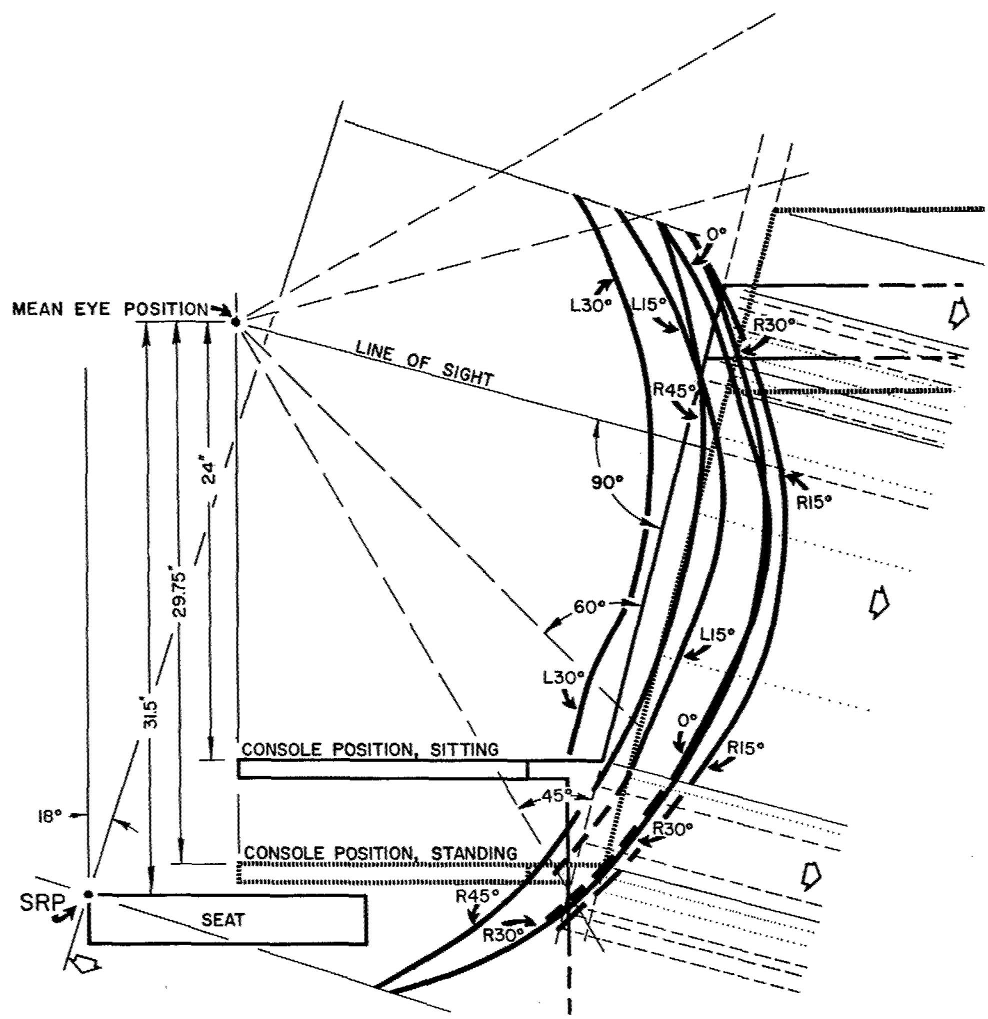

Figure 11. Side View of a Composite of all Console Display Panels Superimposed onto the Side View of a Sector of the 5th Percentile Grasping-Reach Envelope of the Seated Operator.

The axis of the reach envelope was rotated 18° forward of vertical to bring the back angle of the operator from 13° to the rear of vertical to coincide with the operating position, which is with the back at 5° forward of vertical. The sector of the reach envelope was then displaced forward 4 inches to simulate increased reach resulting from shoulder extension. No attempt was made to simulate increased reach resulting from the operator moving laterally from directly in front of the console. The operator will thus have more reach capability than is indicated to his left and right front. To simulate the change in the relative position of the console when the operator changes from the seated position to the standing position, the console profile is represented in its two positions relative to the eyes of the operator. The position of the operator's eyes is assumed to be directly above the end of the writing leaf. A top view of this composite was drawn (not shown). The arrow at SRP indicates this projection. A composite primary auxiliary view showing reach and visual capabilities over the surface of the display panel was drawn and is illustrated in fig. 12. The arrows on the right margin indicate this projection.

In an evaluation of reach and visual capability over the surface of the Sit-Stand display panel, it is difficult to ascertain a single panel breadth which is decidedly better than all others. Although all categories of data in table IV may be useful in such a determination, none is decisive. The most important are: (1) the percentage of panel area within reach of either hand in both the standing and seated positions, (2) the percentage of panel area permitting a viewing angle of 45° or greater, and

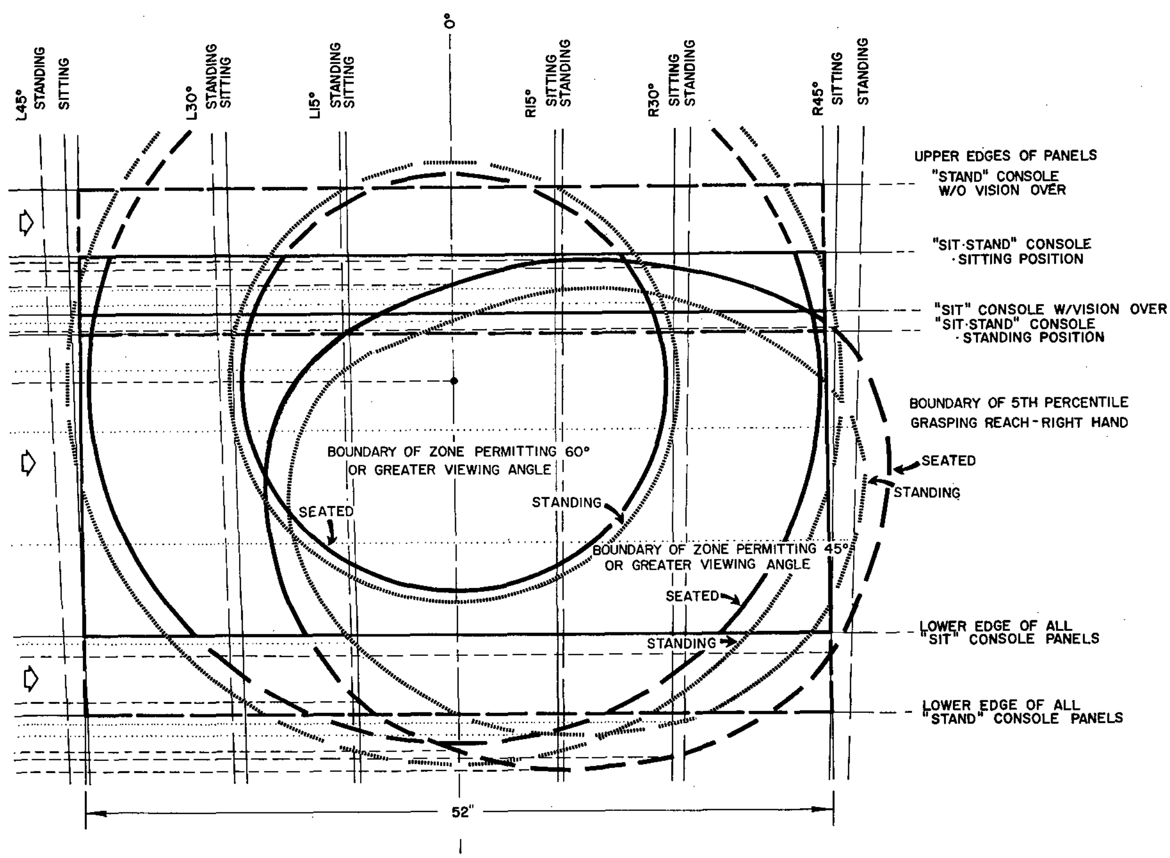

Figure 12. Composite Representation of Visual Capability and Reach with the Right Hand over the Surfaces of all Console Display Panels. Since the positions of the display panels change, relative to the operator when he moves from the seated to the standing position, reach and visual capabilities over the surfaces of the display panels of the Stand consoles are displaced from those of the Sit consoles. The amount of displacement is 5.75 inches, the vertical distance between the level of the mean standing Eye Height and the adjusted Eye Height, Sitting (see fig. 3). To obtain a true composite view, the panels must be aligned so that their lower edges coincide. Reach capability for the left hand must be included. It is assumed to be a mirror image of that of the right. The true composite view is presented in fig. 13.

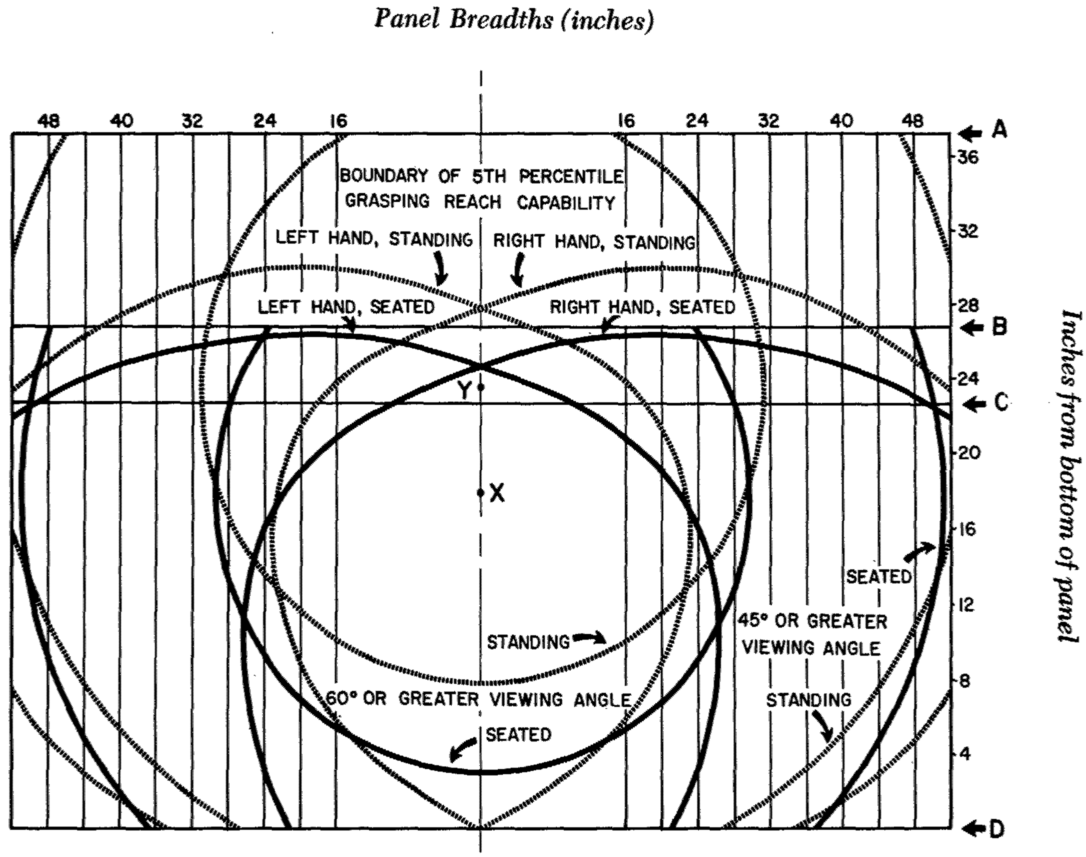

Figure 13. True Composite Representations of Reach and Visual Capabilities over the Surfaces of All Console Display Panels. Dotted contours represent reach and visual capabilities, standing; solid contours represent these capabilities, seated. X represents the point at which the line-of-sight is perpendicular to the display panel for the seated operator with mean Eye Height, Sitting. Y represents this point for the standing operator with mean standing Eye Height. The space between 16 on one side of the centerline and the 16 on the other side represents the breadth of the 16-inch panel: between 24's, the 24-inch panel, etc. A represents the upper limit of the Stand Console without Vision Over. B represents the upper limit of the Sit-Stand Console, the Stand Console with Vision Over and the Sit Consoles without Vision Over (High and Low Variations). C is the upper limit of the Sit Consoles with Vision Over (High and Low Variations). D is the lower limit of all console panels.

(3) the percentage of panel area within the reach of either hand in both the standing and seated positions and which is within a 45° or greater viewing angle.

Insofar as concerns the percentage of panel area within reach of either hand in both the standing and seated positions, the panel can be any width between 16 inches, at which 96 percent of the total panel area can be reached, and 44 inches wide, at which 95 percent can be reached. It decreases to 90 percent at the 52-inch width.

A 45° or greater viewing angle is possible over 100 percent of all panels through a 32-inch breadth. Thereafter, it falls to 88 percent with the 52-inch panel.

The percentage of this panel within sit-stand reach of either hand and which is also within the area permitting a 45° or greater viewing angle, is reduced from 96 percent with the 16-inch panel to 94 percent with the 40-inch panel. It thereafter falls to 84 percent with the 52-inch panel.

In selecting an optimum panel breadth, it is essential that none of the above three accommodation criteria be unduly compromised. Since there are no sharp drop-offs in accommodation associated with a particular breadth, we have no decisive selection criteria for panels up to 52 inches wide. However, we do find a gradual drop-off in the percentage of panel space available to either hand and which is within that part of the panel permitting a 45° or greater viewing angle. Consequently, the Sit-Stand panel probably should not exceed the 52-inch breadth.

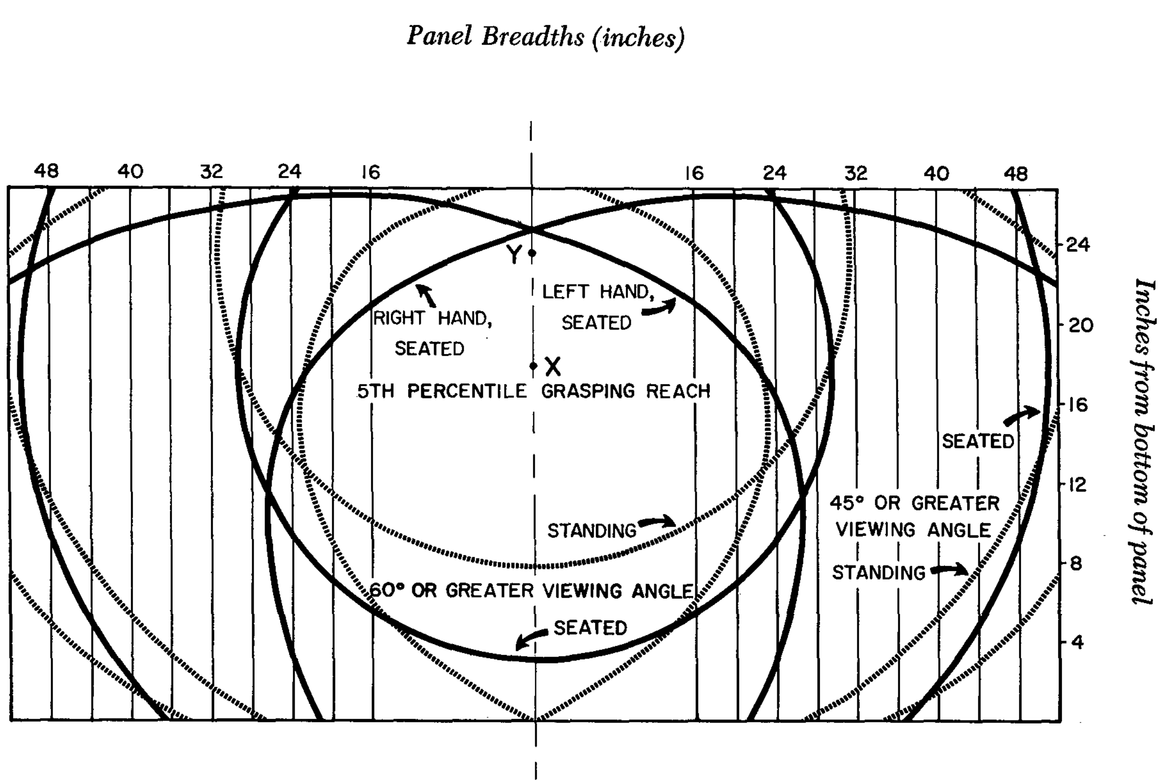

Figure 14. Reach and Visual Capabilities over the Surface of the Sit-Stand Console Display Panel. Dotted contours represent capabilities, standing; solid contours represent capabilities, seated. X represents the point at which the line-of-sight will be perpendicular to the display panel for the seated operator with mean Eye Height, sitting. Y represents this point for the standing operator with mean standing Eye Height.

TABLE IV

REACH AND VISUAL CAPABILITIES OVER THE SURFACE OF THE DISPLAY PANEL OF THE SIT-STAND CONSOLE

		Panel Breadths (inches)									
		16	*20*	*24*	*28*	*32*	*36*	*40*	*44*	*48*	*52*
A	Total Panel Area (TPA)*	430	538	646	753	861	968	1076	1184	1291	1399
B	Area, Sit-Stand Reach, 1 Hand	372	448	513	577	629	680	728	772	813	845
	Percent of TPA	86	83	79	77	73	70	68	65	63	60
C	Area, Sit-Stand Reach, Either Hand	413	518	624	729	833	935	1032	1120	1201	1266
	Percent of TPA	96	96	96	97	97	96	96	95	93	90
D	Area, Sit-Stand Reach, Both Hands	328	379	402	402	402	402	402	402	402	402
	Percent of TPA	76	70	62	53	47	42	37	34	31	29
E	Area, Sit-Stand, Permitting 60° + Viewing Angle	296	361	419	460	465	465	465	465	465	465
	Percent of TPA	69	67	65	61	54	48	43	39	36	33
F	Area, Sit-Stand, Permitting 45° + Viewing Angle	430	538	646	753	858	957	1049	1132	1203	1237
	Percent of TPA	100	100	100	100	100	99	97	96	93	88
G	Area, Sit-Stand Reach, Either Hand Within F	413	518	624	729	830	925	1010	1083	1140	1171
	Percent of TPA	96	96	96	97	96	96	94	91	88	84

* All areas in square inches.

In selecting an appropriate breadth, the designer must give thorough consideration to the operators' tasks. The standard 24-inch panel, which is often used, is quite conservative when considering only visual and reach capabilities. The calculations made here with respect to the Sit-Stand Console panel suggest the possibility that these capabilities may not be used to their maxima at the 24-inch panel.

Reach and visual capabilities over the surface of the display panel of the Stand Console with Vision Over are estimated by deleting from fig. 14 the reach and vision contours for the seated operator. Those for the standing operator are retained and are illustrated in fig. 15. Sections of the panel meeting reach and visual requirements were measured in a similar manner as those for the Sit-Stand display panel and data regarding them are found in table V.

When considering the percentage of this panel which is within reach of either hand, the operator can perform essentially as well at any panel from 16 through 52 inches. One-hundred percent of each panel from 16 through 40 inches is within his reach. It drops to 94 percent with the 52-inch panel. As with the Sit-Stand Console, the entire area of all panels between 16 and 32 inches wide permit a 45° or greater viewing angle. Ninety-four percent of the 52-inch panel permits a 45° or greater viewing angle. The percentage of the panel within reach of either hand and also within the area permitting a 45° or greater viewing angle remains at 100 percent from 16 through 32 inches, and thereafter falls to 88 percent with the 52-inch panel.

Both of the latter measures show a gradual drop-off in capability begining at about the 40-inch width. Accommodation remains adequate at least to the 44-inch width. Because of this and because we are considering the standing operator, whose position with respect to the console is highly variable, the panel breadth of the Stand Console with Vision Over may be greater than that of the Sit-Stand Console. In the latter, panel breadth is more conservative because of the necessity to consider the restrictions placed on the seated operator with regard to moving from side to side.

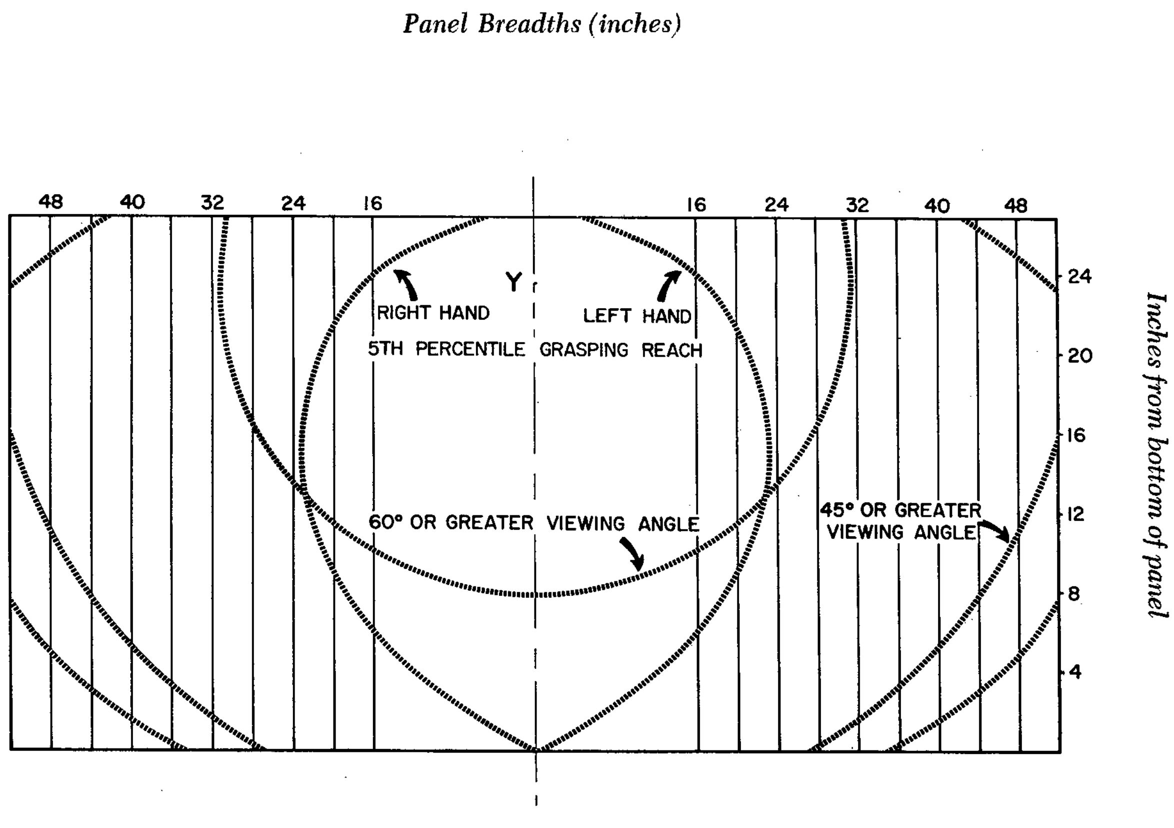

Figure 15. Reach and Visual Capabilities over the Surface of the Display Panel of the Stand Console with Vision Over. Y represents the point at which the line-of-sight will be perpendicular to the display panel for the standing operator with mean Eye Height.

TABLE V

REACH AND VISUAL CAPABILITIES OVER THE SURFACE OF THE DISPLAY PANEL OF THE STAND CONSOLE WITH VISION OVER

		Panel Breadths (inches)									
		16	*20*	*24*	*28*	*32*	*36*	*40*	*44*	*48*	*52*
A	Total Panel Area (TPA)*	430	538	646	753	861	968	1076	1184	1291	1399
B	Area, Standing Reach, 1 Hand	404	488	555	609	663	716	768	817	855	892
	Percent of TPA	94	91	86	81	77	74	71	69	66	64
C	Area, Standing Reach, Either Hand	430	538	646	753	861	968	1072	1170	1246	1319
	Percent of TPA	100	100	100	100	100	100	100	99	96	94
D	Area, Standing Reach, Both Hands	373	434	461	461	461	461	461	461	461	461
	Percent of TPA	87	80	71	61	54	48	43	39	36	33
E	Area, Standing, Permitting 60° +										
	Viewing Angle	296	361	419	467	494	494	494	494	494	494
	Percent of TPA	69	67	65	62	57	51	46	42	38	35
F	Area, Standing, Permitting 45° +										
	Viewing Angle	430	538	646	753	858	957	1049	1132	1203	1259
	Percent of TPA	100	100	100	100	100	99	97	96	93	90
G	Area, Standing Reach, Either Hand										
	Within F	430	538	646	753	858	957	1049	1130	1196	1239
	Percent of TPA	100	100	100	100	100	99	97	95	93	88

* All areas in square inches.

Reach and visual capabilities over the surface of the display panel of the Sit Console without Vision Over are estimated by deleting from fig. 15 the reach and vision contours for the standing operator. Those for the seated operator are retained and are illustrated in fig. 16. Data regarding this panel can be found in table VI.

The percentage of panel area within reach of either hand varies by only 3 percent among all the panels between 16 and 52 inches in width. At the 16-inch width, 96 percent is within reach of either hand, at 32 inches, 97 percent, and at 52 inches, it is still at 94 percent. All of each panel between 16 and 40 inches wide permits a 45° or greater viewing angle: 8 inches more panel width than at the Sit-Stand Console. However, the percentage falls off more rapidly than with the Sit-Stand Console, reaching 92 percent at the 52-inch breadth. The percentage of the panel within reach of either hand and also within the area permitting a 45° or greater viewing angle, is 96 percent with the 16- and 20-inch panels. This percentage rises to 97 percent with the 24- through the 36-inch panels and falls to 87 percent with the 52-inch panel.

All measures of accommodation remain high through the 44-inch width. The visual and reach accommodation afforded by the 48-inch and 52-inch panels are significantly reduced. The Sit Console

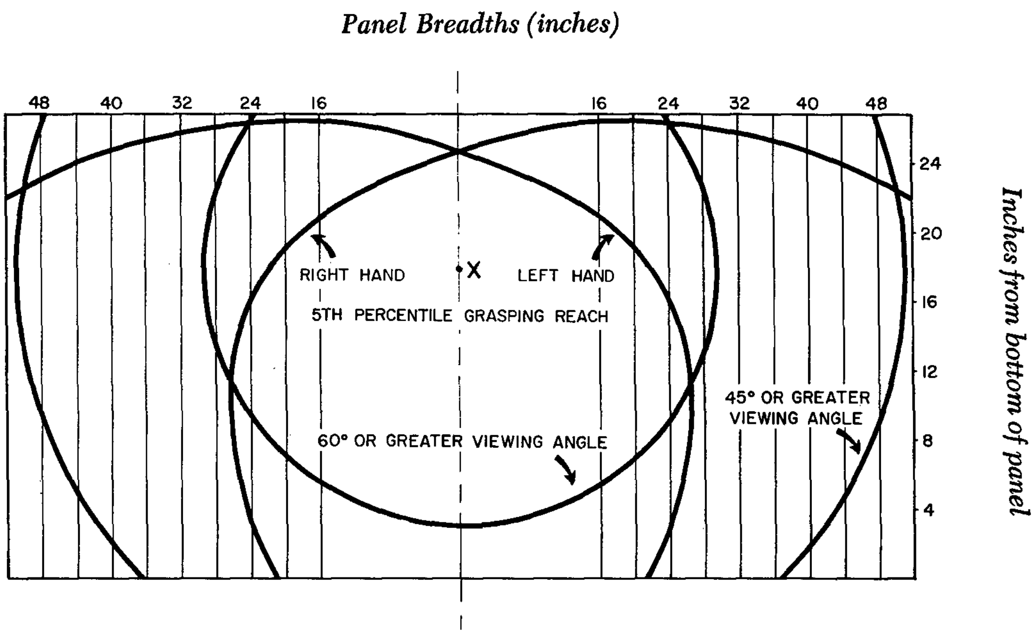

Figure 16. Reach and Visual Capabilities over the Surfaces of the Display Panels of the Sit Console without Vision Over (High and Low Variations). X represents the point at which the line-of-sight will be perpendicular to the display panel for the seated operator with mean Eye Height, Sitting.

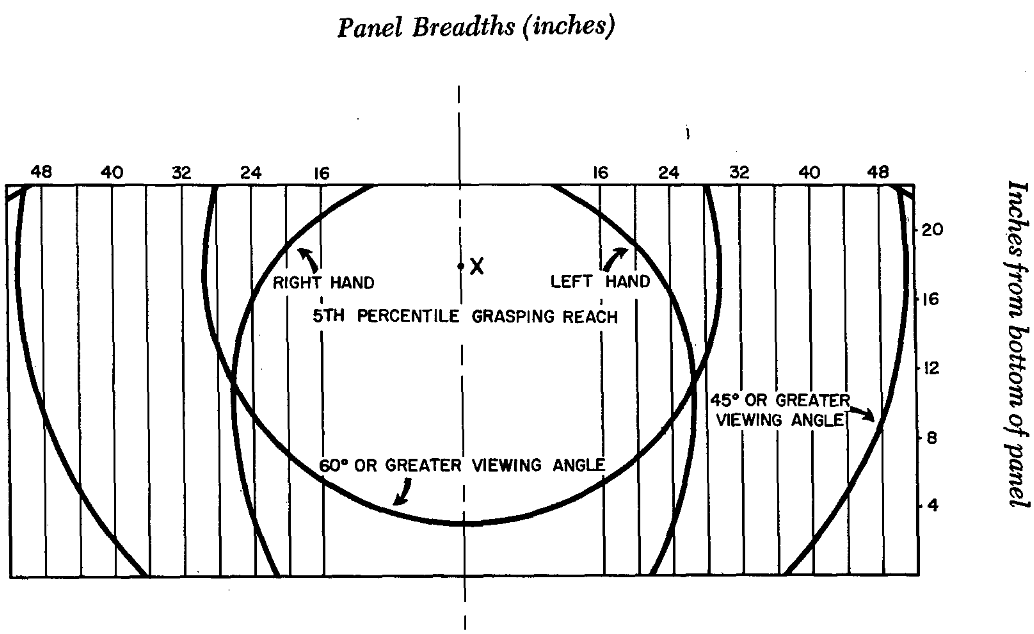

Figure 17. Reach and Visual Capabilities over the Surfaces of the Display Panels of the Sit Consoles with Vision Over (High and Low Variations). X represents the point at which the line-of-sight will be perpendicular to the display panel for the seated operator with mean Eye Height, Sitting.

TABLE VI

REACH AND VISUAL CAPABILITIES OVER THE SURFACES OF THE DISPLAY PANELS OF ALL SIT CONSOLES WITHOUT VISION OVER

		Panel Breadths (inches)									
		16	*20*	*24*	*28*	*32*	*36*	*40*	*44*	*48*	*52*
A	Total Panel Area (TPA)*	430	538	646	753	861	968	1076	1184	1291	1399
B	Area, Seated Reach, 1 Hand	390	482	569	633	684	736	787	835	882	927
	Percent of TPA	91	90	88	84	79	76	73	70	68	66
C	Area, Seated Reach, Either Hand	413	518	624	729	833	935	1037	1133	1228	1318
	Percent of TPA	96	96	97	97	97	97	96	96	95	94
D	Area, Seated Reach, Both Hands	372	449	517	538	538	538	538	538	538	538
	Percent of TPA	87	83	80	71	63	56	50	45	42	38
E	Area, Seated, Permitting 60° + Viewing Angle	369	453	527	583	594	594	594	594	594	594
	Percent of TPA	86	84	82	77	69	61	55	50	46	42
F	Area, Seated, Permitting 45° + Viewing Angle	430	538	646	753	861	968	1072	1166	1248	1283
	Percent of TPA	100	100	100	100	100	100	100	98	97	92
G	Area, Seated Reach, Either Hand Within F	413	518	624	729	833	935	1034	1118	1184	1218
	Percent of TPA	96	96	97	97	97	97	96	94	92	87

* All areas in square inches.

without Vision Over can be as wide as 44 inches without adversely affecting operator performance.

The display panels of the Sit Consoles with Vision Over (High and Low Variations) are the same as that for the Sit Console without Vision Over, except that 4.25 inches have been removed from the upper edge. It is illustrated in fig. 17. Data from table VII indicate that all of each panel width is within reach of either hand. A 45° or greater viewing angle is conveniently attainable at any point on the surface of all panels from 16 to 40 inches wide. The percentage of the panel within reach of either hand and also within the area permitting a 45° or greater viewing angle remains at 100 percent from 16 through 44 inches.

Reach and visual capabilities over the surface of the Stand Console without Vision Over are illustrated in fig. 18. As with the Stand Console with Vision Over, it is assumed that the writing surface is up and that the position of the operator's eyes is directly above the forward edge of the writing surface. The estimates of reach and visual capabilities over the surface of the display panel, which are illustrated in fig. 19 and reported in table VIII, are perhaps more conservative than need be. The operator may lower the writing leaf and thereby stand closer to the front of the console when reaching toward the upper edge of the panel.

To test the efficiency of the proposed console standards, wooden mockups of some of the configurations were fabricated. The Sit-Stand Console is shown in figs. 19 and 20. Figure 19 illustrates that a man of relatively small size, when standing, experiences no difficulty seeing over the console or in reaching over the surface of the display panel. Figure 20 illustrates that a relatively large man, when seated, has sufficient knee space below the writing-working surface, as well as adequate grasping reach over the surface of the panel. A mockup of the Sit Console with Vision Over (High Variation) appears in fig. 21; that for the Sit Console with Vision Over (Low Variation) will be found in fig. 22. As expected, reach capability of a series of small subjects over all panels proved to be in excess of that described. The small subject in most cases could reach over the entire panel space with either hand with only minor alterations of body position, whether sitting or standing, and with the writing leaf in the horizontal position.

TABLE VII

REACH AND VISUAL CAPABILITIES OVER THE SURFACES OF THE DISPLAY PANELS OF ALL SIT CONSOLES WITH VISION OVER

		Panel Breadths (inches)									
		16	*20*	*24*	*28*	*32*	*36*	*40*	*44*	*48*	*52*
A	Total Panel Area (TPA)*	364	455	546	637	728	819	910	1001	1092	1183
B	Area, Seated Reach, 1 Hand	361	446	524	579	625	670	716	761	807	852
	Percent of TPA	99	98	96	91	86	82	79	76	74	72
C	Area, Seated Reach, Either Hand	364	455	546	637	728	819	910	1001	1092	1182
	Percent of TPA	100	100	100	100	100	100	100	100	100	100
D	Area, Seated Reach, Both Hands	359	439	505	528	528	528	528	528	528	528
	Percent of TPA	99	96	92	83	73	64	58	53	48	45
E	Area, Seated, Permitting 60° + Viewing Angle	304	369	429	476	487	487	487	487	487	487
	Percent of TPA	83	81	79	75	67	60	54	49	45	41
F	Area, Seated, Permitting 45° + Viewing Angle	364	455	546	637	728	819	908	984	1048	1081
	Percent of TPA	100	100	100	100	100	100	100	98	96	91
G	Area, Seated Reach, Either Hand Within F	364	455	546	637	728	819	908	984	1048	1081
	Percent of TPA	100	100	100	100	100	100	100	98	96	91

* All areas in square inches.

TABLE VIII

REACH AND VISUAL CAPABILITIES OVER THE SURFACE OF THE DISPLAY PANEL OF THE STAND CONSOLE WITHOUT VISION OVER

		Panel Breadths (inches)									
		16	*20*	*24*	*28*	*32*	*36*	*40*	*44*	*48*	*52*
A	Total Panel Area (TPA)*	596	745	894	1043	1192	1341	1490	1639	1788	1937
B	Area, Seated Reach, 1 Hand	419	510	582	642	700	758	805	846	889	924
	Percent of TPA	70	68	65	62	59	56	54	52	50	48
C	Area, Seated Reach, Either Hand	463	585	702	820	937	1054	1148	1229	1314	1385
	Percent of TPA	78	78	79	79	79	78	77	75	74	71
D	Area, Seated Reach, Both Hands	378	438	466	466	466	466	466	466	466	466
	Percent of TPA	63	59	52	45	39	35	31	28	26	24
E	Area, Seated, Permitting 60° + Viewing Angle	459	559	646	715	745	745	745	745	745	745
	Percent of TPA	77	75	72	68	62	56	50	45	42	38
F	Area, Seated, Permitting 45° + Viewing Angle	596	745	894	1043	1188	1327	1458	1582	1696	1793
	Percent of TPA	100	100	100	100	100	99	98	97	95	92
G	Area, Seated Reach, Either Hand Within F	596	745	894	1043	1188	1327	1458	1582	1696	1793
	Percent of TPA	100	100	100	100	100	99	98	97	95	92

* All areas in square inches.

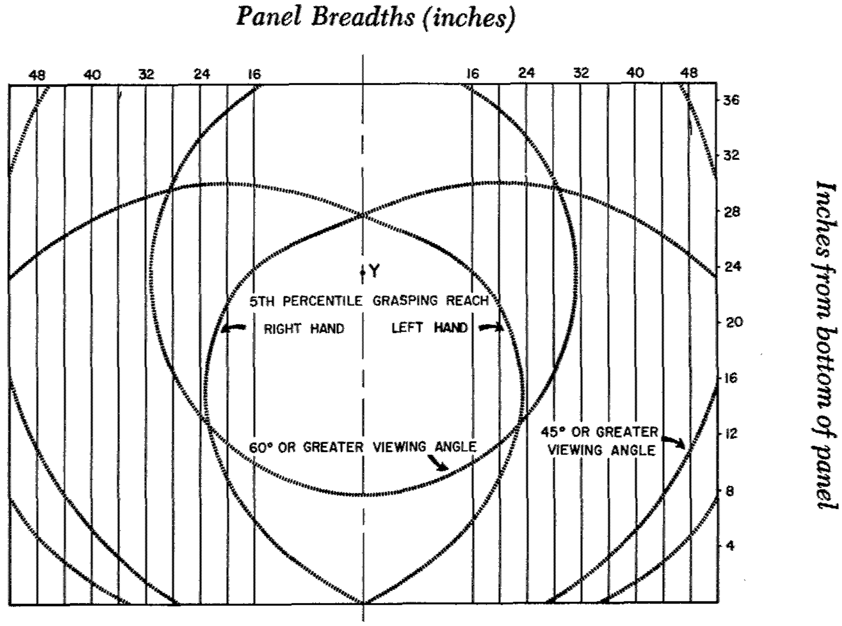

Figure 18. Reach and Visual Capabilities over the Surface of the Display Panel of the Stand Console without Vision Over. Y represents the point at which the line-of-sight will be perpendicular to the display panel for the standing operator with mean standing Eye Height.

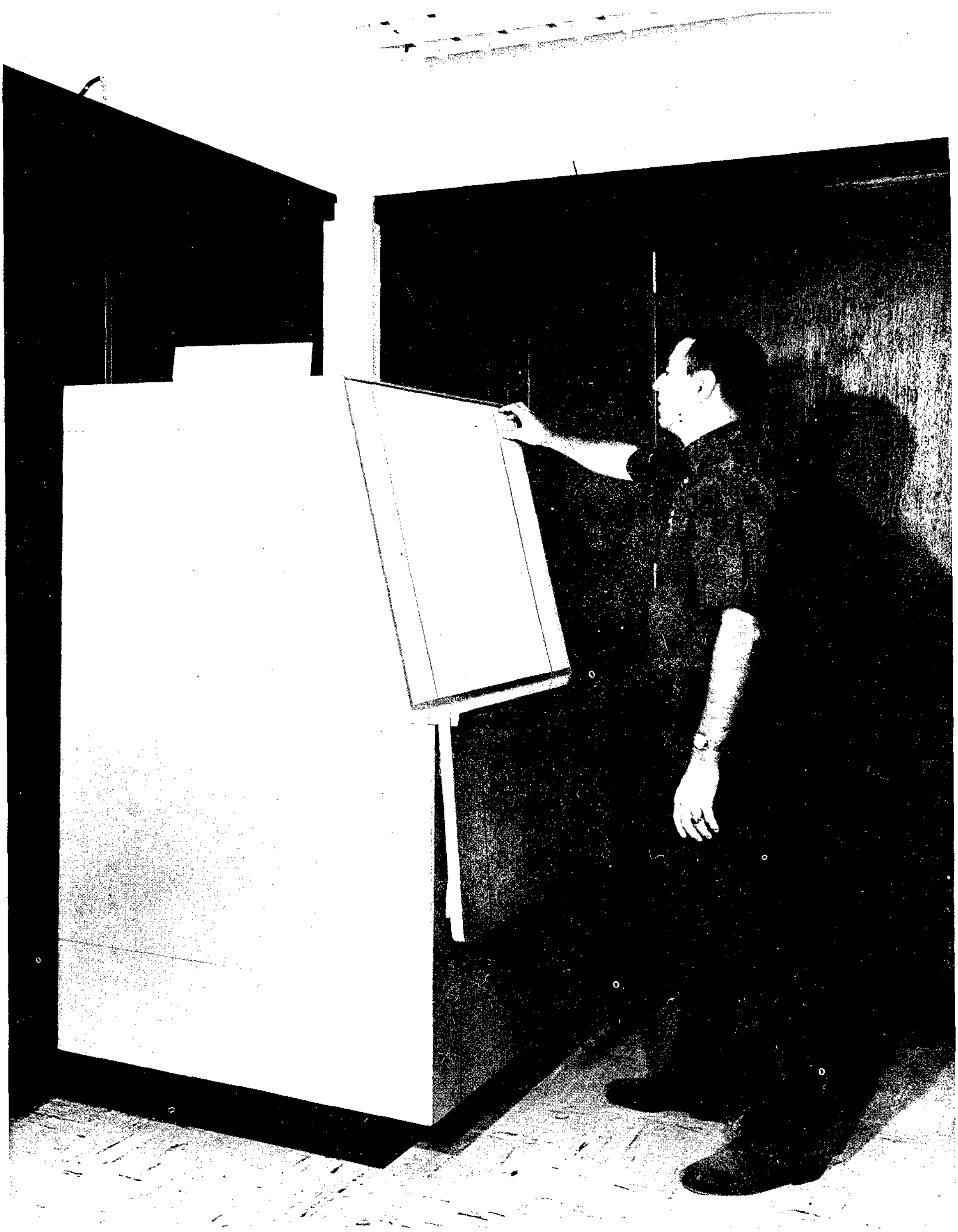

Figure 19. Mockup of the Sit-Stand Console with Standing Operator of Relatively Small Size. When standing, a man of relatively small size experienced no difficulty seeing over the console or in reaching over the surface of the display panel. Vertical lines on the front of the console define the 24-inch breadth. The total breadth of the mockups is 36 inches.

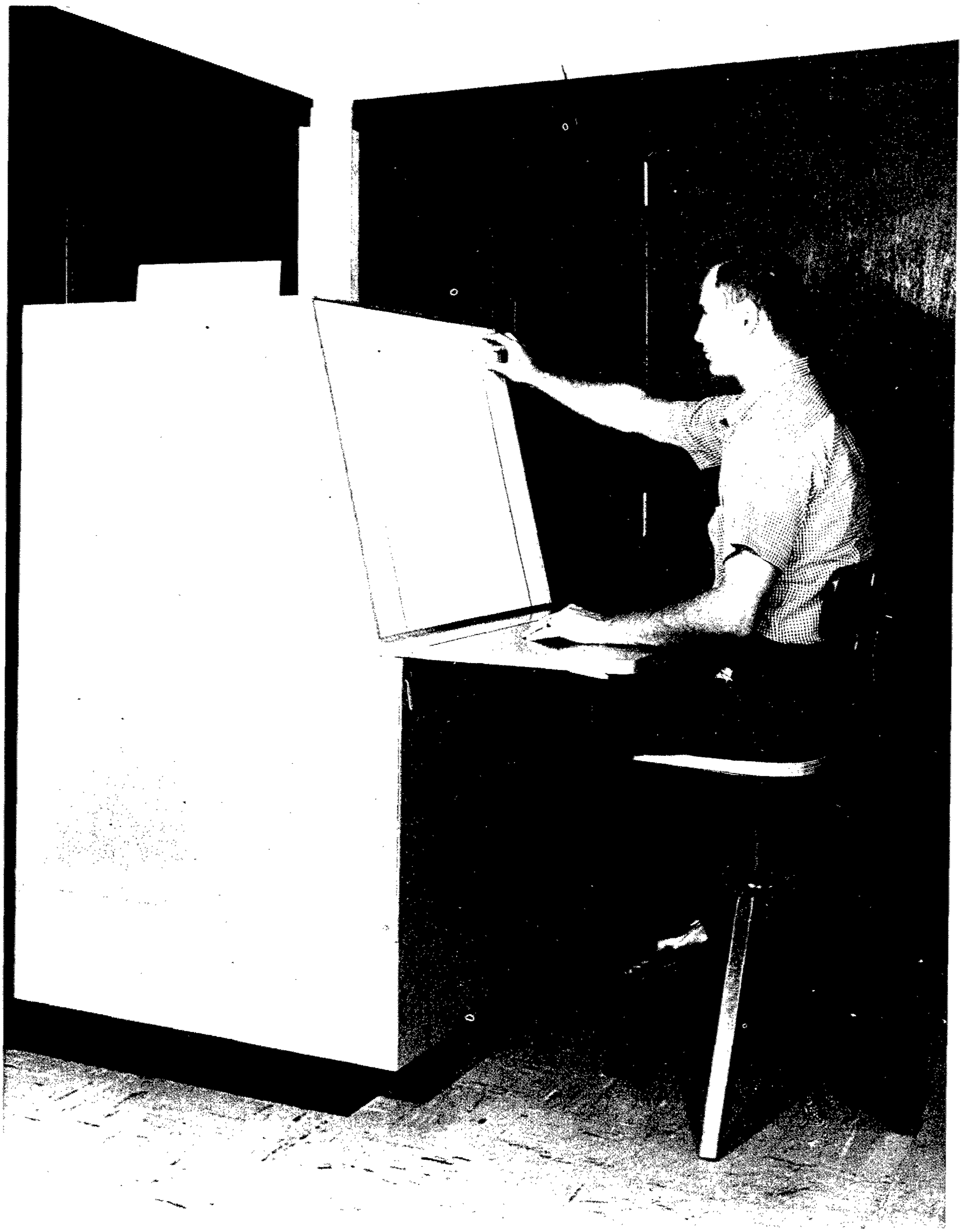

Figure 20. Mockup of the Sit-Stand Console with Seated Operator of Relatively Large Size. When seated, a man of relatively large size has sufficient knee space below the writing-working surface. Chair height is 28.5 inches.

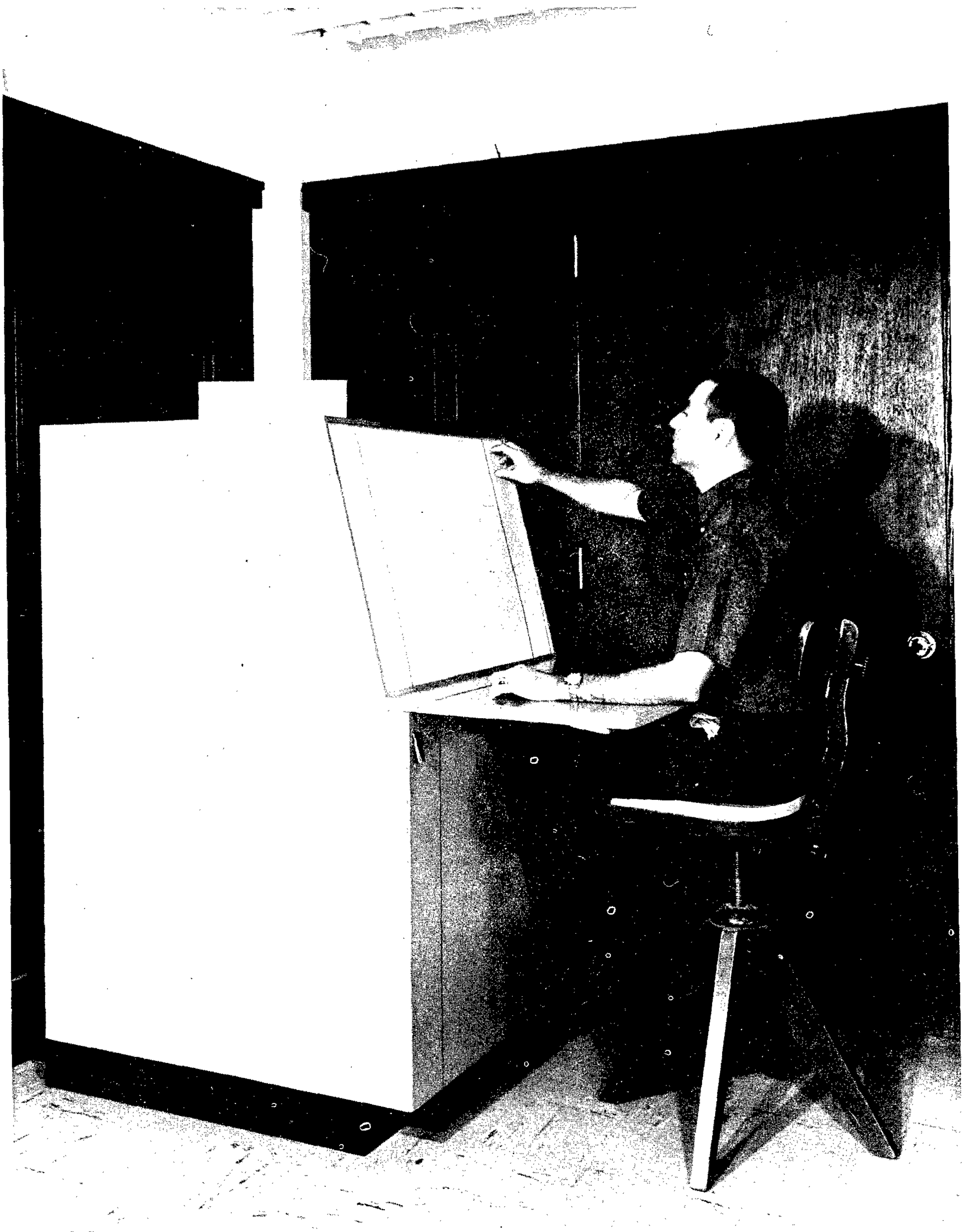

Figure 21. Mockup of the Sit Console with Vision Over (High Variation) with Seated Operator of Relatively Small Size. The smaller operator has no difficulty seeing over the mockup or reaching any location on the surface of its display panel. Chair height is 28.5 inches.

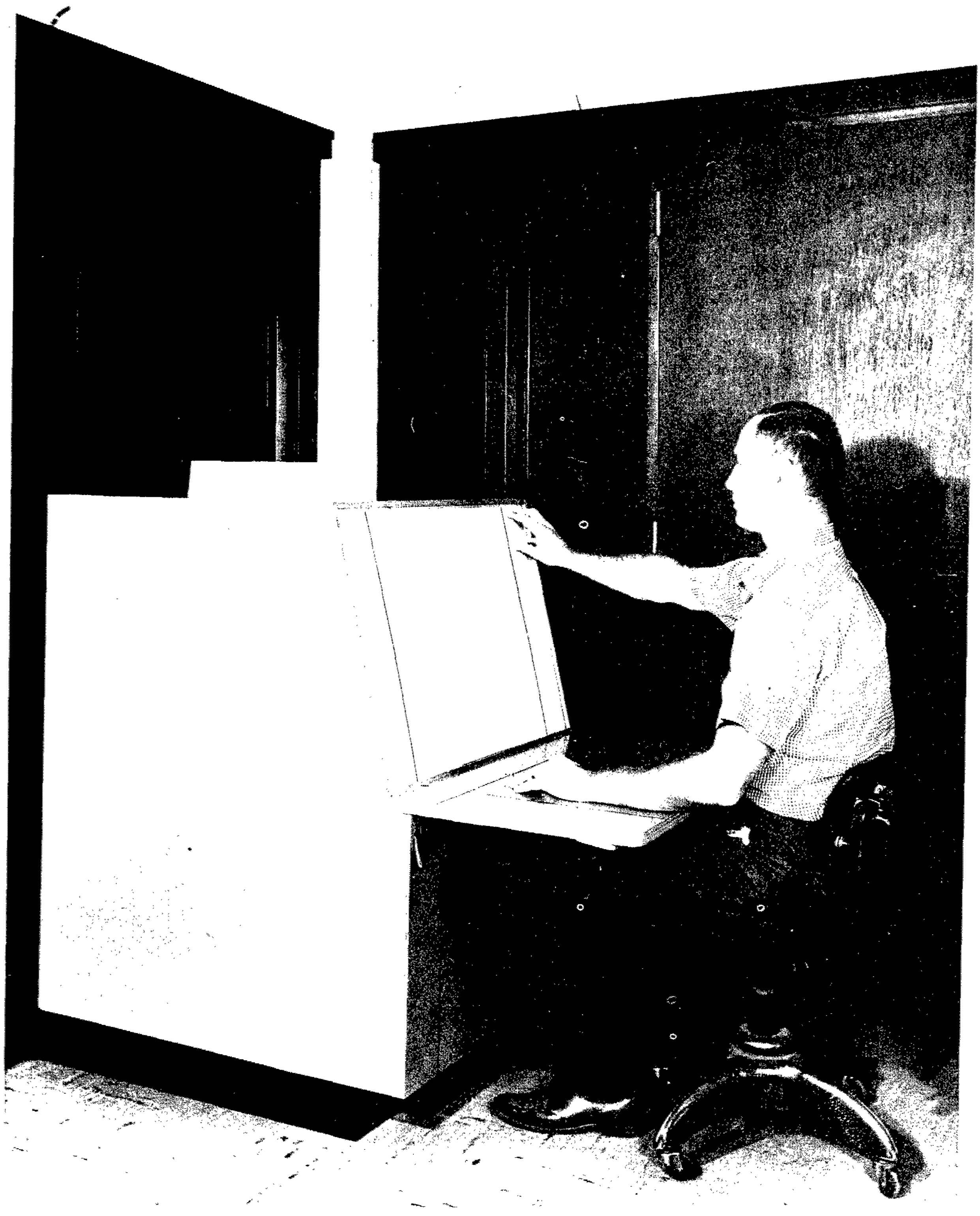

Figure 22. Mockup of the Sit Console with Vision Over (Low Variation) with Seated Operator of Relatively Large Size. The larger operator has sufficient knee space below the writing-working surface. Chair height is 18 inches.

SECTION V

Components

Since all consoles are based on the Sit-Stand configuration and basic positional relationships between the operator and the display panel are maintained throughout all designs, a logical procedure is to determine the minimum number of components from which all consoles can be assembled. Instituting the manufacture of such components rather than complete console shells would make possible a high level of flexibility in console utilization. Under such a plan the manufacturer could, on order, fabricate and ship the components. After receipt of the components, they would be assembled into the required consoles. On-site reassembly into different consoles and console arrangements would be convenient.

There are at least two approaches in breaking down the consoles into components. In one approach, the smallest console may be considered the basic component. This approach is illustrated in fig. 23. For convenient reference we will call this the first component series. One console could conceivably consist of all components. Starting with the Stand Console without Vision Over, the components can be developed in the manner shown in fig. 23(a). The remaining consoles would be assembled as shown in fig. 23(b), (c), (d), and (e).

An alternate and more convenient approach to the component concept is to design them so that the individual console will consist of only two major parts. This can be achieved by dividing each console into two components. The division can be at either the upper or lower edge of the writing surface. Five components will be needed to assemble all types of consoles. They are: (A) the upper half of the Sit-Stand Console, (B) the lower half of the Sit-Stand Console, (C) the upper half of either Sit Console with Vision Over, (D) the lower half of either Low Variation Sit Console, and (E) the upper half of the Stand Console without Vision Over. We shall call this the second component series. Figure 24 illustrates the various types assembled from these components.

When it is necessary to provide a console with casters and leveling legs, two approaches may be considered: (1) a permanent installation and (2) a temporary installation. First we shall consider the requirements of permanently installed equipment with each series of components.

Permanently attached wheels and leveling legs would be installed directly into the base of the console, that is, into component E of the first series (fig. 23) or into components B and D of the secone series (fig. 24). The vertical space available in component E of the first series is probably not sufficient to contain all the necessary hardware associated with raising and lowering wheels and leveling legs and to provide adequate support for the console. Combining components E and D of the first series would provide a component with ample space, but one that could not be used with any of the Low Variations of the Sit Consoles. Permanently attached wheels and leveling legs with regard to the first series, then, is impractical.

Permanent installation of wheels and leveling legs into the base of components B and D of the second series appears to be possible, without undue encroachment of space below the writing leaf. It

Figure 23. Console Components: Series 1. Component C is the basic component. Others are added as required to assemble the larger consoles. The Stand Console without Vision Over requires all components. The Sit-Stand Console is equivalent to the Sit Console without Vision Over and the Stand Console with Vision Over.

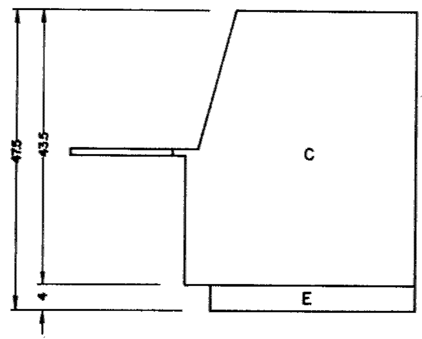

Figure 23(c)

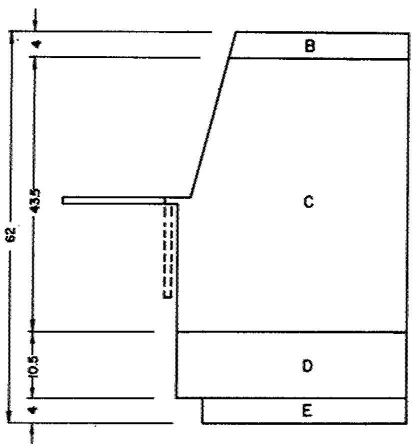

Figure 23(a)

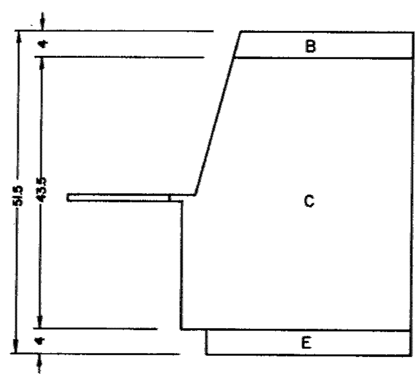

Figure 23(d)

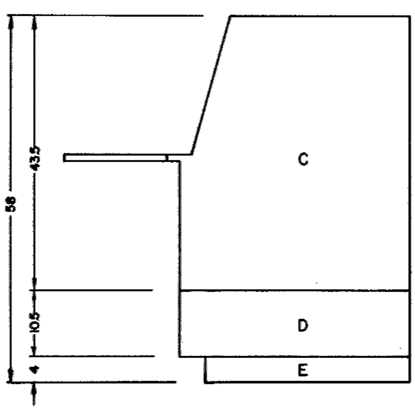

Figure 23(b)

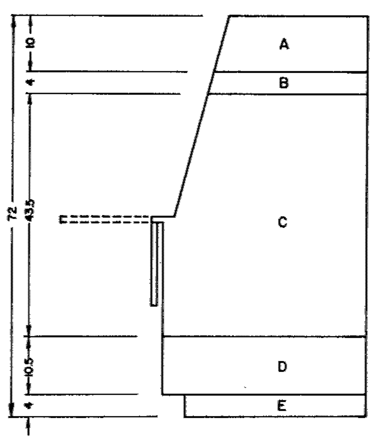

Figure 23(e)

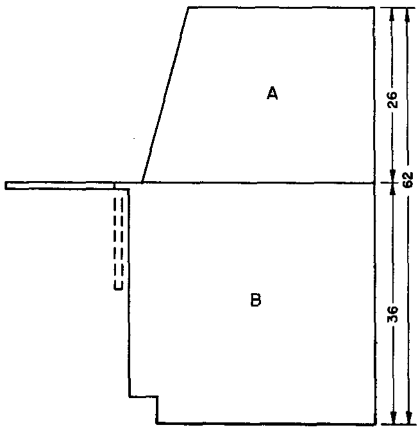

Figure 24(a)

Figure 24. Console Components: Series 2. These components were derived by dividing each console at the level of the writing leaf. Five components are thus created.

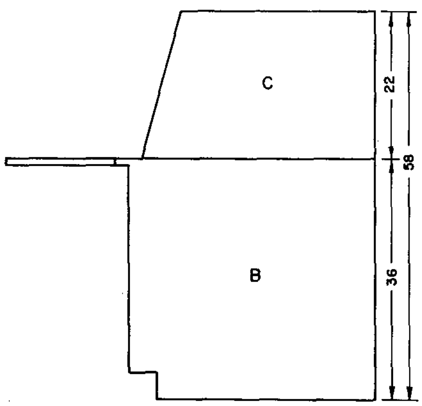

Figure 24(b)

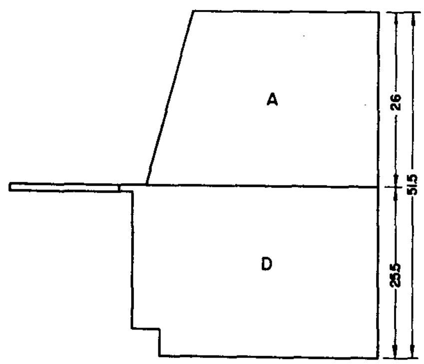

Figure 24(d)

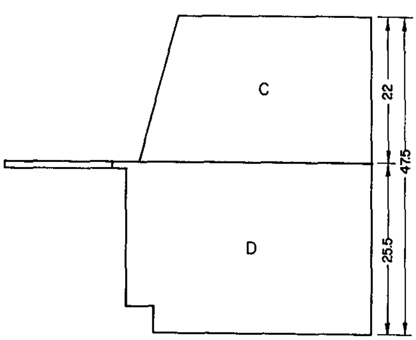

Figure 24(c)

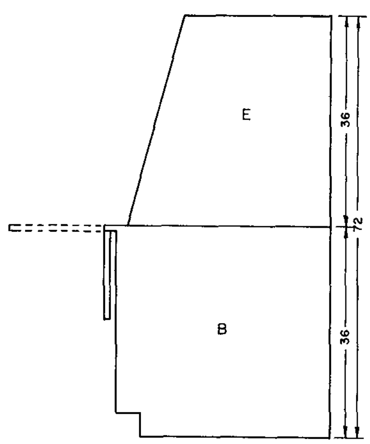

Figure 24(e)

would be convenient to modify the profile of the console to the extent of removing the toe space of components B and D (that space which is equivalent to component E of the first series).

Temporary installation of wheels and legs precludes the use of pallets. Unless we are willing to use at least two pallet designs, this approach is impractical when used with the components of the first series for the same reasons cited above with regard to leveling legs and wheels. Pallets can, however, be used in association with the second series. A single, minimum-height pallet could be used with all components. By using such a pallet, available space below the writing surface will likely be sufficient, but would not be so great as with a permanent installation. With the addition of a pallet, the number of components in the second series is increased to six. The heights of components D and E would be reduced by the amount equal to the height of the pallet with wheels extended. Useful space could be made available within the pallet. If possible, it should be continuous with those spaces within components B and D.

It is possible that in some situations pallets may be used as essentially permanent parts of the console. In others they may be removed. If there is no assurance the one or the other will be universally practiced, platforms of suitable height must be made available for use when the pallets are removed. This, in effect, adds a seventh component to this series. If the pallet is to remain a permanent attachment to the console, the platform, of course, is unnecessary. It appears that it would be more economical in manufacturing costs and console assembly time to install the wheels and legs directly into the body of the console.

There are a number of advantages in using component series two. Since in most cases, the number of components per console is smaller, the manufacturing cost per console is likely to be less. With only two major components per console, assembling will be more convenient. Integration of only two components is likely to be more successful than 5 to 7 components.

THE SEAT

Visual and reach accommodation of both the seated and standing operator must be assured. Since the standing operator will not usually change the vertical distance from his eye to the floor, his position with respect to the console is controlled in this dimension. The distance between the seated operator's eyes and the floor is subject to a moderate amount of manipulation since this distance depends on the height of the seat. To assure equivalent accommodation for each position, it is necessary that the seat be 6.5 inches below the underside of the writing leaf. For the Sit Consoles (Low Variations), it is 18 inches above the floor. The 28.5-inch chair, however, is too high to permit the operator to rest his feet comfortably on the floor. A heel-catch is, therefore required and should be attached to the seat so that, with seat adjustment, it remains at a distance of 18 inches below the seat. A minimum of 4 inches of seat height adjustability will be required: 16 to 20 inches for the 18-inch chair and from 26.5 to 30.5 inches for the 28.5-inch chair. The Seat Reference Point (SRP) should lie about 8.25 inches in front of and 6.5 inches below the underside of the writing leaf when the seat is at the midpoint of adjustability. The back should slope away from the front of the console at about 13° from vertical. The seat-back should provide support for the operator's back at least from about the second lumbar vertebra to the 10th thoracic vertebra.

Arm supports can cause a problem. If they are too long, they can butt against the writing leaf and prevent the operator from placing the chair into the correct position relative to the console. To avoid this, arm rests should not extend more than 8.25 inches forward from SRP. This will enable the operator to bring himself and his chair into proper relationship to the console and yet provide him with the convenience of an arm rest when relaxed against the back of the seat. The arm rest should be 9 inches above the seat. When assuming the alert position, the operator will break contact with the back of the chair and assume an upright sitting posture. In this position, he will not require the use of the chair's arm rest, but can rest his forearms and hands on the writing leaf. The arm rest should not interfere with the use of the writing leaf.

SECTION VI

Inter-Console Compatibility and Console Grouping

By maintaining essentially the same spatial relationships between the operator and the display panel for each console, reorientation on the part of the operator is minimized when his attention is transferred from one console to another. Visual and reach capabilities at all levels relative to the operator remain essentially the same for all consoles. Figure 25 illustrates one arrangement of all console types. It is unfortunate that design requirements would not permit elevation of the mean eye position, sitting, to the same level as the mean standing Eye Height. Should this have been possible, reach and visual accommodation would have been identical for any operator whether seated or standing. The necessity for the operator to reorient himself to a different console would have been completely eliminated. Since we have striven for maximum operator accommodation and maximum console utility, which are equally important but often opposing considerations, it was necessary that both be compromised to some extent on occasion to retain the greatest of each.

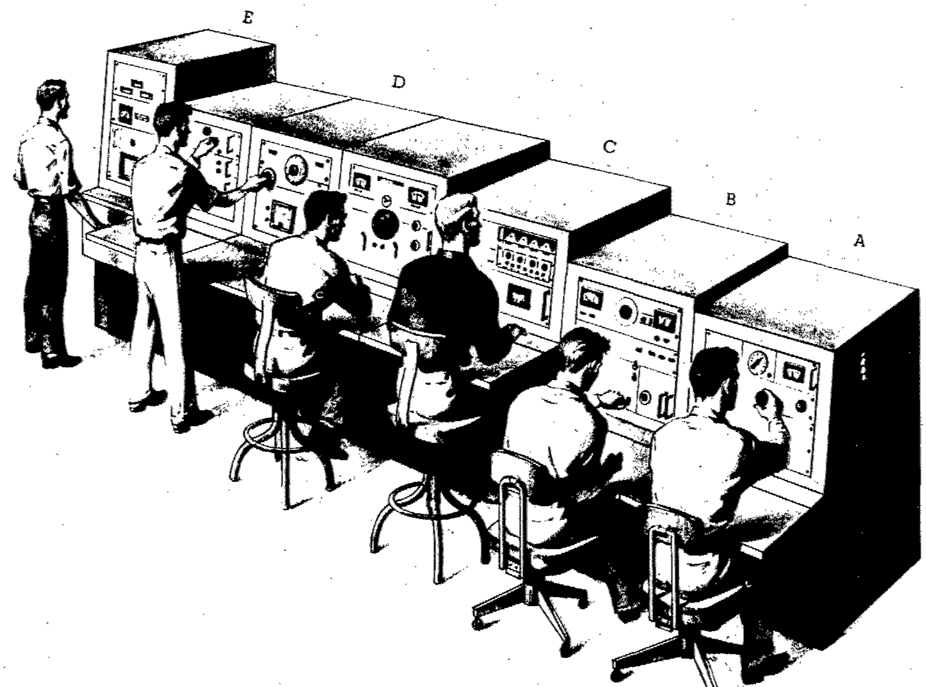

Figure 25. The Five Standard Consoles. At A is the Sit Console with Vision Over (Low Variation), B, the Sit Console without Vision Over (Low Variation), C, the Sit Console with Vision Over (High Variation), D, 3 consecutive Sit-Stand Consoles, and E, a Stand Console without Vision Over. The Sit-Stand Console is repeated to illustrate its flexibility. In the first the technician is monitoring from the seated position. The 2nd and 3rd are both being monitored by a single operator in the standing position.

SECTION VII

Recommendations

Based on experience with standardizing ground support console design within a weapon system and on the design information presented in this report, the following recommendations are made to those responsible for the design of weapon and ground support systems:

1. As soon as possible determine the number of ground crew stations required for the operation, maintenance checkout, etc. of the systems.

2. Define the function to be performed at these crew stations to the greatest detail practical within time and other restraints.

3. Prepare a human performance specification for each crew station including such factors as the length of time the station will be manned, physical environment, importance of function for system success, time stress, etc.

4. Based on the above information, crew station design can be broken down into three classes: (a) Those crew stations requiring tailored design, e.g., wrap-around console for the seated operator, etc., (b) Those crew stations requiring human engineering design attention where a standardized console configuration would be an economy from both a cost and a design effort standpoint, and (c) Those crew stations that will require a minimum of human engineering design attention where standard engineering racks and packaging will suffice. This third category (c) will also include much standard equipment, mobile power coils, etc., for which design is fixed.

5. Standardization on a single console configuration is recommended for the class (b) crew station described above. In the experience of the writers, the basic sit-stand configuration described in this report will prove adequate for most weapon system applications. Mil Standard 803A-1, *Human Engineering Design Criteria for Aerospace Systems and Equipment*, contains summary recommendations for console standardizations and should be consulted prior to implementing any standardized console design.

6. Should a standardized design be developed in lieu of one of those discussed in this report, it is strongly recommended that it be developed to satisfy electronic equipment packaging requirements. Electronic equipment typically imposes the most stringent packaging requirements relative to pneumatic and hydraulic systems, etc.

SECTION VIII

Summary

Manufacturers have supplied the increasing demand for consoles without guidance from specific design standards. As a result, the variety of sizes and shapes of consoles introduced have led to variable levels of accommodation to the capabilities of different sizes of operators. This variability of console designs has undoubtedly been the source of human error generation, since the operator must reorient himself when he is required to transfer his attention from one console to another.

To remedy this situation, console design standards have been evolved specifically to accommodate ranges of body sizes and visual and reach capabilities of the United States Air Force population. From a basic Sit-Stand console configuration, four additional consoles have been developed. Since all have been derived from the same basic form, necessity for the operator to reorient himself is minimized when he transfers his attention from one console to another.

It has been proposed that consoles be assembled from components. Two alternative approaches to unitization have been treated. The recommended approach limits to two the number of components comprising each console. From a total of five such components any of the five recommended consoles may be assembled. Advantages of using the component concept include lower manufacturing costs, less assembly time, and greater flexibility within a system of consoles.

Proper spatial relationship between the seated operator and the console depends upon the configuration of the chair. To assure proper seating, important chair dimensions have been suggested.

Recommendations have been made regarding the design of weapon and ground support consoles.

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13. ABSTRACT

Experience gained in using a single standardized ground-support console configuration in the WS 131-B, Hound Dog, is discussed. Other ground console designs for possible standardization in future systems are described in detail. All designs are derived from a basic sit-stand configuration and will accommodate approximately 95% of the USAF male population and approximately 60% of the USAF female population. Each of the consoles can be made from five standard subassemblies. The suggested standard configurations permit engineering design freedom, yet restrict certain dimensional characteristics of the consoles to assure accommodation to the requirements and capabilities of the operator.

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