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ZERO-G WORKSTATION DESIGN



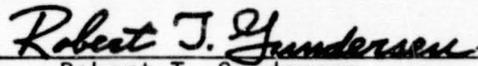
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JUNE 1976

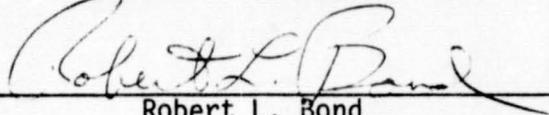
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ZERO-G WORKSTATION DESIGN

PREPARED BY:



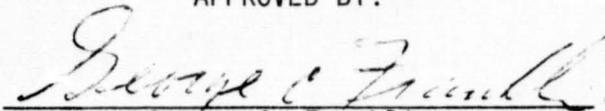
Robert T. Gundersen



Robert L. Bond

Head, Man-Machine Engineering Section

APPROVED BY:



George C. Franklin

Chief, Crew Station Design Branch



Allen J. Louviere

Chief, Spacecraft Design Division

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

JUNE 1976

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1.0 SUMMARY

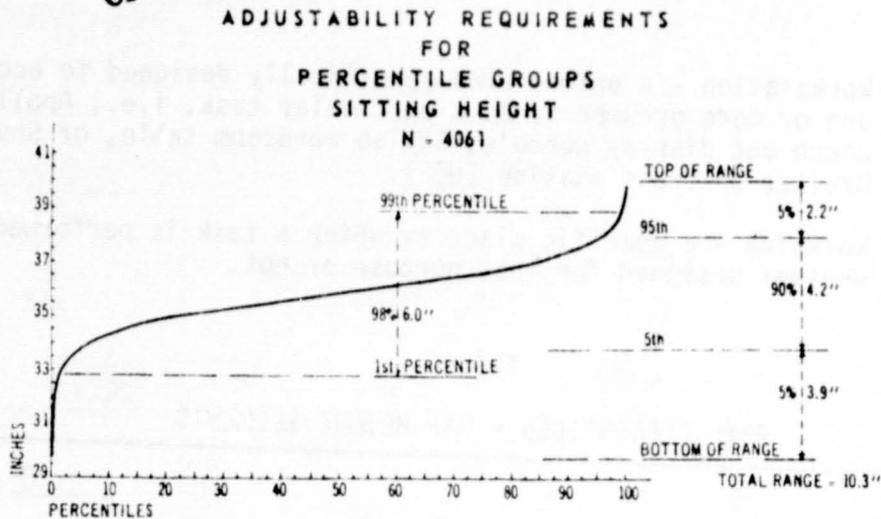
Zero-g workstations have been designed throughout manned spaceflight based on different criteria and requirements for different programs. This report traces the history of design of these workstations, presents a thorough evaluation of selected Skylab workstations (the best zero-g experience available on the subject), and applies the results to on-going and future programs, with special emphasis on the correlation of neutral body posture in zero-g to workstation design. Where selected samples of Shuttle Orbiter workstations are shown as currently designed and compared to experience gained during prior programs in terms of man-machine interface design, the evaluations are done in a generic sense to show the reader the methods of applying evaluative techniques. The Shuttle Program had progressed through a major portion of its design phase prior to the publication of this report, and the numerous programmatic decisions made necessary by cost, weight, volume, and other operational constraints that resulted in the designs shown are not discussed nor are they faulted. This report attempts to establish a path toward optimum design practices in laying out zero-g workstations, it is not an attempt to conduct a design review of products already committed to the manufacturing process.

2.0 INTRODUCTION

This report traces the history of zero-g workstations throughout NASA manned spaceflights. Attention is given to workstations designed to accommodate intravehicular activity (IVA) and to those designed to support extravehicular activity (EVA). The evolution of zero-g workstations is addressed on a program-by-program basis, including the requirements which forced some of the early designs to support more than just zero-g use. Particular attention is given to the Skylab Program and the wealth of experience gained during the more than 12,000 man-hours of flight time accrued during its three missions.

Even though EVA workstations had been designed for Gemini and Apollo spacecraft, IVA zero-g workstation design first became a primary consideration in its own right with the advent of the Skylab Program. Skylab's Orbital Workshop provided U.S. astronauts their first opportunity to traverse through large open volumes and to perform tasks at workstations and functional interfaces which were designed to accommodate a standing posture. It was suspected that man's posture in zero-g differed from his one-g posture, but no particular significance was attached to this phenomenon until long-term and repetitive tasks were undertaken at the standup workstations aboard Skylab. As a result of the interest shown by the Skylab crewmen in the effects of zero-g posture on workstation interfaces, a quantitative definition of the relaxed body posture in zero-g was assembled from inflight data (Reference 1). During the data analysis that led to the definition, many instances were noted where workstation layout seriously influenced the user's posture. User restraint at a workstation is an integral part of this total subject area, and the various means by which Skylab crewmen could restrain themselves has received thorough treatment in a series of previously published reports (References 2, 3, and 4). However, these reports did not address the question of how to optimize the design of future workstations to best accommodate the neutral body posture. Thus, the basic design goal of achieving the highest possible integration between the machine and its operator remains unsettled, and the primary purpose of this report is to openly address that issue and to offer some recommendations on how zero-g workstations might be designed for better user efficiency in future manned spacecraft.

One of the major difficulties associated with workstation design is the dependence upon percentile data to define the range of operators to be accommodated by any given man-machine interface. Percentiles are useful tools to create boundary conditions on a population, but the variability encountered at the extremes of any given distribution may be so great as to account for more of the designer's sizing problem than the major portion of the population. Figure 1 shows the range of variability of sitting height in a group of more than 4061 male subjects. Particular



SITTING HEIGHTS OF 4061 MALES

FIGURE 1

attention is called to the fact that more variation occurs in the extreme 10 percent of the population (upper and lower 5 percent combined) than appears in the remaining 90 percent of the sample. In addition to the variation that appears at the extremes of any population, there are also the segmental differences inherent in each individual that must be considered. That a small or a large individual is nothing more than a miniature or expanded version of the average-sized person is an erroneous assumption. Pure percentile forms are not only unrealized in nature but are statistically impossible as reflected in Table 1 where a stature of 79.6 in. (202 cm) is obtained if the total of all 95th percentile segmental links is taken; this height is about a full foot (30 cm) greater than the 95th percentile for stature and 7.6 in. (19.2 cm) larger than the tallest subject measured.

This report will reflect judicious use of percentile information and will indicate where various situations call for using certain parameters as being most applicable to a specific design problem.

Additionally, since terminology tends to be confusing when not viewed from the same baseline by all readers, for the purposes of this report the following definitions will apply:

- a. Crew station - an overall area or module of a manned spacecraft where multiple crew functions occur; i.e., an entire Gemini cockpit, Apollo Command Module, Skylab Multiple Docking Adapter (MDA), or Shuttle Orbiter Middeck.

- b. Workstation - a unique area specifically designed to accommodate one or more crewmen to do a particular task; i.e., Apollo CM couch and display console, Skylab wardroom table, or Shuttle Orbiter on-orbit station (OOS).
- c. Worksite - a specific place at which a task is performed, whether designed for that purpose or not.

TABLE 1

95th PERCENTILES - WAF HEIGHT SEGMENTS

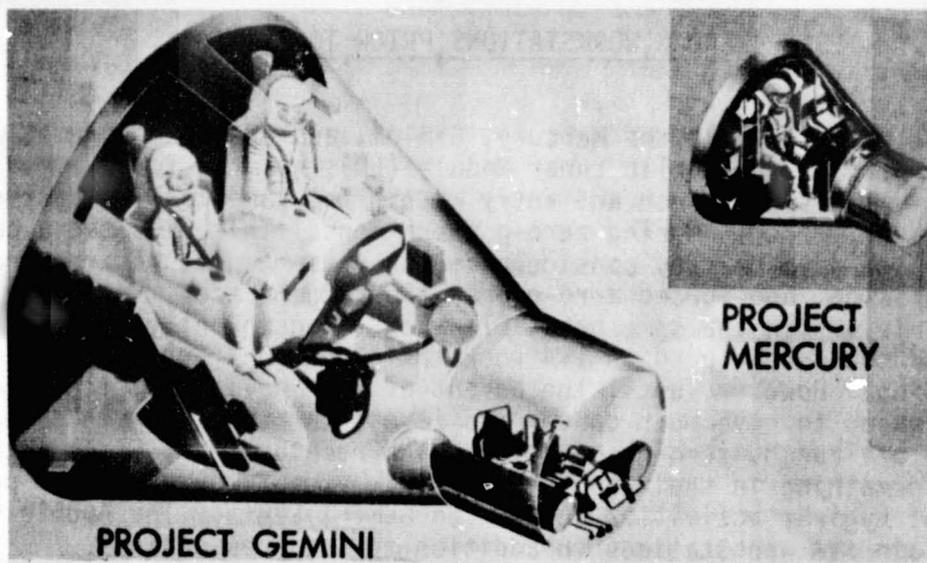
	<u>(cm)</u>
Floor to lateral malleolus level	7.8
Lateral malleolus level to ankle level	6.8
Ankle level to tibiale level	34.4
Tibiale level to gluteal furrow level	34.8
Gluteal furrow level to crotch level	5.1
Crotch level to buttock level	10.5
Buttock level to trochanteric level	3.9
Trochanteric level to abdominal extension level	13.6
Abdominal extension level to waist level	9.7
Waist level to bustpoint level	21.9
Bustpoint level to acromial level	16.8
Acromial level to suprasternale level	2.4
Suprasternale level to cervicale level	9.4
Cervicale level to vertex	<u>25.1</u>
TOTAL	202.2

3.0 ZERO-G WORKSTATIONS PRIOR TO SKYLAB

The spacecraft flown in the Mercury, Gemini, and Apollo Programs, with the exception of the Apollo Lunar Module (LM), all had to accommodate the high-g loads of launch and entry within the same crew compartment which housed the crew during zero-g operations. This dictated a cabin design which gave primary consideration to these two high stress periods of the mission, and forced zero-g operations to be accommodated as well as possible within the same habitable area. Consequently, only limited attention could be placed on IVA workstation design for specific zero-g application. However, until the advent of the Apollo vehicles, there was little reason to give much concern to zero-g workstations since the full sequence of launch, zero-g operations, and recovery took place with the crewmen remaining in their couch restraint, except for brief IVA periods of Gemini hygiene activities and during Gemini EVA's. The Apollo vehicles did contain IVA workstations in addition to the crew couches.

3.1 MERCURY AND GEMINI IVA

The first two NASA manned spaceflight programs were built around small, weight-conscious, volume-restricted vehicles. As shown in Figure 2, the Mercury spacecraft was a solo vehicle offering virtually no freedom to the restrained crewman, and the Gemini spacecraft was a "growth" version of its predecessor which housed two astronauts but offered little more freedom of movement than Mercury. Thus, all workstations were by necessity limited to the reach envelope attainable from the restraint couch. Not until the Apollo Program were IVA zero-g workstations to require design definition beyond that needed to support a couch restrained crewman. However, EVA workstations did come into prominence during the Gemini missions.



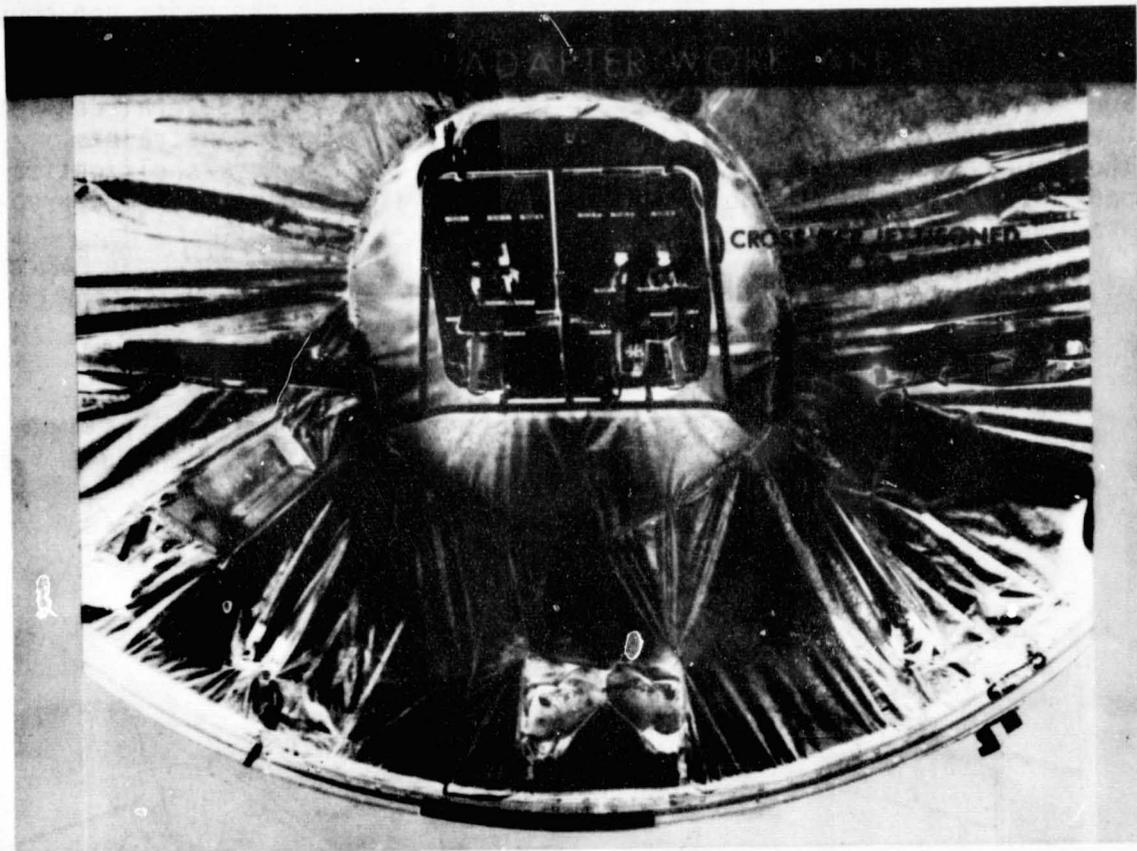
MERCURY AND GEMINI CREW CABINS

FIGURE 2

3.2 GEMINI EVA

During the Gemini IV mission, Astronaut Ed White left the protective confines of the cockpit for a 20-minute excursion into the weightless vacuum outside his spacecraft. In order to harness this new found freedom and render it operationally useful, some method had to be found for restraining the EVA crewman in proper proximity to his job. Three subsequent Gemini mission (IX, X, XI) experienced only partial success of planned EVA tasks. One of the contributing factors to this lack of success was the failure to properly simulate the zero-g environment during training so that the crewman could establish a realistic interface with his work; essentially the creation of a suitable EVA workstation. A regrouping of training, design, and operational planning efforts preceding the Gemini XII mission led to a very successful series of EVA tasks, and the establishing of a number of basic conclusions and recommendations concerning the future application of EVA and the general hardware needed to support such activity. One of the guidelines developed was the need to properly restrain EVA crewmen with respect to the task to be done; i.e., to create an EVA workstation for any assigned task. Figure 3 shows the Gemini XII EVA workstation in the adapter section of the spacecraft. The foot restraints in the lower portion of the adapter properly position the astronaut to perform tasks at the work area located about chest-high, while firmly restraining him in place and leaving both hands free for work. Apollo orbital EVA's employed basic workstation hardware adapted from the Gemini equipment.

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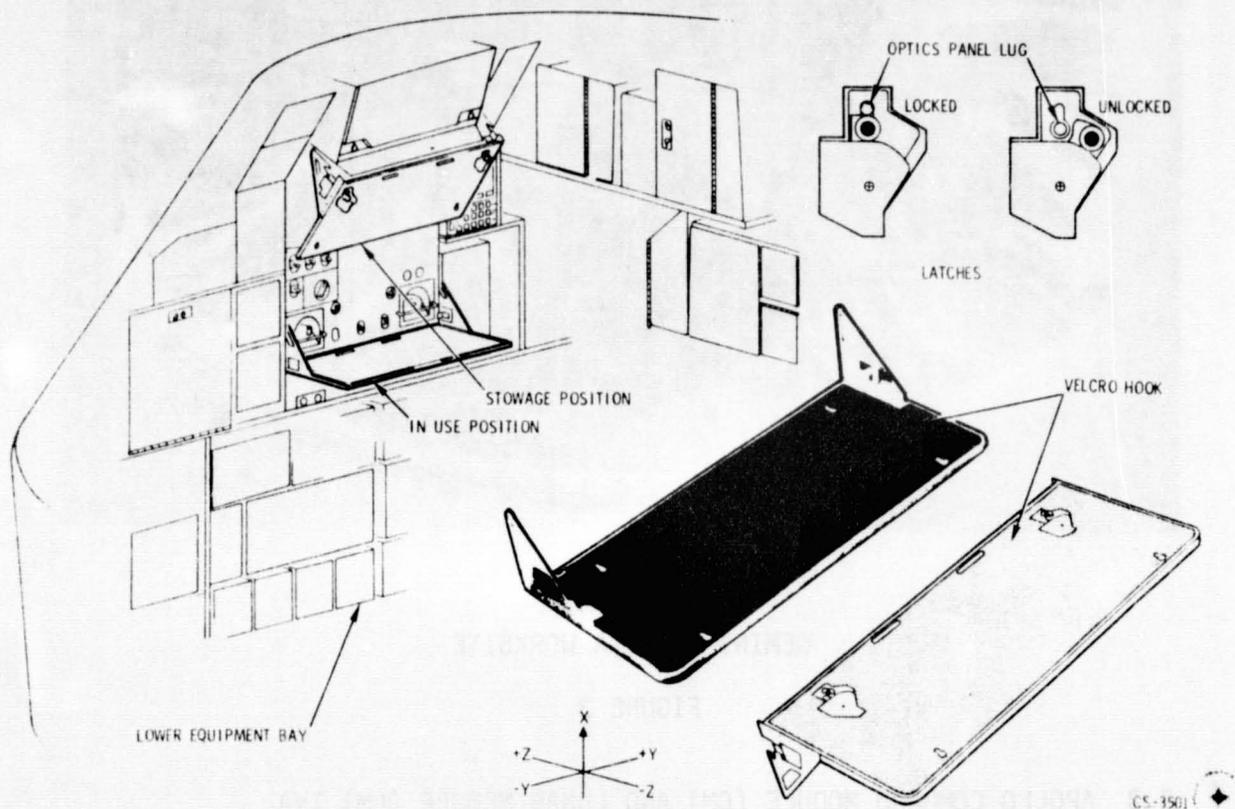
GEMINI XII EVA WORKSITE

FIGURE 3

3.3 APOLLO COMMAND MODULE (CM) AND LUNAR MODULE (LM) IVA

The Apollo manned spacecraft were relatively small volume vehicles compared to Skylab but were a great improvement in IVA free volume compared to the previous programs. For the first time, crewmen were able to translate freely within and between two manned vehicles. This freedom allowed specific workstations to be established at positions other than those reachable from the couch restraints.

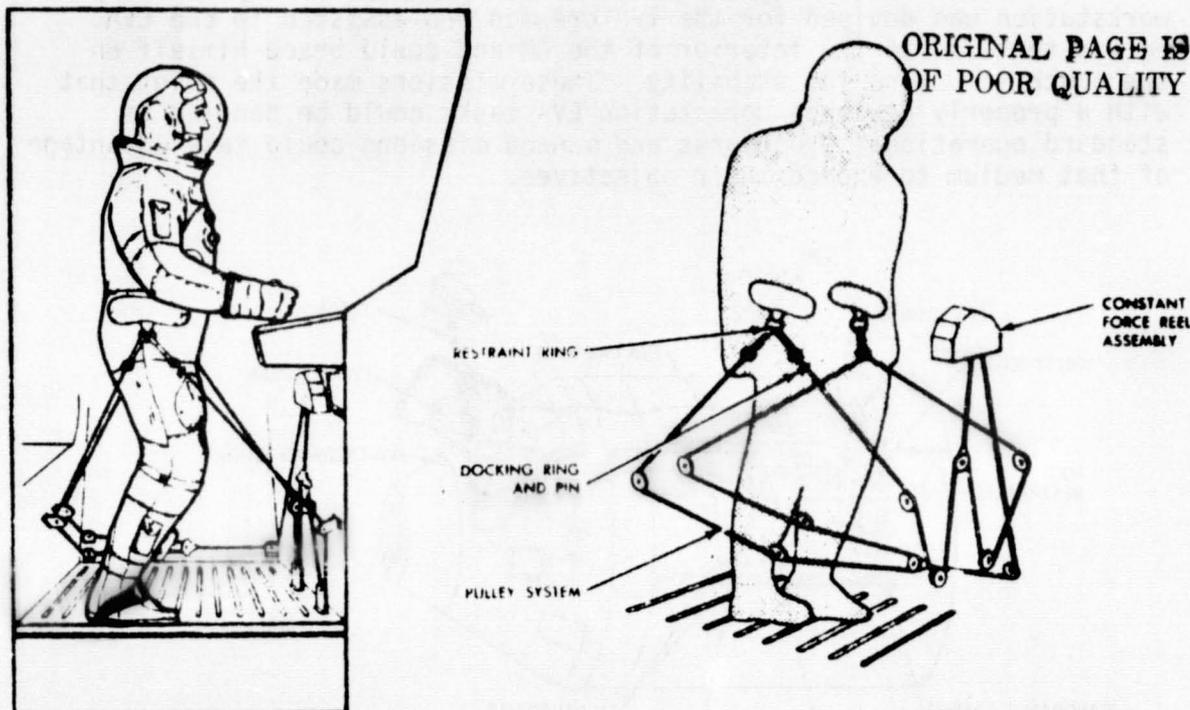
Command Module piloting and systems management were conducted from couch positions. However, the couches could be repositioned from a standard seat to a flat bed or even be completely removed from their mountings and stowed. The CM lower equipment bay was the major non-couch workstation aboard the spacecraft, but the tasks conducted there were performed in such close proximity to adjacent structure that posture and restraint were not considered to be design drivers. Several concepts for IVA restraint were discarded due to cost and weight constraints. The only cabin workstation is shown in Figure 4. The work shelf/optics panel cover provided a table for map or checklist reading and food preparation.



APOLLO CM LOWER EQUIPMENT BAY WORKSITE

FIGURE 4

The LM operations were primarily conducted while suited and attached to the vehicle's cable-type restraint system (see Figure 5). This subject has been thoroughly treated previously in Skylab Experience Bulletin No. 10 (Reference 4). Since the restraint force created a vector toward the floor of the vehicle, the crewmen could react against it to achieve any posture which was desired or required to make the LM zero-g workstation flexible and capable of supporting the piloting and systems management functions required. Once the LM was stationary in the 1/6-g environment of the lunar surface, the entire cabin became a very accessible workstation from a standing posture.



APOLLO LM PILOTING WORKSITE

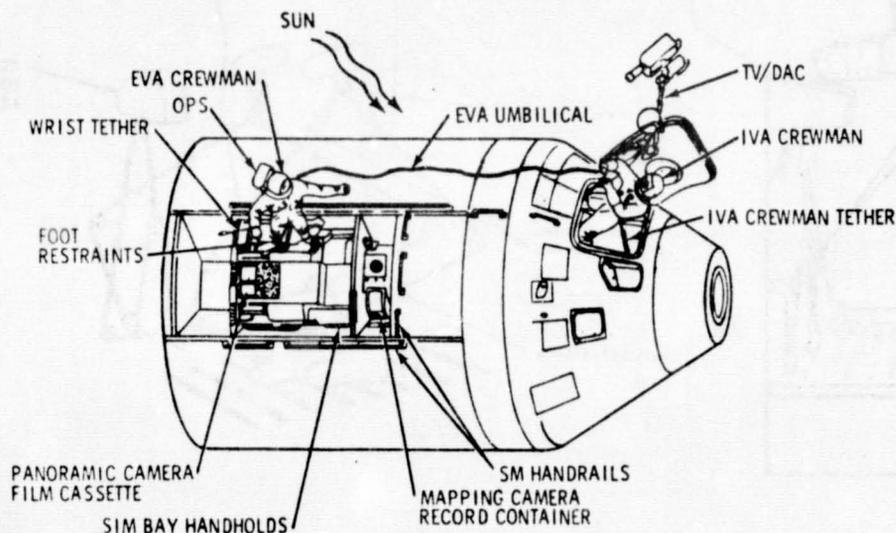
FIGURE 5

3.4 APOLLO SERVICE MODULE (SM) EVA

Early Apollo missions addressed EVA only as a potential contingency mode of transfer between the LM and CM and not as an operational mode of activity. Lunar landing missions, of course, employed 1/6-g EVA's as their prime mode of operation, but not until Apollo 15 did EVA from the

CM become a standard inflight mode of retrieving data from instruments located remote to the cabin. The final three Apollo missions (15, 16, and 17) each used this method to transfer film canisters from the SM to the CM during the trans-earth portion of the flight.

Figure 6 shows the workstation in the SM, which used the Gemini type foot restraint as its basic crew retention device. The workstation was somewhat constrained by the confines of the SM bay within which it was located and the surrounding equipment, but sufficient room was allowed to accomplish the assigned tasks. The retrieval task was designed to be accomplished rather quickly, and the SM workstation was in use for only a few minutes of the 15-20 minute total EVA period. A complementary workstation was devised for the IVA crewman who assisted in the EVA. He was tethered to the interior of the CM and could brace himself on the couch structure for stability. These missions made the point that with a properly designed workstation EVA tasks could be handled as standard operational procedures and manned missions could take advantage of that medium to expand their objectives.



APOLLO SM EVA WORKSTATION

FIGURE 6

4.0 SKYLAB WORKSTATIONS

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4.1 IVA

Much of the interior of Skylab was structured to present a standard one-g environment. Designers retained a "visual gravity vector", i.e., a floor/ceiling one-g reference, in the Orbital Workshop. This convention was not used in the layout of the Multiple Docking Adapter, however, which consisted of an open cylinder arrangement with workstations radiating out from non-symmetrical points within the module. Most facilities aboard Skylab were designed to accommodate a standing one-g posture.

This report will not attempt to cover every individual IVA workstation aboard Skylab but will address at least one of each type in order to assess the adequacy of various classes of functional man-machine interfaces. For the purposes of this report, Skylab was considered to contain four types of IVA workstations: (1) standing, restrained at the feet; (2) seated; (3) free floating; and (4) improvised.

4.1.1 ATM

The ATM workstation aboard Skylab was designed to accommodate either a standing or a seated crewman and consisted of the ATM console, the foot restraint platform, an optional chair-type restraint, and a speaker intercom assembly (SIA). Figure 7 shows the entire ATM workstation. The ATM foot restraint platform was designed to provide crew restraint at the ATM console. The 20-inch wide platform was vertically adjustable to three positions in 6-inch increments (see Figure 8), intended to provide sufficient variation in crewman/console interfaces to meet the standard design criterion of accommodating 5th to 95th percentile males. The platform was designed for use with triangle shoes alone or with a chair. The chair (see Figure 9) was designed and built to provide crewman support during the planned long hours of operating the ATM console, and it was designed with sufficient adjustments to place any of the prime or backup Skylab crewmen at an acceptable design eye point, based on current astronaut anthropometric data at the time (see Figure 10). The ATM console was the most complex scientific control and display device designed for zero-g operation as of its date of flight. It consisted of 1700 sq. in. (10,968 sq cm) of panel space in two planes containing 96 switches and 37 various displays. Long-term monitoring of status displays and visual scenes with potential quick reaction to dynamic situations represented the spectrum of tasks to be supported by the ATM workstation.



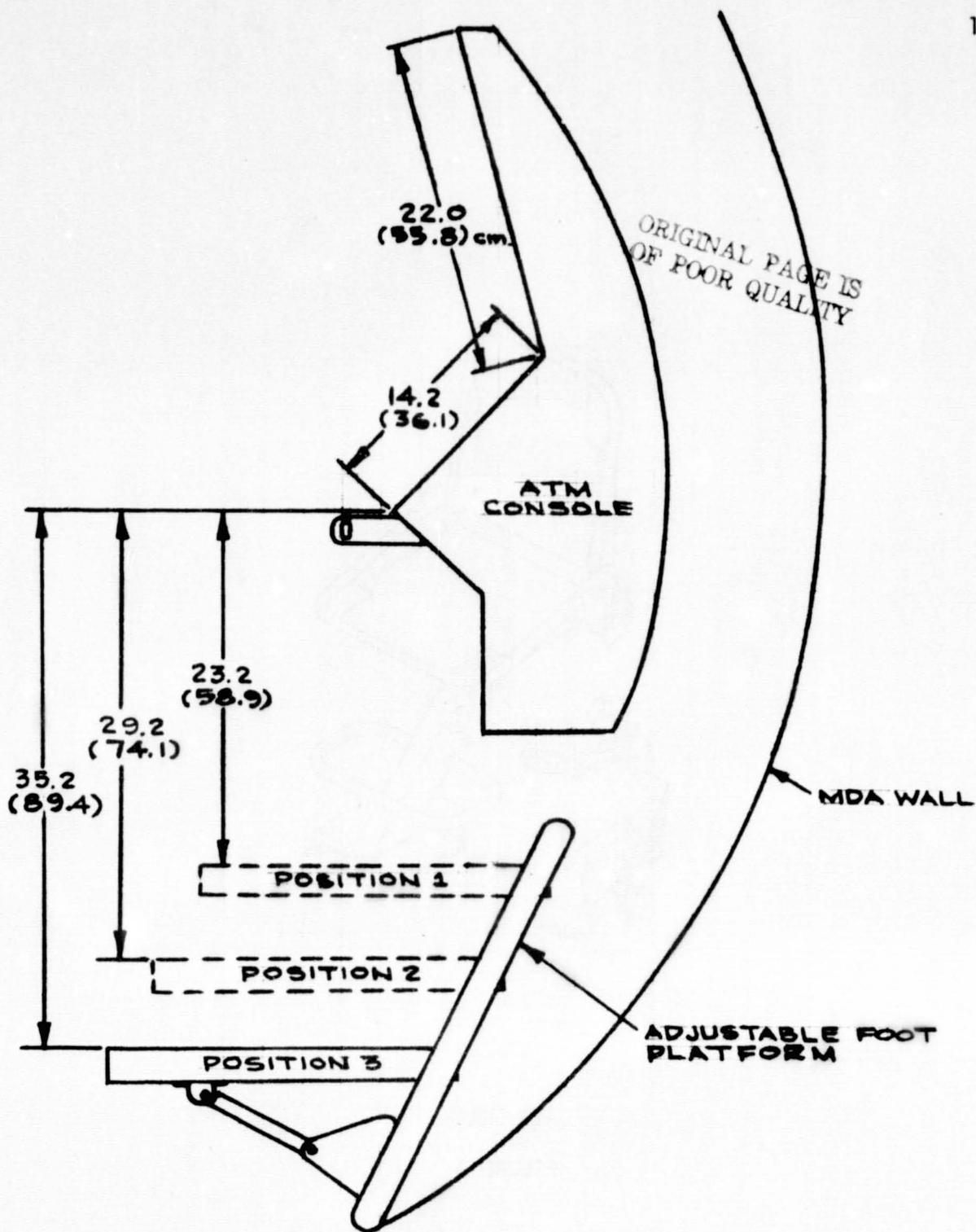
ATM WORKSTATION (SEATED MODE)

FIGURE 7

4.1.2 Scientific Airlock (SAL)

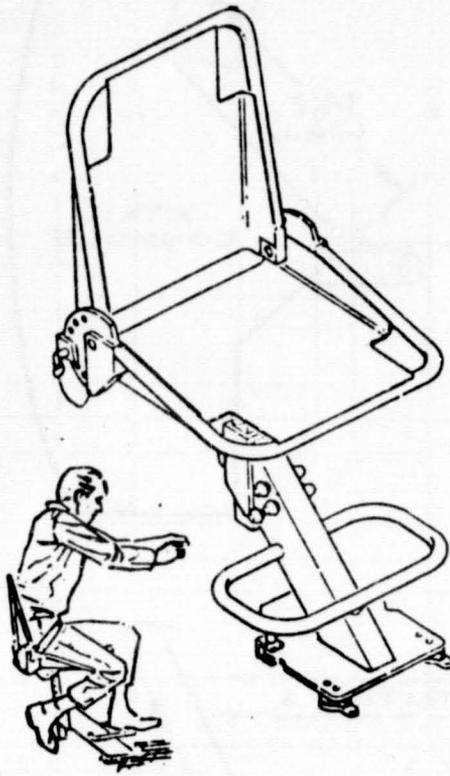
Two scientific airlocks were located in the OWS forward compartments (see Figure 11), one on the solar side (+z) of the vehicle and one on the anti-solar (-z) side. The airlocks were airtight openings in the OWS wall which provided access to space without depressurizing the cabin. They were designed to allow deployment of experiment or operational hardware to a point beyond the meteoroid shield of the OWS. They could also be used as viewing ports for experiment or photographic instruments which did not require extension beyond the outer bulkhead of the vehicle. Figure 12 shows the SAL location with respect to adjacent equipment in the forward compartment. Its position relative to the floor of the compartment [window centerline 43 in. (109 cm) above the floor] dictated

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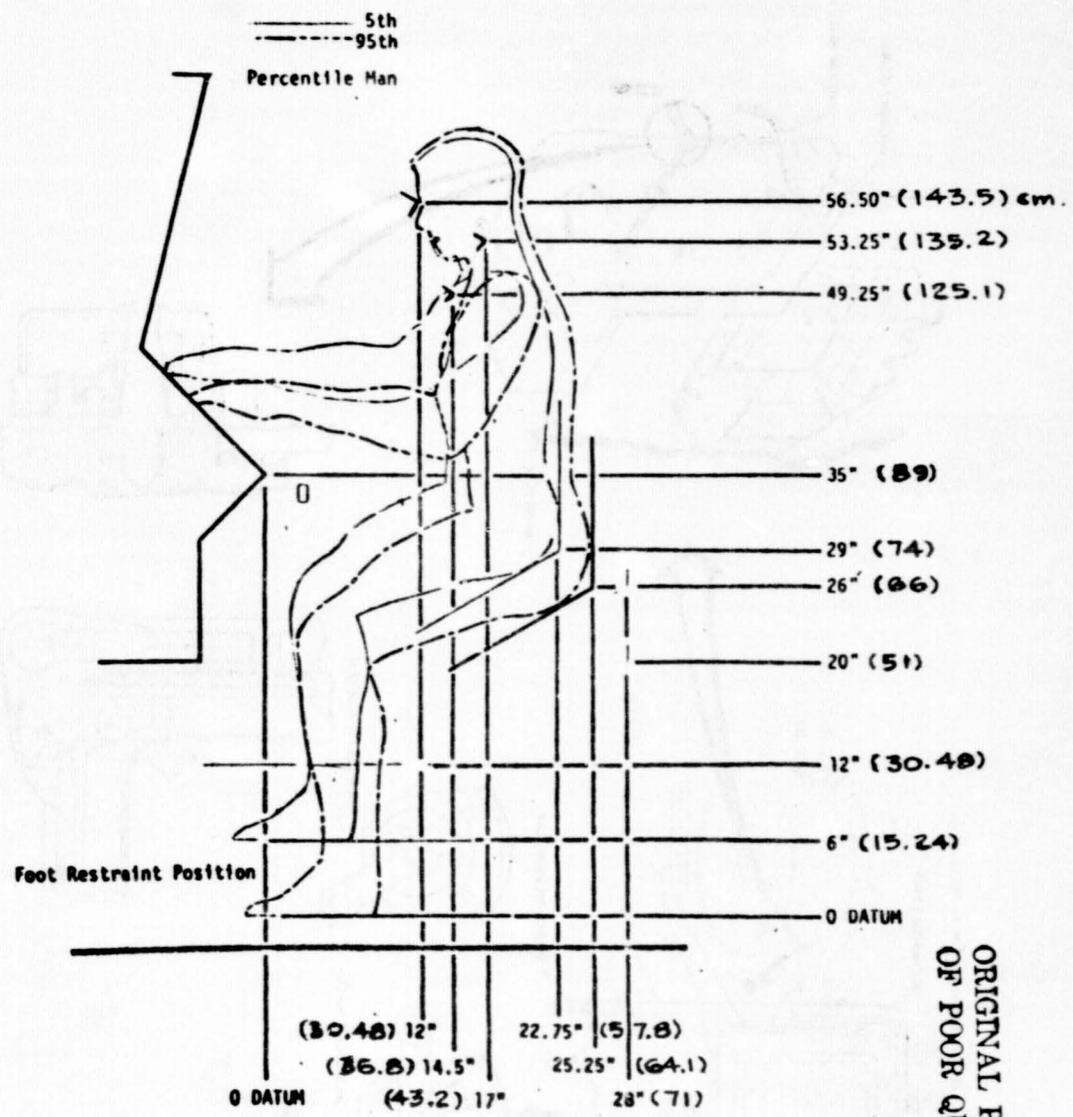
PROFILE DRAWING OF ATM CONSOLE AND FOOT RESTRAINT PLATFORM

FIGURE 8



ATM CHAIR

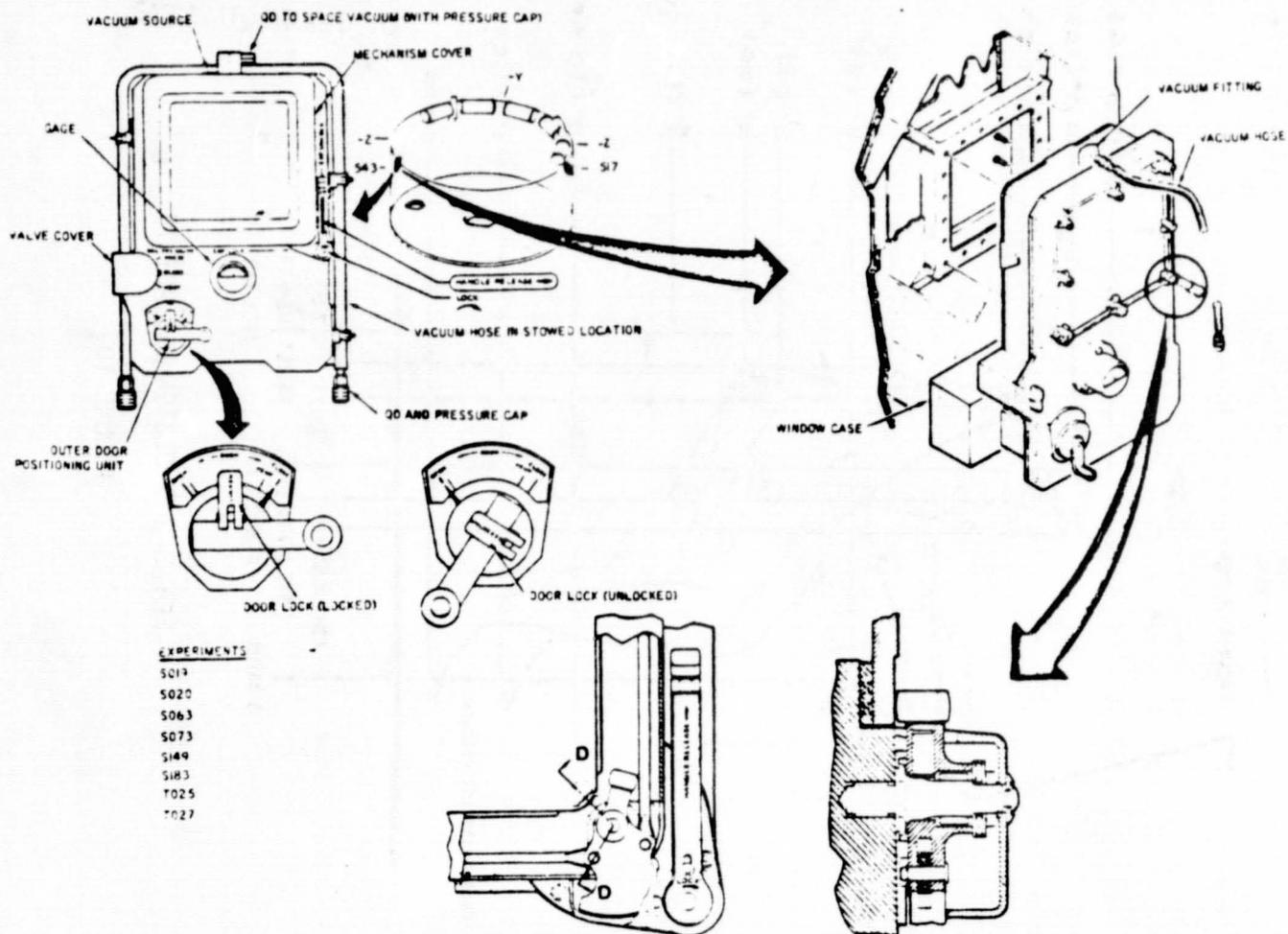
FIGURE 9



SEATED ATM DESIGN EYE POINTS

FIGURE 10

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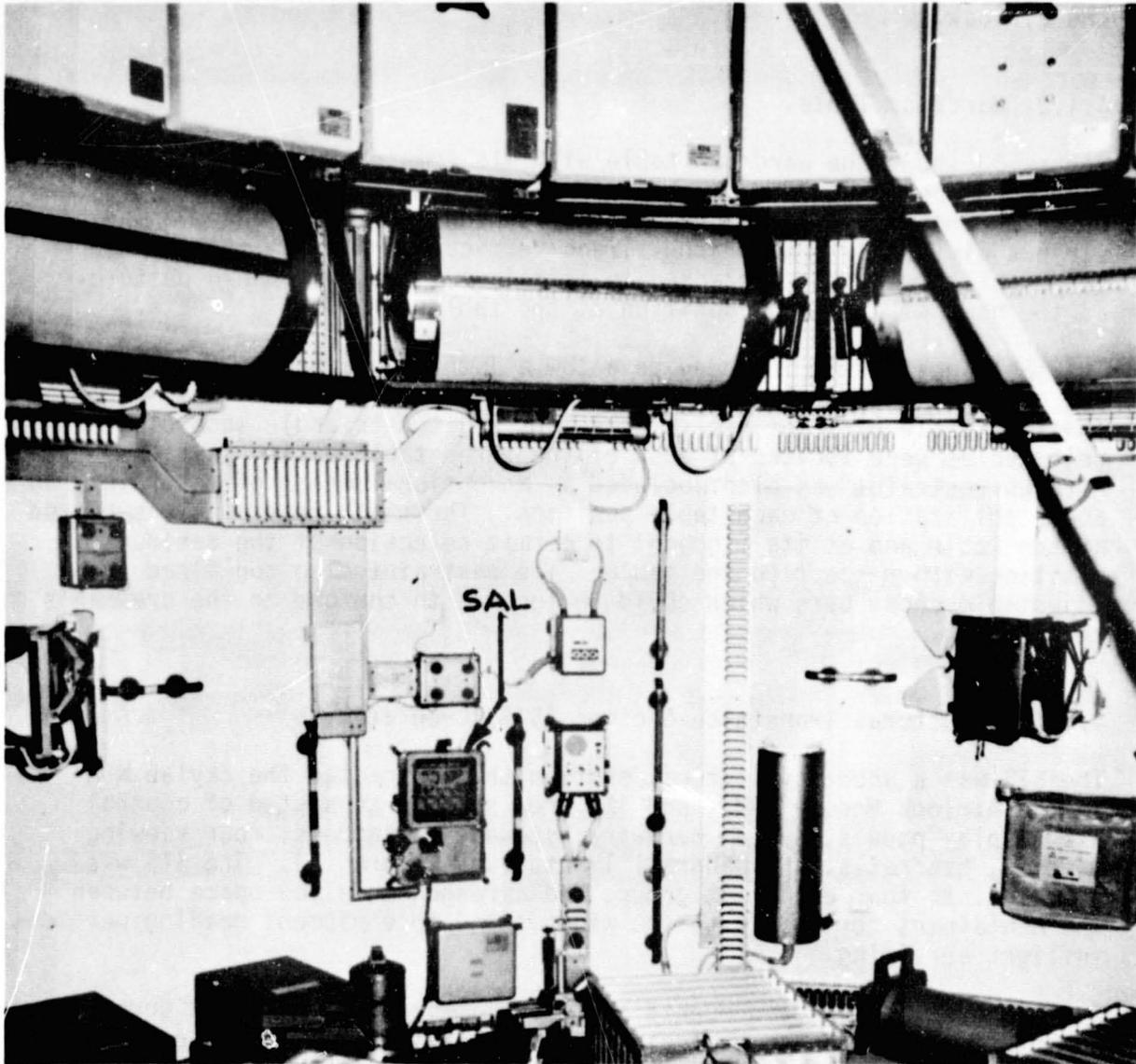
- EXPERIMENTS
- S019
 - S020
 - S063
 - S073
 - S149
 - S183
 - T025
 - T027

SKYLAB SCIENTIFIC AIRLOCK

FIGURE 11

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VIEW OF SCIENTIFIC AIRLOCK IN SKYLAB FORWARD COMPARTMENT

FIGURE 12

that it be used as a standing workstation. This posture was required to maintain restraint contact with the grid floor while inserting, operating, or extracting equipment at the SAL workstation. Handholds (visible in Figure 12) were located on either side of the SAL to provide points for reaction of forces when installing or removing hardware from the airlock.

4.1.3 Wardroom Table

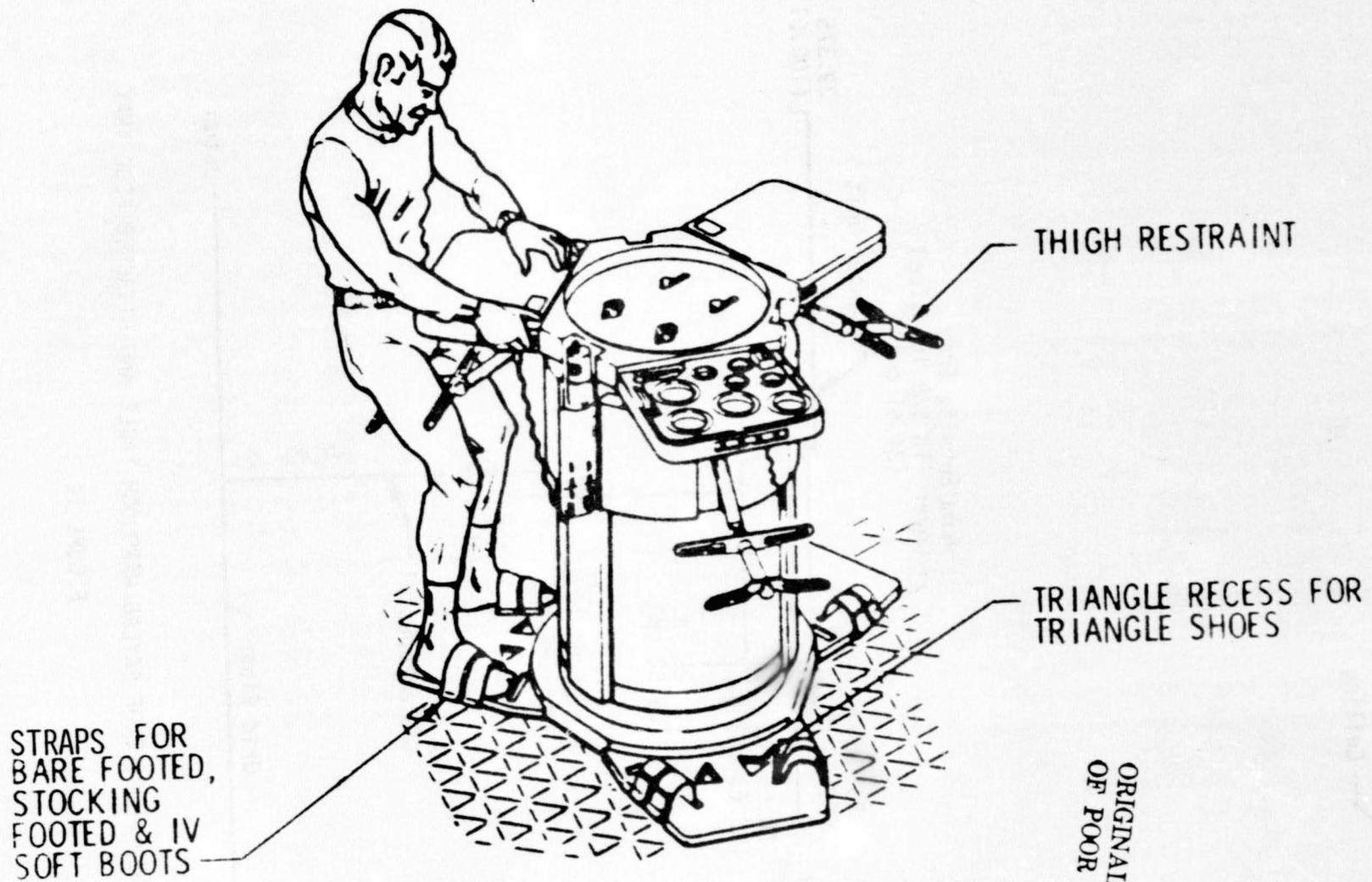
Figure 13 shows the wardroom table with its combination restraint system, capable of being used as a foot restraint alone, a thigh restraint alone, or both concurrently. The dimensional sketch shown in Figure 14 indicates various distances from horizontal and vertical zero datum points. The resultant geometry was intended to establish a standing one-g posture as the nominal operating position at the table.

The table design was intended to allow all three crewmen to prepare and consume their meals together in a comfortable and efficient manner. Two adjustable barefoot restraint straps and two triangle shoe cleat receptacles were located at each of the three table eating stations. A thigh restraint was also included as an optional means of restraint and stabilization at each table position. The thigh restraint was hinged at the table and at its midpoint to permit selection of the desired position with respect to the table. The restraint also contained adjustable cross bars which could be located to conform to the crewman's thigh depth.

4.1.4 Structural Transition Section (STS) Crew Station

The STS was a short cylindrical section that connected the Skylab MDA to the Airlock Module (AM), and its crew station consisted of control and display panels, system hardware, stowage containers, four viewing windows, handrails, and handrail lights (see Figure 15). The STS was divided into four equipment groups and arranged to allow space between the containers for access to the windows and to equipment needing periodic inflight servicing.

The STS crew station represents a prime example of an open and unrestrained workstation, containing handrails to assist in mobility and one-handed retention but no specific restraint devices. The spaces between equipment items were sized to be large enough to provide access for a crewman with ancillary equipment (such as cameras) yet small enough that some body restraint could be obtained by bracing between adjacent equipment surfaces. The installed equipment was arranged so that each module had at least one side exposed as an access to its interior. Such access was required for



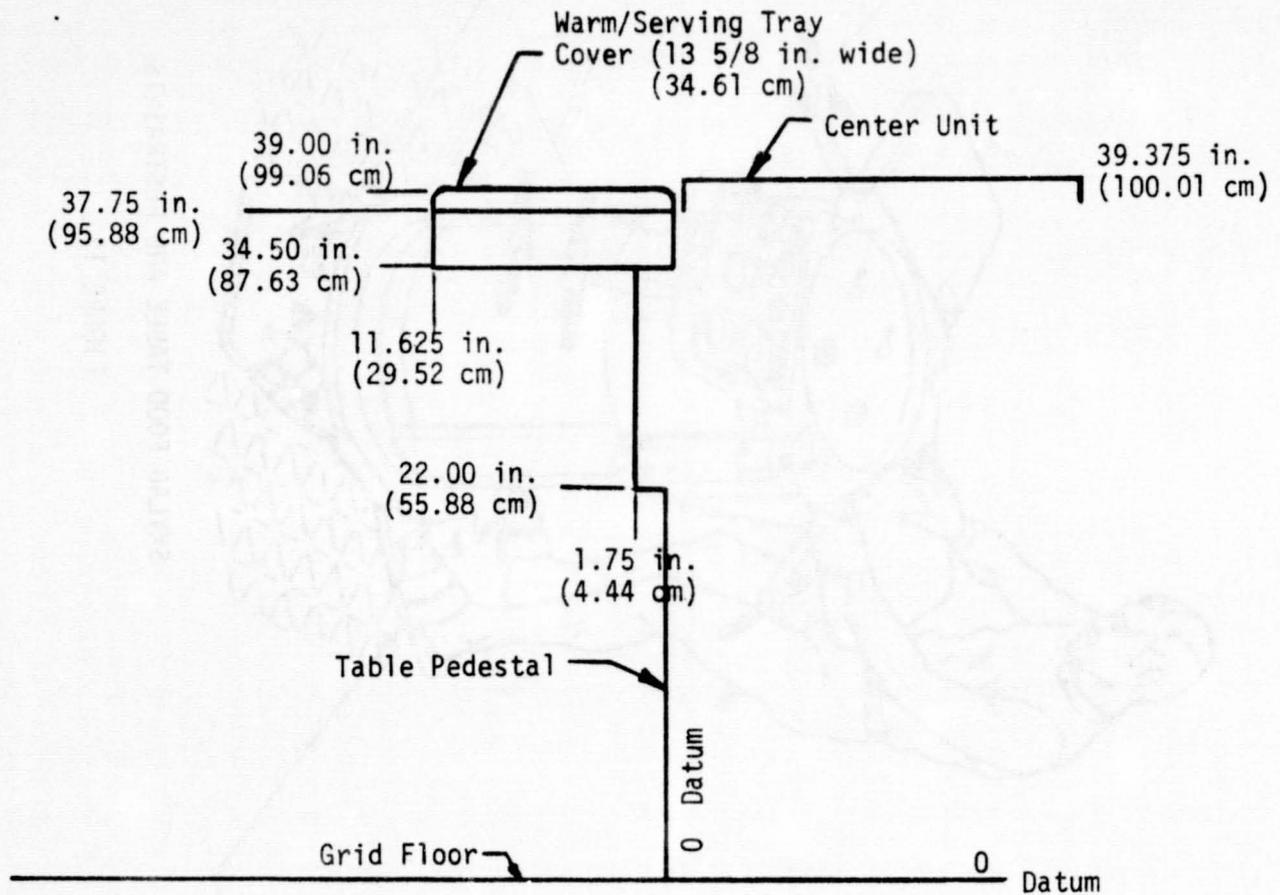
SKYLAB FOOD TABLE AND RESTRAINTS

FIGURE 13

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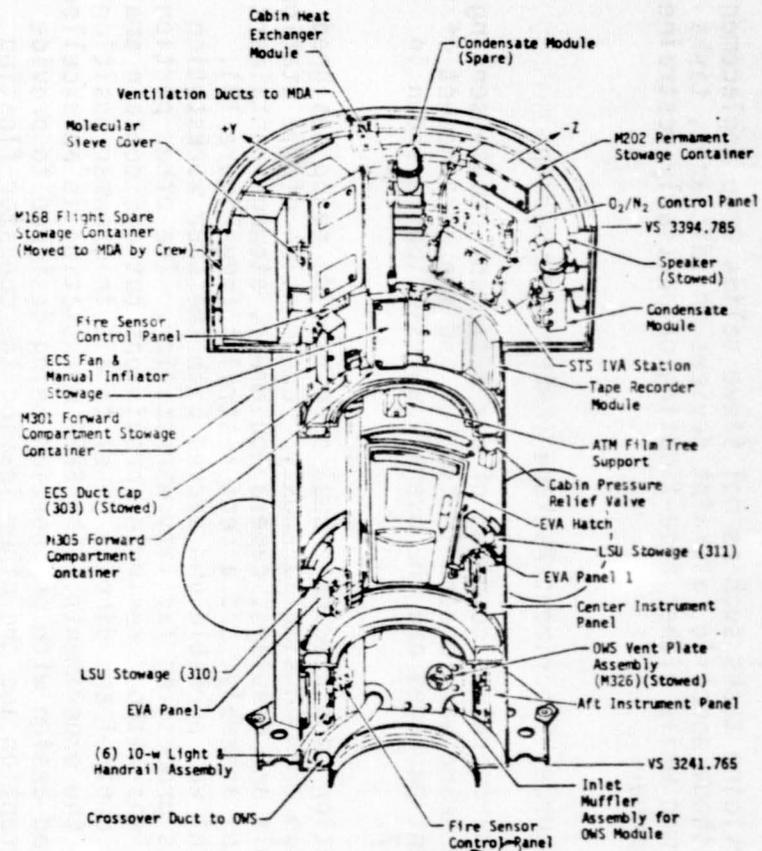
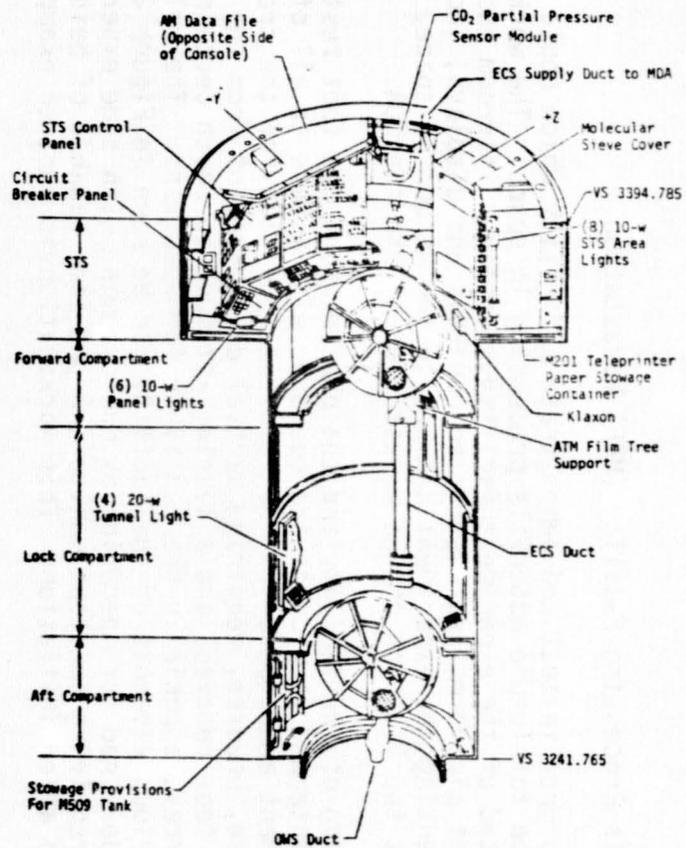
78.534 in.
(189.5 cm)

Ceiling



DIMENSIONED PROFILE OF SKYLAB WARDROOM TABLE AND ATTACHED FOOD TRAY

FIGURE 14



INBOARD PROFILE OF SKYLAB STS/AIRLOCK

FIGURE 15

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the periodic servicing tasks such as mol sieve solids trap replacement. Nevertheless, without specific restraint devices in this area, tasks had to be performed while either free-floating or partially restrained in a makeshift manner.

4.1.5 Earth Resources Experiment Package (EREP) Workstation

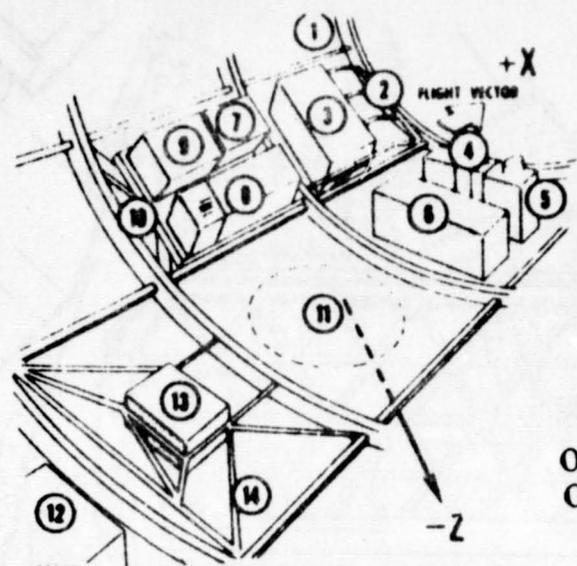
The Skylab EREP hardware was composed of six different remote sensing systems. The hardware was located in the MDA and the arrangement of the various experiment packages and the overall workstation is shown in Figures 16 and 17.

The EREP workstation consisted of a dual side-by-side setup designed to be operated by two crewmen simultaneously. One portion of the station contained controls and displays, camera equipment, stowage containers, a speaker intercom assembly, and a foot restraint (see Figure 18). The foot restraint was portable and served both the EREP workstation and the materials processing facility workstation. The other portion of the EREP station was without restraint provisions but did contain small handholds on the control and display panel to aid in crewman positioning and operation of the experiments. The EREP workstation is an excellent example of a mixed design with one portion being designed to provide positive crew retention and the other leaving the operator floating freely or otherwise occupying part of his attention and energy to maintain stability while operating the hardware.

4.1.6 Materials Processing Facility (MPF) Workstation

The MPF was designed to test and demonstrate a facility which could have application for future materials processing in space. The workstation consisted of the experiment facility, a speaker intercom assembly, a foot restraint platform, and associated controls and displays, including controls for venting the experiment chamber to the vacuum of space. Figure 19 shows the location of the workstation within the MDA.

The wall mounting of the facility and the placement of the foot restraint platform were intended to provide the operator with access to all of the facility equipment and controls. The resultant position for the crewman was a compromise, however, requiring partial disengagement from the restraint (one foot removed) and a leaning attitude to reach certain items of the array, especially the container for specimens. The relationship of the various elements of the facility can be seen in Figure 20. The array was designed for operation by one crewman, with some experiments and processes requiring constant monitoring and some capable of being left unattended after initiation. This workstation is another example



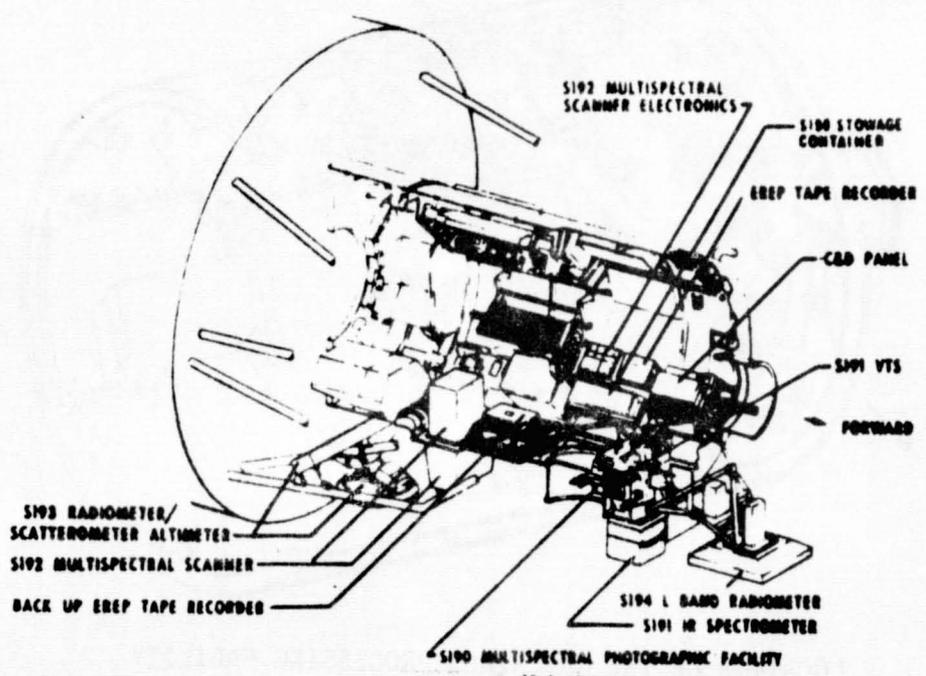
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LEGEND:

- | | |
|-----------------------------|-------------------------------------|
| 1 PWD FRAME-BARREL-DBA | 8 SPOO STORAGE, TAPE STORAGE |
| 2 ESE BACK NO 1 | 9 SPOE ELECTRONICS ASSEMBLY |
| 3 CSD PANEL | 10 ESE BACK NO 2 |
| 4 H SPECTROMETER ELEC | 11 DOCKING PORT |
| 5 VIEWUNDER/TRACKING SYSTEM | 12 MULTISPECTRAL SCANNER (INTERNAL) |
| 6 SPOO | 13 BACKUP TAPE RECORDER |
| 7 TAPE RECORDER | 14 BACKUP TAPE RECORDER SUPPORT |

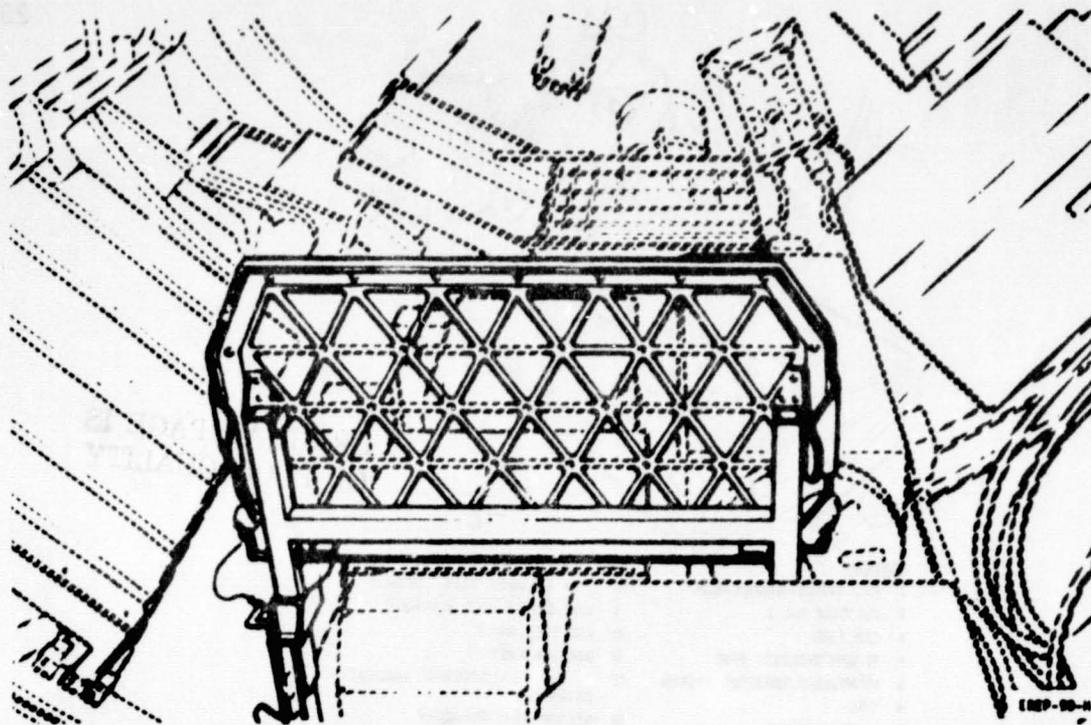
EREP LAYOUT

FIGURE 16



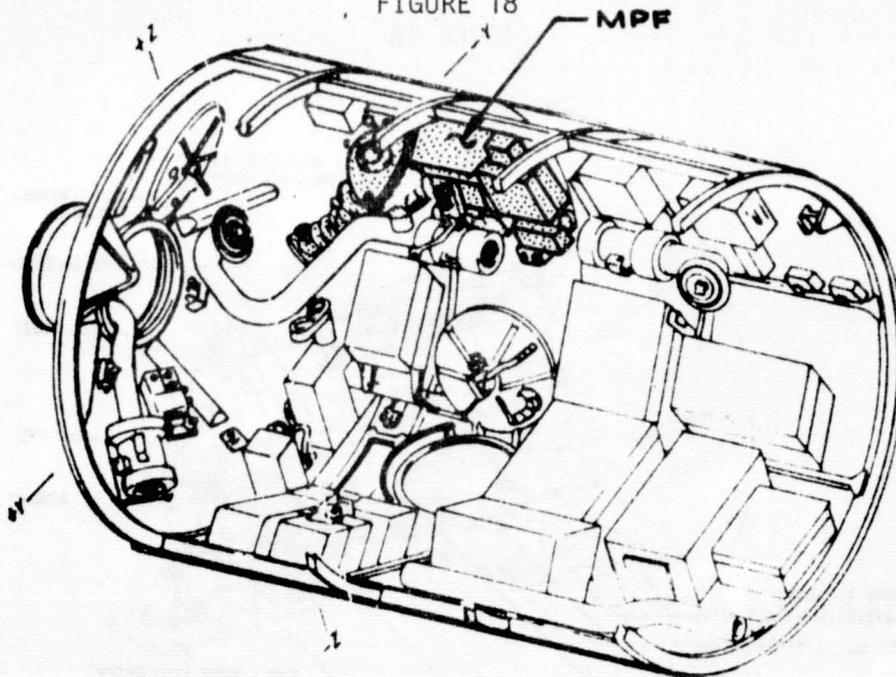
EREP WORKSTATION

FIGURE 17



EREP FOOT RESTRAINT

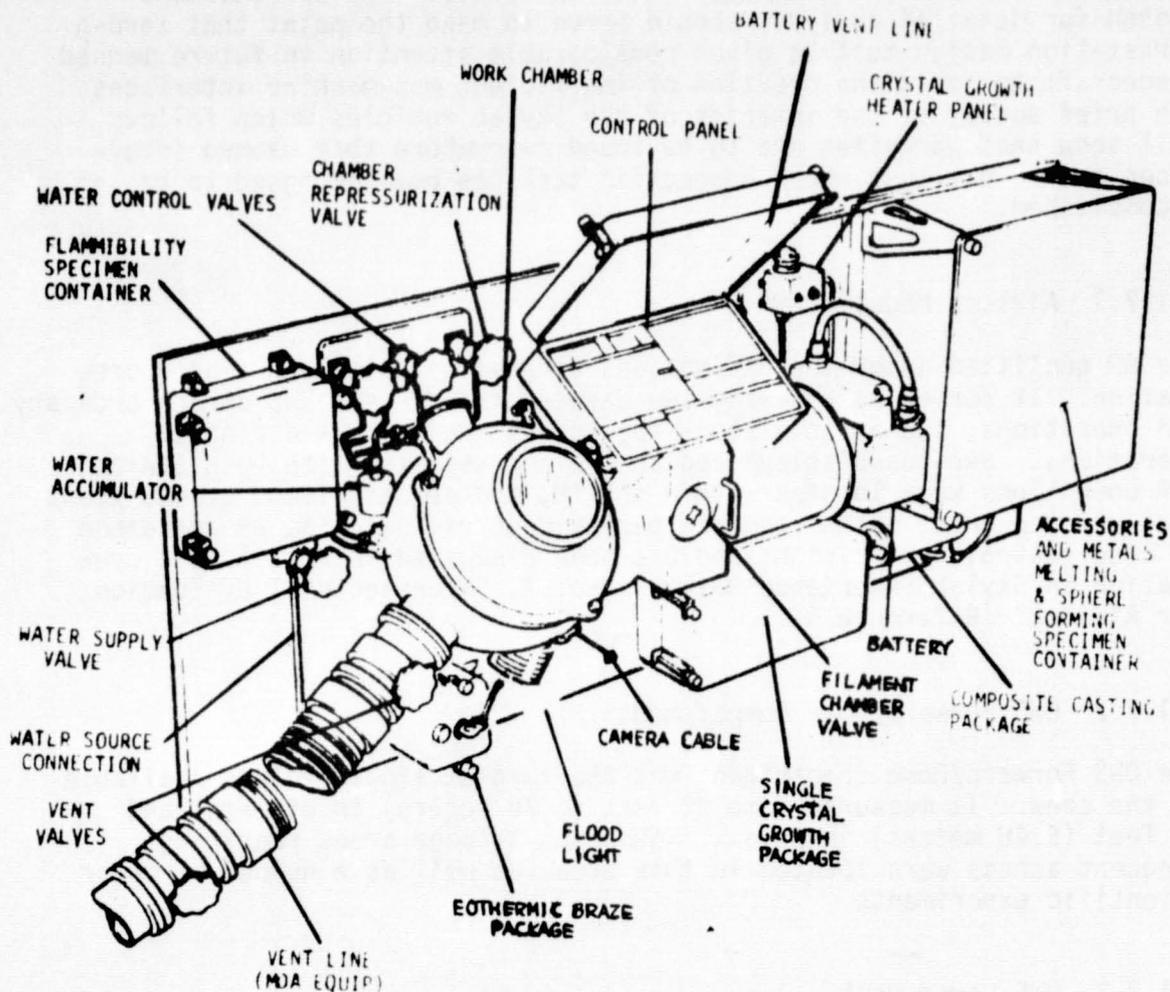
FIGURE 18



LOCATION OF THE MATERIALS PROCESSING FACILITY

FIGURE 19

of a standup workstation requiring two-handed manipulation of multiple piece parts as well as operation of controls and displays.



MATERIALS PROCESSING FACILITY

FIGURE 20

4.1.7 Other Skylab IVA Workstations

The preceding six sections of this report have addressed specific Skylab IVA workstations which were designed for repetitive and sometimes long-term use. These areas will be given thorough evaluation and analysis in the following sections to provide the reader with an appreciation of

their design adequacy and the reaction that their functional utility drew from various crewmembers. There were numerous other areas throughout the Skylab modules that served as IVA workstations on one occasion or another, but in the interest of conciseness they will only be mentioned in passing and not evaluated in detail. The workstations chosen for detailed analysis should serve to make the point that zero-g workstation design must be given considerable attention in future manned spacecraft to avoid the creation of inefficient man-machine interfaces. The brief survey of the interior of the Skylab vehicles which follows will show that worksites are to be found everywhere that manned interfaces occur, not just where a specific task has been designed to be accomplished.

4.1.7.1 Airlock Module (AM)

The AM qualified under the definitions offered by this report as a crew station. It served as a passageway between the MDA and OWS during ordinary IVA operations, and as an airlock for egress and ingress during EVA operations. Various displays and controls associated with both EVA and IVA operations were located within the AM, and certain items of equipment were mounted there which required periodic servicing. The AM contained no crew restraint provisions and has been discussed in detail as a crew station in Skylab Experience Bulletin No. 2, "Architectural Evaluation for Airlock" (Reference 5).

4.1.7.2 OWS Forward/Dome Compartment

The OWS Forward/Dome Compartment was the largest single volume available to the crew. It measured some 22 feet (6.70 meters) in diameter and 18 feet (5.48 meters) in height. Numerous stowage areas requiring frequent access were located in this area, as well as a number of major scientific experiments.

4.1.7.3 OWS Lower Deck

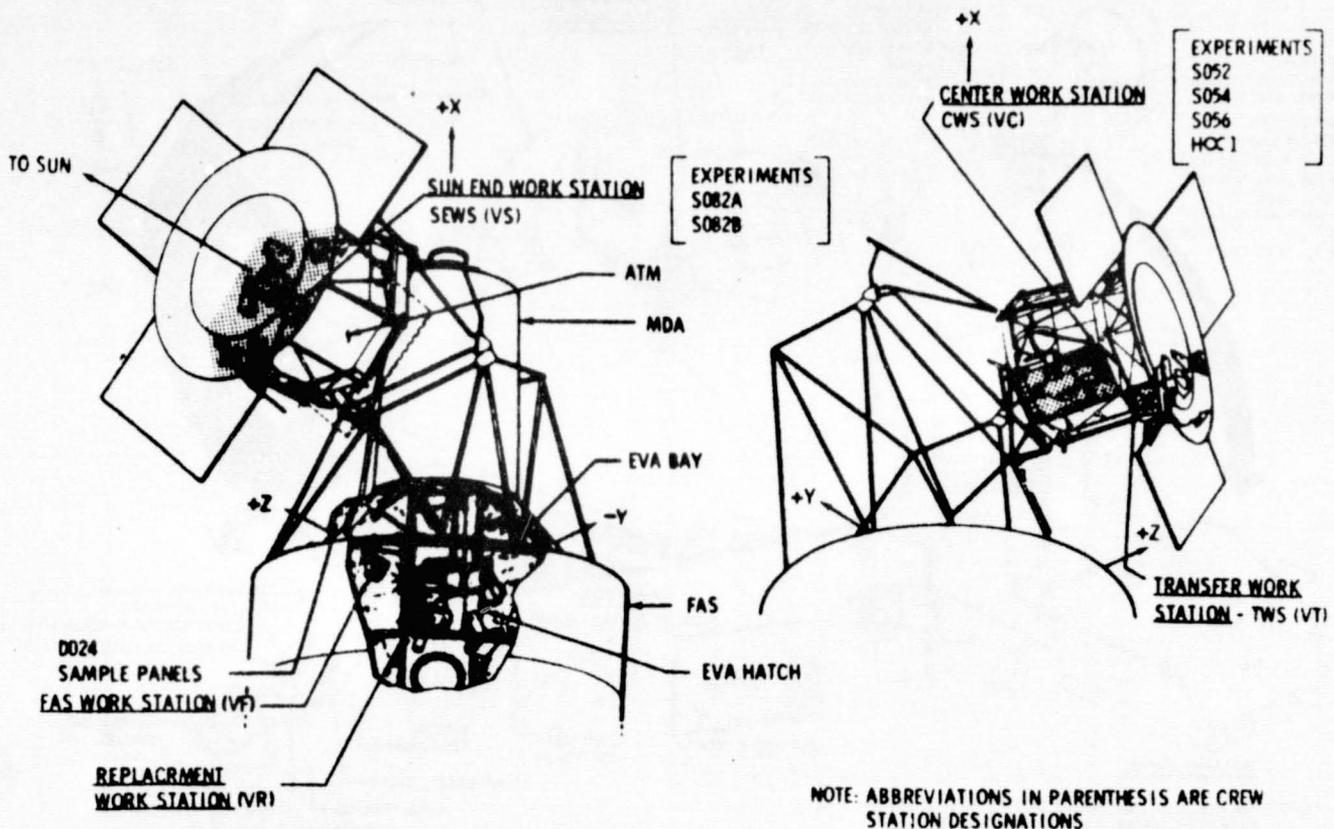
The lower deck of the OWS actually contained four distinct compartments: experiment, wardroom, sleep, and waste management. In addition to numerous stowage accesses, medical experiment chores, and obvious activities associated with self maintenance, this general area served as a congregation point for business and pleasure gatherings of the crew and was a high traffic area. The proximity of the ceiling and floor (6.5 feet, 1.98 meters) rendered this area the most one-g oriented portion of the vehicle and tended to create an atmosphere for semi-erect standing-type postures at most workstations.

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4.2 EVA

Skylab was designed to accommodate EVA as an operational procedure integrated into the routine of each mission. The primary purpose of these EVA's was to recover exposed photographic film from ATM cameras and reload the cameras with unexposed film. A secondary activity was to recover small sample panels that had undergone various lengths of exposure to the space environment.

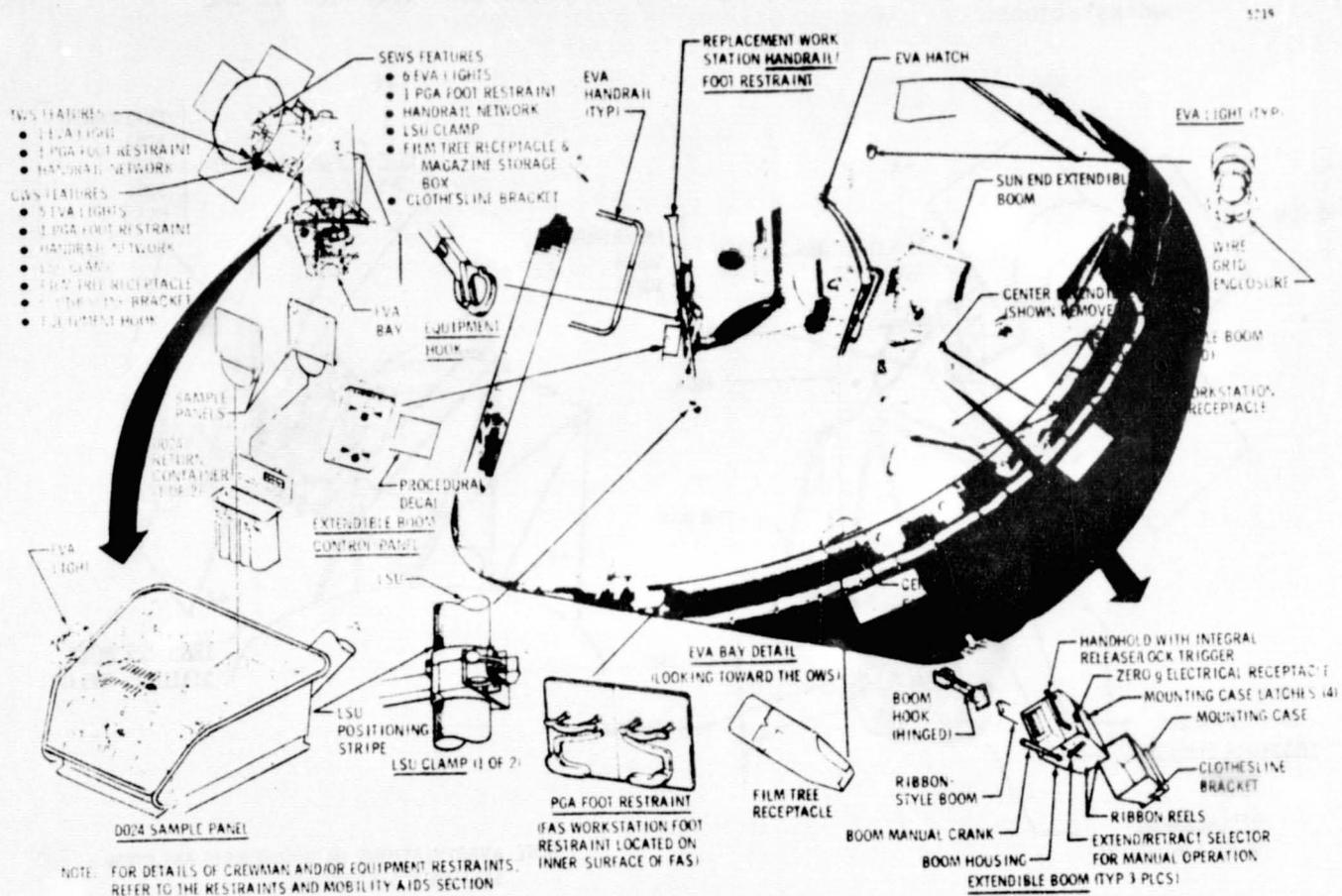
Five EVA workstations were located on the AM and ATM exteriors (see Figure 21). Figure 22 shows the array of provisions provided at the workstations.



SKYLAB EVA WORKSTATIONS

FIGURE 21

The Skylab EVA workstations were all designed to be standup stations with restraint provided at the feet, leaving both hands free for work. The major portion of each work task was located directly in front of the restrained crewman between the waist and shoulder. This maximized efficiency while minimizing the constraints imposed by the suit and life support system.

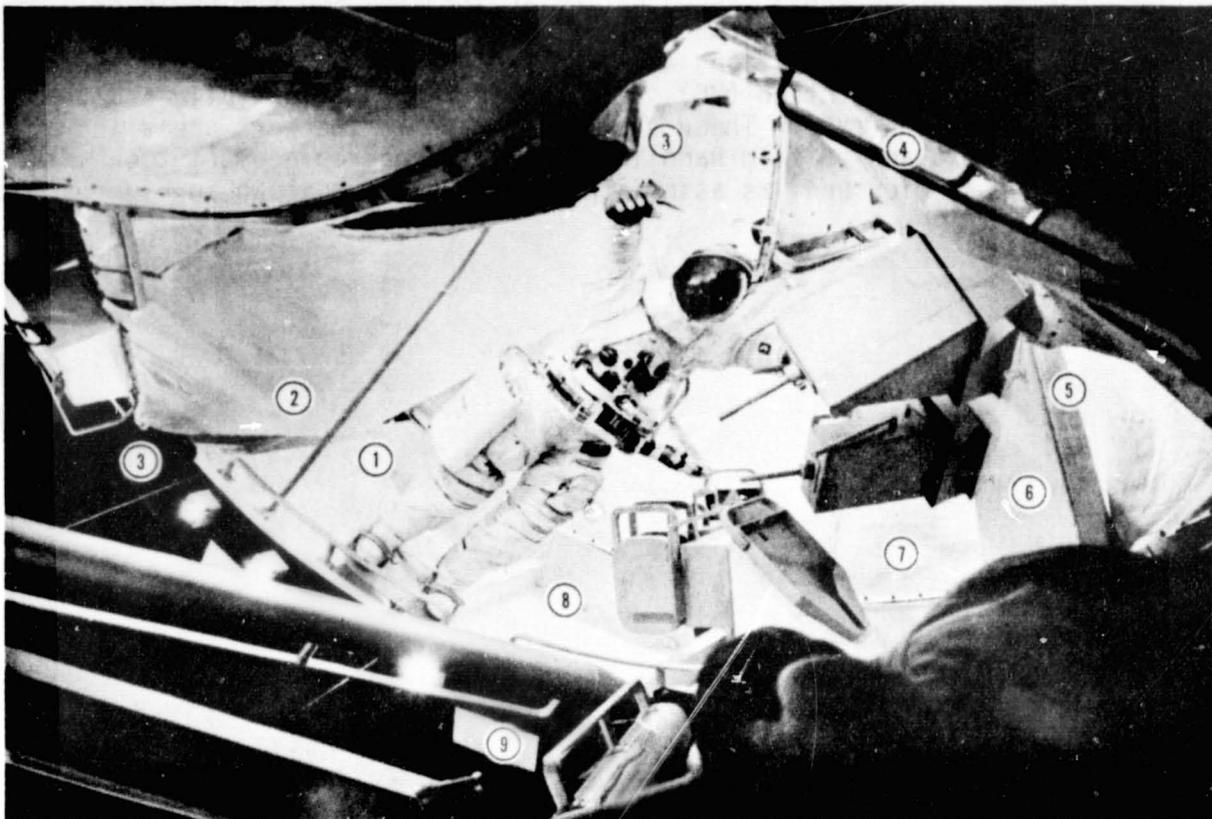


EVA WORKSTATION PROVISIONS

FIGURE 22

Two EVA workstations were located in a sheltered EVA bay immediately outside the AM hatch. These were the primary operating station in the Fixed Airlock Shroud (FAS), known as the VF station, and the replacement station located nearby and used as a contingency or backup operating position. Three other stations were located on the ATM structure. These were the Center Workstation (VC), the Transfer Workstation (VT), and the Sun End Workstation (VS). These stations served as the work areas in which ATM camera and/or film handling, removal, and replacement took place. Each station and its associated provisions are shown in Figures 23 through 26.

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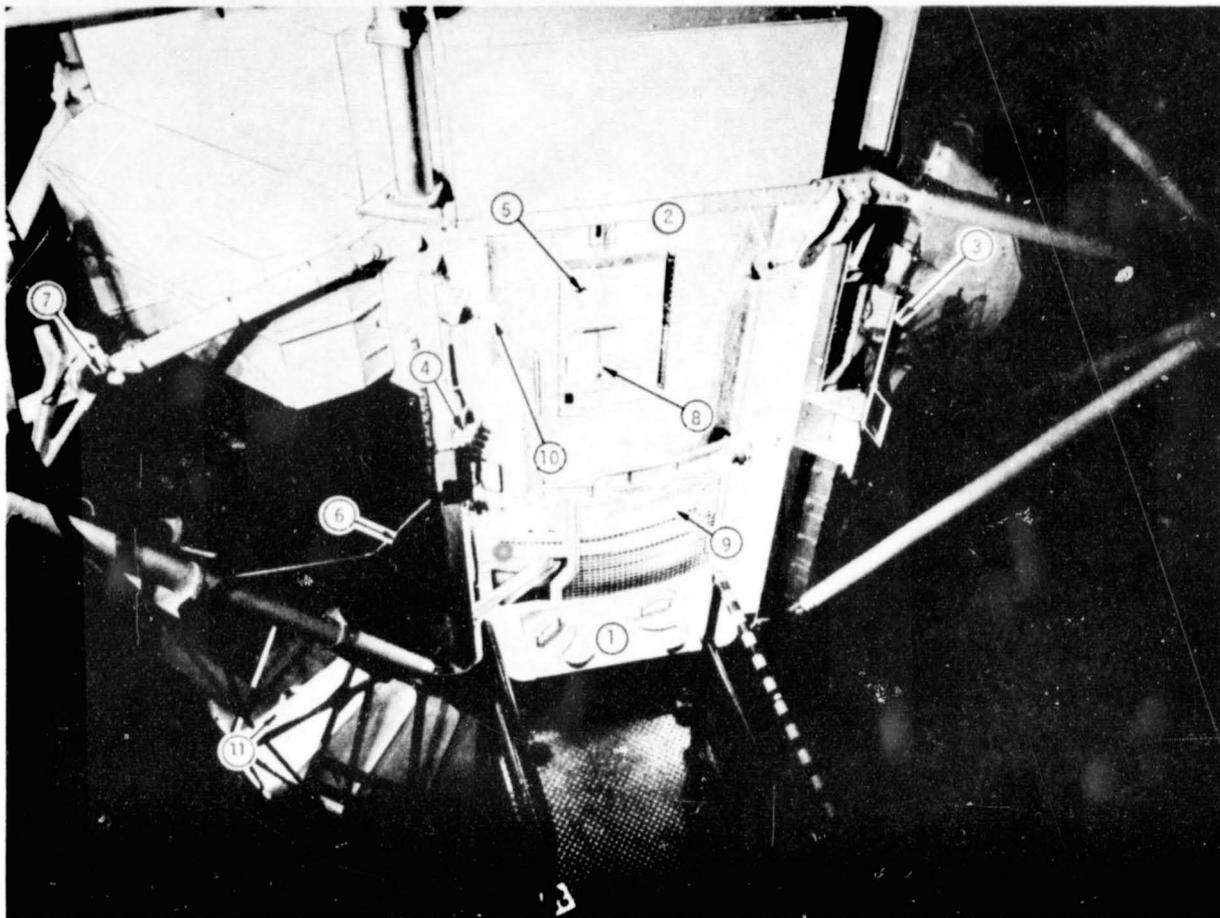


FAS Worksite Support Equipment: (1) Primary Foot Restraints; (2) Handrails; (3) EVA Lights; (4) Airlock Hatch; (5) Sun End Workstation Cargo Transfer Boom; (6) Center Workstation Cargo Transfer Boom; (7) Sun End Cargo Temporary Stowage Receptacle; (8) Center Workstation Cargo; and (9) Translation Rail to ATM Center Workstation.

SKYLAB FIXED AIRLOCK SHROUD (FAS) WORKSTATION (VF)

FIGURE 23

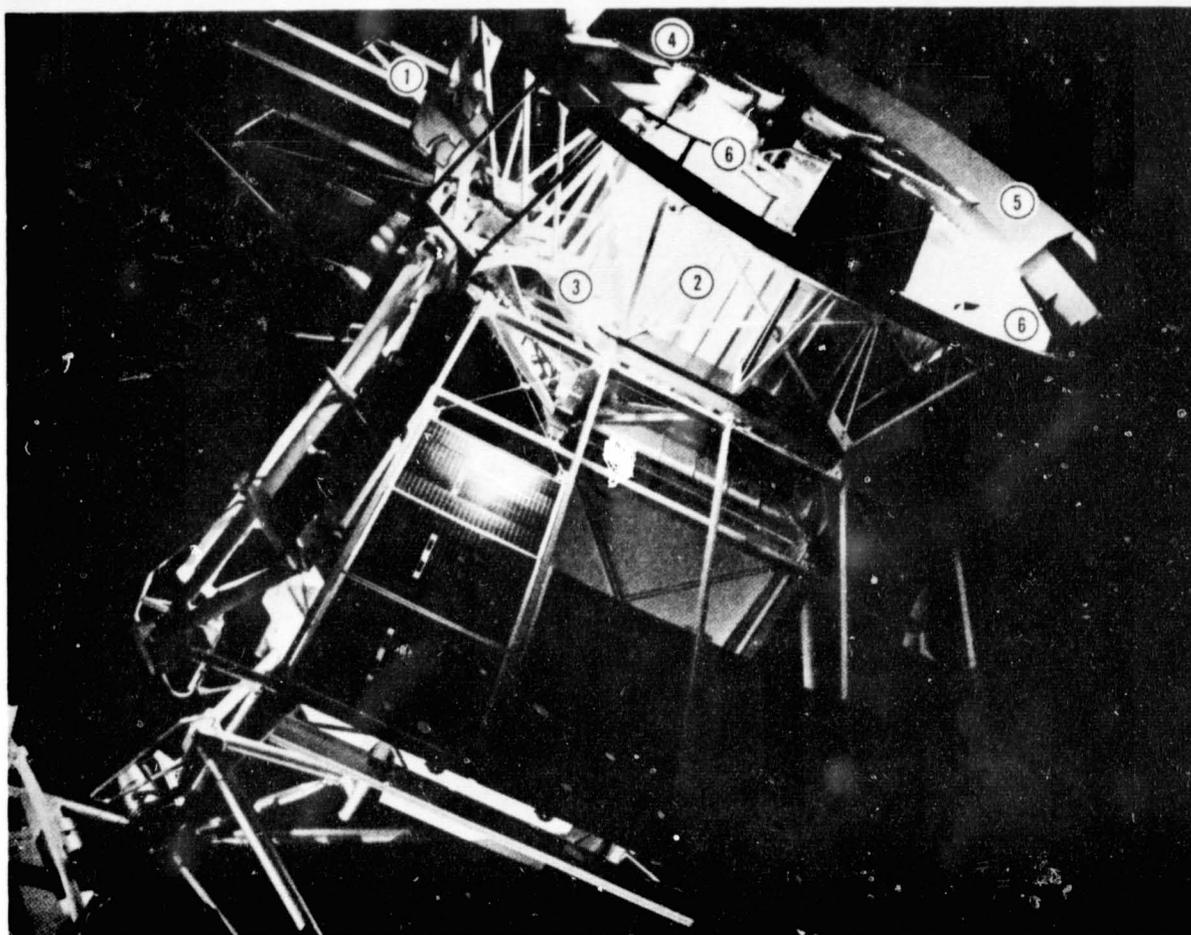
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Center Worksite Support Equipment: (1) Primary Foot Restraints; (2) ATM Canister Alignment Indicator; (3) Contingency Transfer Interface Bracket; (4) ATM Canister Roll Control Panel (5) Film Package Access Door; (6) Translation Rail to/from Dual Translation Rails; (7) EVA Translation Path Light; (8) Access Door Handle; (9) VC Hand-rail and Protective Grid; (10) VC Lights; and (11) Transfer Workstation Light.

SKYLAB CENTER WORKSTATION (VC)

FIGURE 24



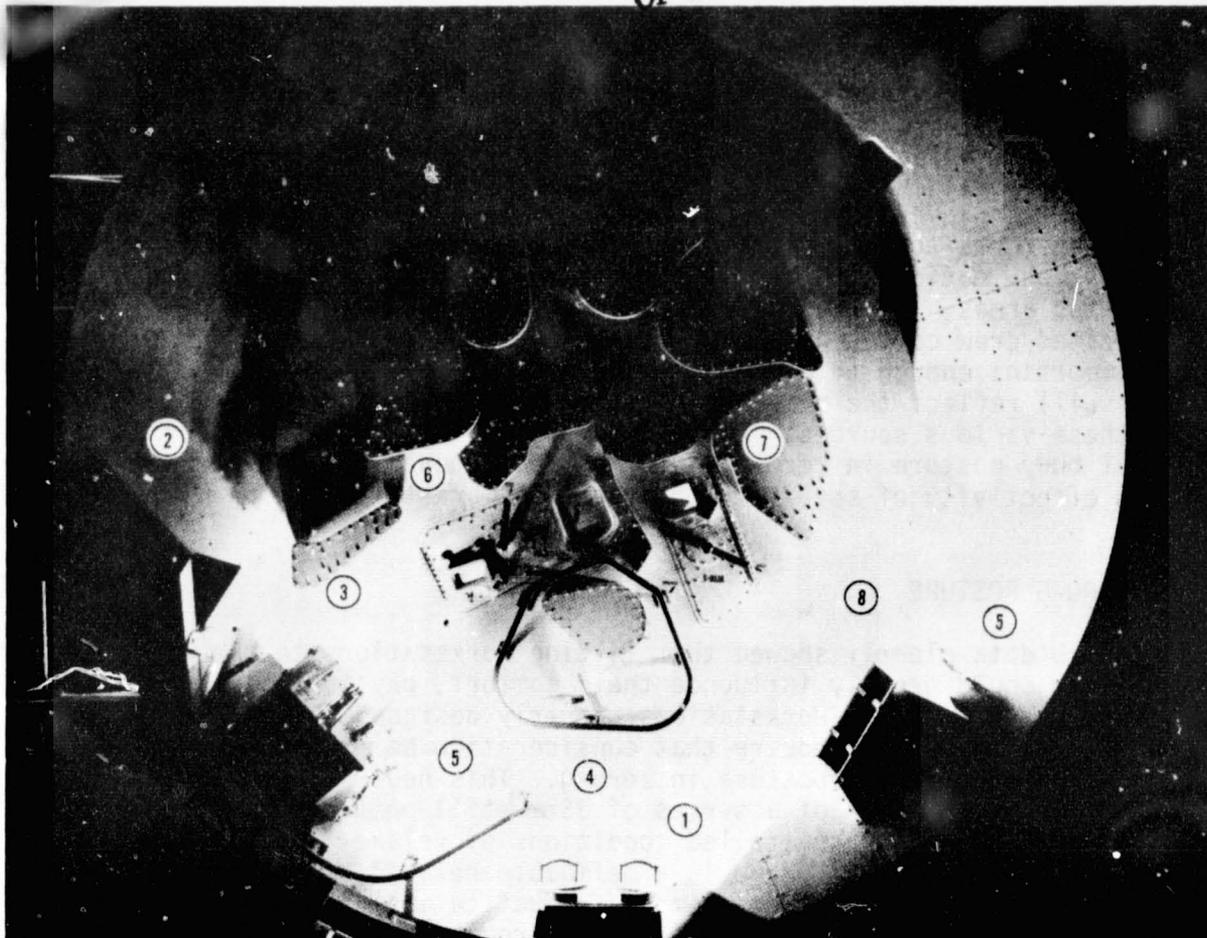
Transfer Worksite Support Equipment: (1) Primary Foot Restraints; (2) Transfer Workstation Light; (3) Dual Translation Rails; (4) Sun End Primary Cargo Stowage Receptacle; (5) Sun End Cargo Temporary Stowage; and (6) Sun End Workstation Lights.

SKYLAB TRANSFER WORKSTATION (VT)

FIGURE 25

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Sun End Workstation Support Equipment: (1) Primary Foot Restraints; (2) Contingency Transfer Interface Bracket; (3) Sun End Cargo in the Primary Stowage Receptacle; (4) Handrails; (5) Sun End Workstation Lights; (6) S082B Film Package Access Door; (7) S082A Film Package Access Door; and (8) Sun End Cargo Temporary Stowage.

SKYLAB SUN END WORKSTATION (VS)

FIGURE 26

5.0 SKYLAB FINDINGS

Several methods of data gathering were employed during Skylab missions to retrieve information pertinent to the man-machine engineering discipline in general and to specific sub-elements of that discipline. The design adequacy of the man-machine interfaces at the various workstations was one of the particular areas of investigation. Among the different techniques used to acquire data were questionnaires and evaluation forms to be periodically accomplished during the course of a mission, motion picture film of specific activities and tasks in designated areas, TV transmissions of general onboard activity, and unsolicited crew commentary on any aspect of an interface which they felt important enough to document. The following sections of this report will reflect the results obtained by analyzing the data returned from these various sources. First, a case will be established for a neutral body posture in zero-g, and then that phenomenon will be applied to the effectivity of several representative workstations.

5.1 ZERO-G POSTURE

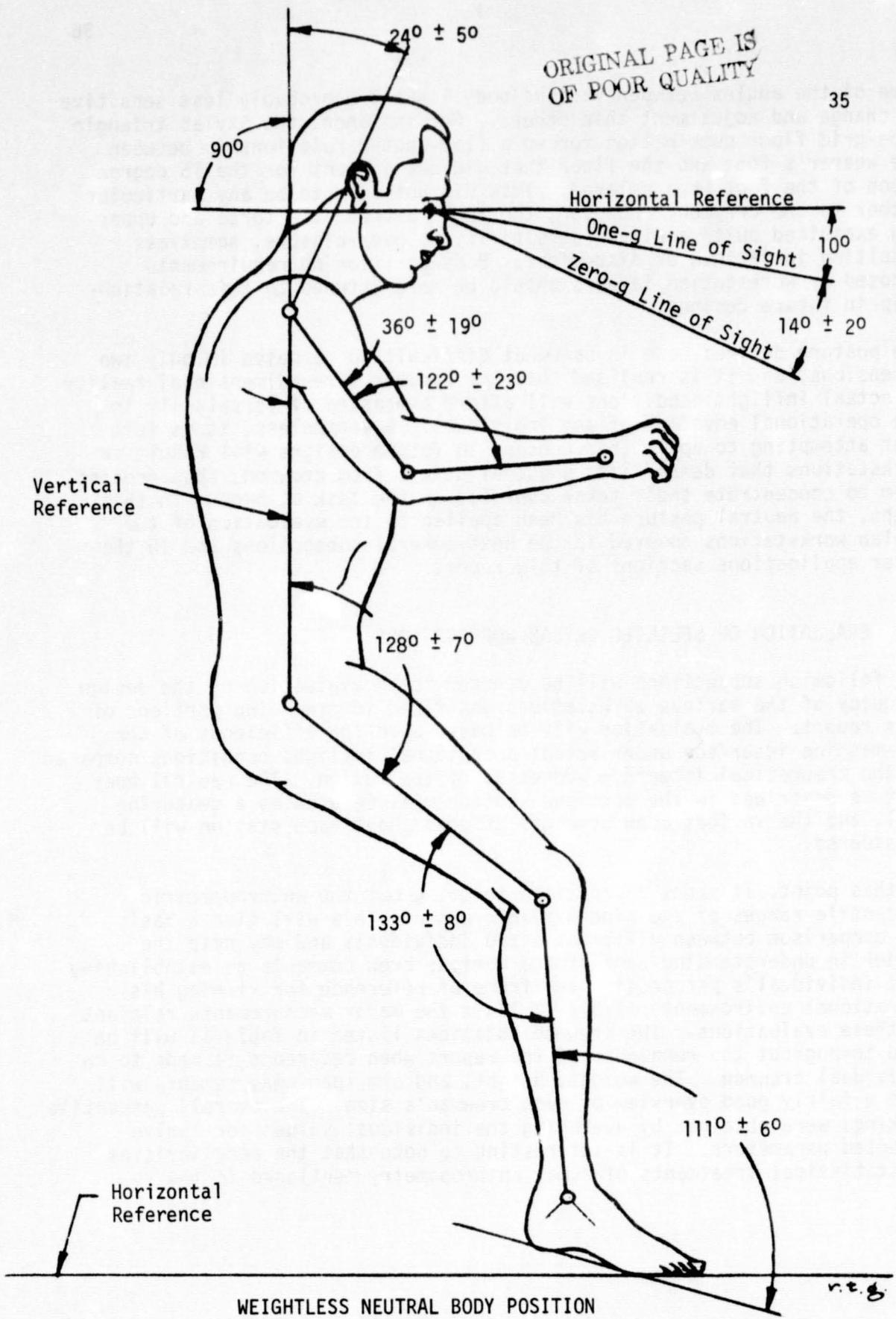
The Skylab data clearly showed that fitting workstations to the crew population could greatly influence their comfort, physical well-being, and output efficiency. Workstations properly designed for use in a weightless environment require that consideration be given to man's relaxed or neutral body posture in zero-g. This neutral position is based upon the analysis of a series of 35mm still photographs taken during the SL-4 mission under controlled conditions of relaxed body posture. The analysis showed that there is a definable relaxed body posture in zero-g, even though it varies from individual to individual and even changes somewhat for any given individual from one data take to the next. Although the sample size was small, numerous data takes were accomplished during the SL-4 mission, and it is felt that a quantified neutral body posture has been defined with an associated envelope of variation described by standard deviations about mean positions of various body links in relation to each other (see Figure 27). This subject has been treated in detail in Skylab Experience Bulletin No. 17, "Neutral Body Posture in Zero-g" (Reference 1).

Figure 27 shows that the body seeks a semi-crouched position in zero-g, neither sitting nor standing. This point should be reflected in future zero-g workstation designs if the most efficient manned interfaces are to be created.

Another point of interest is that the standard one-g line of sight, which is ordinarily depressed in zero-g due to the tendency of the neck and head to droop forward. This artifact should influence the manner in which design eye points are located for zero-g applications.

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WEIGHTLESS NEUTRAL BODY POSITION

FIGURE 27

Some of the angles between various body links are probably less sensitive to change and adjustment than others. For instance, the Skylab triangle shoe-grid floor combination forced a flat-footed relationship between the wearer's foot and the floor that did not account for the 15 degree droop of the foot when relaxed. This did not seem to be any particular bother to the crewmen. However, the angle between the torso and upper leg exhibited quite a bit of sensitivity to over-closure, sometimes resulting in fatigue or discomfort. Body positioning requirements imposed by workstation layouts should be more attuned to this relationship in future designs.

The posture defined here is somewhat difficult to perceive in only two dimensions, and it is realized that the dynamic three-dimensional reality of actual inflight conditions will afford a measure of versatility in the operational envelope of any individual. Nevertheless, it is felt that attempting to apply this concept to future designs will result in workstations that demand less physical stress from crewmen, thus freeing them to concentrate their total energies on the task at hand. In this light, the neutral posture has been applied to the evaluation of the Skylab workstations covered in the next several subsections and in the later applications sections of this report.

5.2 EVALUATION OF SELECTED SKYLAB WORKSTATIONS

The following subsections will be devoted to an evaluation of the design adequacy of the various workstations described in preceding portions of this report. The evaluation will be based upon the efficiency of the man-machine interface under actual operational inflight conditions compared to the theoretical interface addressed by the design. The neutral body posture described in the previous section will be used as a measuring tool, and the various crew comments offered about each station will be considered.

At this point, it seems appropriate to bring out the anthropometric percentile ranges of the nine Skylab crewmen. This will give a basis for comparison between different sized individuals and may help the reader in understanding some of the various crew comments by establishing that individual's perspective and frame of reference for viewing his operational environment. Table II lists the major measurements relevant to these evaluations. The crewmen notations listed in Table II will be used throughout the remainder of the report when reference is made to an individual crewman. The weight, height, and arm-span measurements will give a fairly good overview of each crewman's size. The overall percentile rankings were obtained by averaging the individual values for twelve selected parameters. It is interesting to note that the peculiarities of statistical treatments of human anthropometry mentioned in the

Introduction Section of this report can now be observed in practice. For instance, Crewman 3 ranks as the overall largest individual to fly aboard Skylab even though he is shorter in overall height and considerably lighter in weight than Crewman 5. The point to be emphasized here is that for any given application of sizing data, the most important parameter affecting that situation must be taken as the "design driver" for that particular instance as opposed to blind acceptance of overall averages as being applicable in all design situations. Consequently, Crewman 5 was chosen as the representative large crewman for the workstation evaluations because design eye height, overall height, and reach limitations were of more importance to this application than weight or some of the other parameters. In this light, the three crewmen chosen as representative samples of large, average, and small individuals for the purposes of the following evaluations were Crewmen 5, 9, and 1, respectively.

TABLE II

SELECTED ANTHROPOMETRIC MEASUREMENTS FOR NINE SKYLAB ASTRONAUTS

<u>MISSION</u>	<u>CMN.</u>	<u>PREFLIGHT WEIGHT</u>	<u>STANDING HEIGHT</u>	<u>SPAN</u>	<u>PERCENTILE RANKING</u>
SL-2	1	138.35 lbs 62.75 Kg	66.0 in. 167.6 cm	68.25 in. 173.3 cm	14
	2	178.6 lbs 81.0 Kg	70.1 in. 177.9 cm	71.37 in. 181.23 cm	67
	3	172.0 lbs 78.0 Kg	71.5 in. 181.7 cm	75.37 in. 191.44 cm	84
SL-3	4	151.0 lbs 68.5 Kg	68.57 in. 174.0 cm	71.0 in. 180.2 cm	47
	5	194.0 lbs 88.0 Kg	72.5 in. 184.1 cm	73.5 in. 186.8 cm	82
	6	136.7 lbs 62.0 Kg	68.9 in. 175.3 cm	68.37 in. 174.0 cm	32
SL-4	7	150.0 lbs 68.0 Kg	68.1 in. 173.0 cm	71.0 in. 180.2 cm	48
	8	149.0 lbs 67.6 Kg	68.6 in. 173.3 cm	71.25 in. 180.8 cm	51
	9	157.0 lbs 71.3 Kg	68.1 in. 173.2 cm	68.0 in. 172.72 cm	42

Mean or Average = 51

5.2.1 ATM

As noted in Section 4.1.1, the ATM workstation consisted of a C&D console and an accompanying foot restraint platform. In order for the operator to properly position himself with respect to the console, some type of restraint was necessary. The platform provided an interface for the triangle restraints on the shoes worn by the crewmen, but an optional seated restraint was provided based upon the previous zero-g experience of one of the Skylab crewmen. Both restraint methods will be addressed in the following sections.

5.2.1.1 ATM Seated Operations

The ATM chair evolved as the result of one crewman's concern about long-term operations at the ATM console possibly leading to muscular or structural discomfort in the operator's back unless some type of back support was provided. Thus the ATM chair was developed as an optional restraint that would more or less force posture to conform to a given configuration, selectable by the crewman by varying the various chair and platform adjustments.

The SL-2 crew used the ATM chair throughout their mission but in strikingly different modes by different crewmen. The Commander used it in conventional "strapped-in" chair fashion. The Pilot used it in a "non-strap-in" manner as illustrated in Figure 28. The Science Pilot used the chair in many ways, including "strapped", "unstrapped", and as a handhold while operating the console in a "free-floating" mode. Each SL-2 crewman summarizes his use of the chair in the following excerpts from their inflight and postflight comments:

SL-2 SPT: "The ATM chair. We finally arrived at a compromise setting for the chair that was acceptable for both Pete and me, with Paul kind of in the middle. I wound up not strapping myself in the chair all the time. You don't really sit at the ATM like you do in one-g. Sometimes it was pleasant to strap your waist in and cinch it up nice and tight and stay that way for awhile. It certainly gave you good reach and a nice stable point. But your muscles would get tired if you stayed that way all the time. Sometimes you would use the chair simply as a backbrace and you wouldn't use the belt at all. You would slide in, let your thighs ride up against the bottom of the tray, and your backside against the top of the back of the chair and work that way. And sometimes I would work hanging onto the back of the chair with one hand and my body floating straight out perpendicular to the

ATM console, operating in that way. You moved around a lot." (SL-2 Technical Crew Debriefing)

SL-2 CDR: "I operated the chair differently than Joe did. When I operated the ATM, I cinched in the chair. I adjusted the chair to what I thought was the optimum for that panel but because I'm smaller than these two guys, they couldn't leave it there.

I thought we'd get away without having any cushions but I had a reasonable pressure point on my back. But I always operated the ATM by strapping in the chair and without moving out of it or floating or hanging on to it. I did use it in a chair mode. I also found that hooking my feet in the little bar at the bottom was what I liked to do. (SL-2 Technical Crew Debriefing)

SL-2 PLT: "And even though I don't strap myself into the Captain's chair, I do kind of half sit, half lie at it with my toes hooked over the little tubular foot rest thing that goes around the bottom." (SL-2 Dump Tape 167-12)

The SL-3 crew used the chair for a few days at the beginning of their mission and then discarded it in favor of the triangle shoes and foot restraint platform, preferring the freedom of movement that the foot restraints permitted. The SL-4 crew did not use the ATM chair at all. In fact, six of the nine Skylab crewmen (during five-sixths of total mission time flown) chose not to use it.

The following crew comments are indicative of the SL-3 and SL-4 crews preference for working at the ATM console in the semi-standing mode:

SL-3 PLT: "ATM seat/backrest restraint, I haven't used. I don't think anybody has except for maybe right at first. We find it just as convenient to fix ourselves at the ATM with our feet. So, we're not using the ATM seat/backrest restraint." (SL-3 Dump Tape 223-08)

SL-3 SPT: "ATM seat/backrest restraint -- tried it once and threw it away. It works a lot better to just put your feet in the triangles and stay there." (SL-3 Dump Tape 227-02)

SL-4 CDR: "You get the impression looking at that (ATM) panel, that it was designed for a person to sit down at in one-g." (ATM Experiments Debriefing)

SL-4 SPT: "There's no way anyone could sit in a chair and operate it. We were always having to go over to the STS panel; we had to lean back to look at all the S055 information we had pinned up on lockers in the back. We had to lean over to the right to pick up Polaroid cameras or reach the VTR. Furthermore, we wanted to move around when we were there for a long period of time, and a chair wouldn't permit that."
(ATM Experiments Debriefing)

SL-4 CDR: "I guess you get the picture; we didn't use the chair." (ATM Experiments Debriefing)



UNSTRAPPED MODE OF ATM CHAIR USE

FIGURE 28

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The foregoing discussion has not been intended as an analysis of the relative merits of "whole-body" versus "foot-type" restraint systems but rather as a presentation of information concerning two radically different methods of placing a crewman in proper perspective to a workstation. The conclusions drawn with respect to properly positioning a crewman at a zero-g workstation are now offered.

The convenience of operation and freedom of movement permitted by the foot restraints far outweigh any potential benefit that may have been gained by using the ATM chair. A thorough analysis of this experience has led to the conclusion that seated type operations in zero-g are very undesirable and that workstations should be laid out to accommodate an operator standing in the neutral body position and restrained at the feet. Several things contribute to this conclusion. First, sitting is unnatural in zero-g where the body tends to seek a neutral relaxed position, and trying to force a seated posture needlessly works against the natural postural tendencies. Second, the "tied down" crewman in a seated restraint suffers an unnecessary restriction of motion and reach. Finally, uncomfortable pressure points can be brought to bear on the user's body. Seats seem to have no place at zero-g workstations. If, for some reason, operation of controls in future spacecraft demand the use of hands and feet then a new technology must be developed to develop a zero-g chair suitable for supporting such operations.

5.2.1.2 ATM Standing Operations

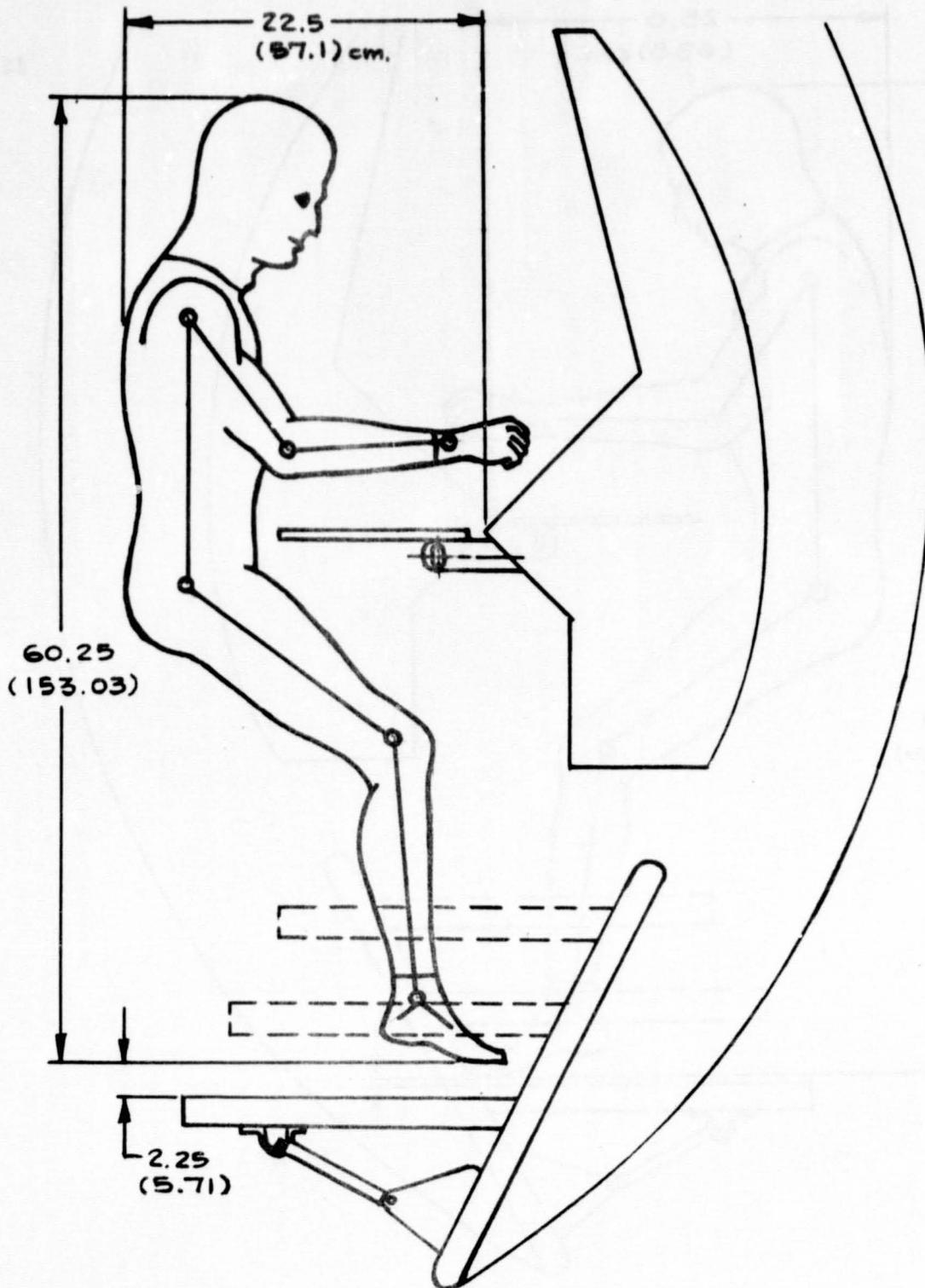
The inadequacies of chair type "zero-g body positioning devices" described in the previous section will be balanced by presenting an analysis of another approach to solving the problem of how to design the best possible man-machine interface at a zero-g work station. The overwhelming choice of operating positions at the ATM console was to "stand" on the foot restraint platform and use major muscle groups within the body to achieve the exact position required at any given time. This conscious choice on the part of the operators, combined with the availability of more crew interface data (TV, motion and still photography, crew comments) for the ATM workstation, has led to that interface being treated as the baseline for evaluation in this report. Additionally, it is also easily diagrammed in profile to graphically demonstrate the points to be made concerning the workstation design implications of the zero-g neutral body position. Finally, a better understanding of some of the crew comments regarding this workstation will probably be fostered by noting that the ATM console was used in a seated posture during preflight simulator training, and the foot restraint platform may have been influenced less than necessary by zero-g body posture. Consequently, the crew's total exposure to the console before flight was from a chair in a trainer and their perspective became fixed from that viewpoint. When placed in the weightless environment, proper adjustments did not seem available, as indicated by the following comments from the SL-3 SPT:

"Working at the ATM panel is considerably better than it is working in a chair in the simulator. The most neutral position did tend to have my eye approximately 6 inches higher than it would be if I were sitting in the chair in the simulator."
(Corollary Experiments Debriefing)

The first step in evaluating the ATM workstation as a truly zero-g interface was to attempt to place the three representative crewmen (small, average, large) at the station in an optimized posture, without respect to the physical constraints of the actual layout. Figures 29, 30, and 31 show the results of this "optimized" interface with an eye position established that was as near possible equidistant from the three major work surfaces; the vertical panel face, the sloped panel face, and the horizontal writing surface. The details in these figures (and all other drawings in this report unless otherwise noted) are scaled as closely as possible to be accurate. The hardware is dimensionally correct at one-tenth scale, and the crewmen are as near one-tenth scale as available anthropometric data and drawing techniques will allow. It is apparent in each case that no "ideal" position was available, with each man failing by some margin to end up on one of the three foot restraint platform positions. Individual differences in anthropometry are once again clearly emphasized when the link dimensions of the three crewmen are compared so that measurable differences in eye position can be defined for the zero-g position as opposed to an erect one-g standing position. The following table lists the incremental measurements and shows the deltas between zero-g and one-g eye heights as measured from the ankle. Even though Table II indicated a two-inch (5.08 cm) height difference between the small and average crewmen in Table III, the manner in which individual anthropometric differences are distributed between links results in a common zero-g eye position for the two individuals.

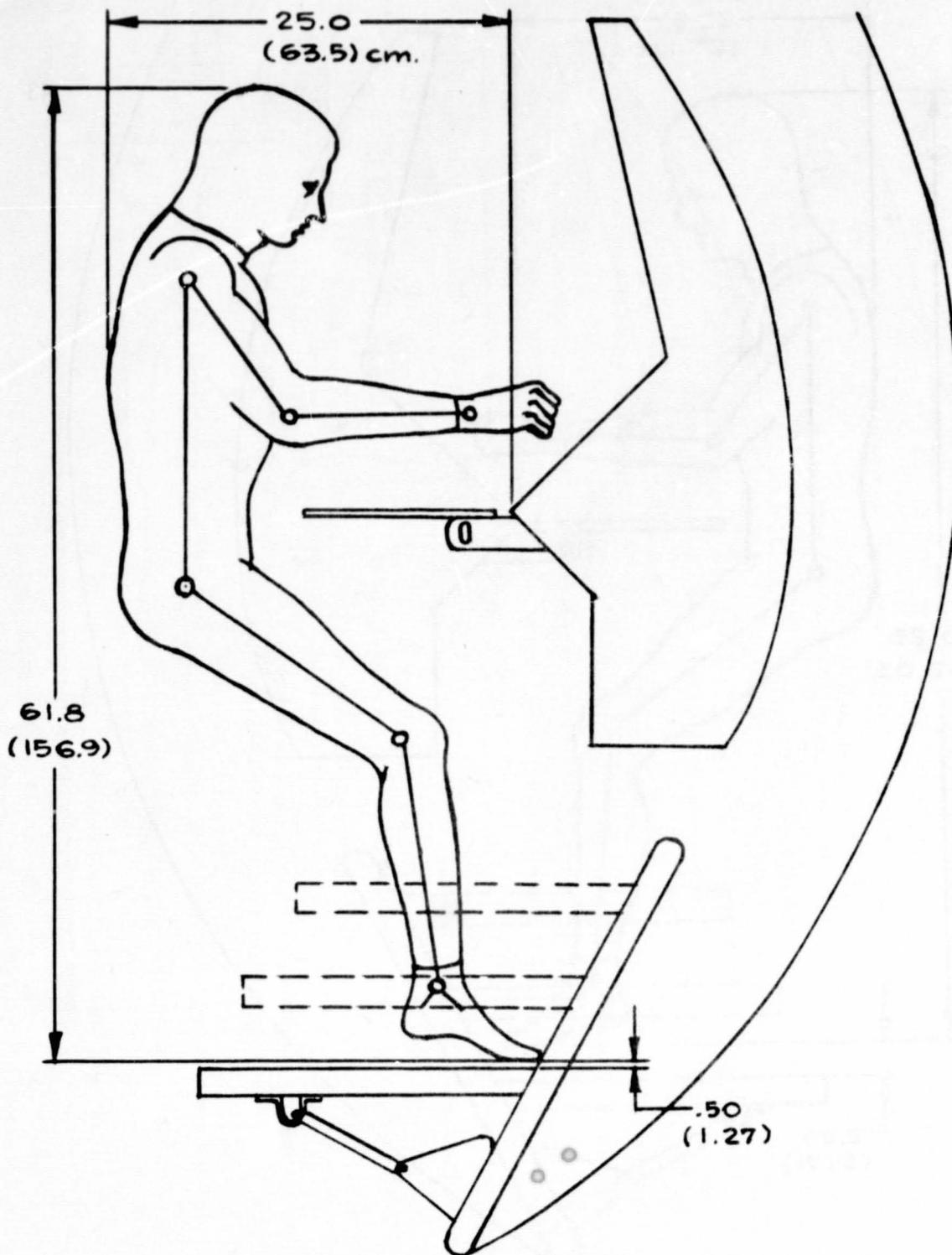
The major points to be made from this data are that there are significant differences between one-g and zero-g eye positions when defined from a common base-point (in this case the ankle), and that these differences are not the same for everyone nor are they necessarily even distributed in the neat orderly fashion that one might expect. Different results would probably be obtained for different base points for comparison, i.e., knee, hip, etc.

Since there was no "optimum" fit available at the ATM workstation, but since the mission history shows that satisfactory work was accomplished at the station, we must look at the manner in which the interface was accommodated to produce a "best fit" for doing the job. Figure 32 depicts the position generally used to operate the ATM console. Depending upon the position of the foot restraint platform, the operator was either forced toward or away from the neutral body position at the mean of the



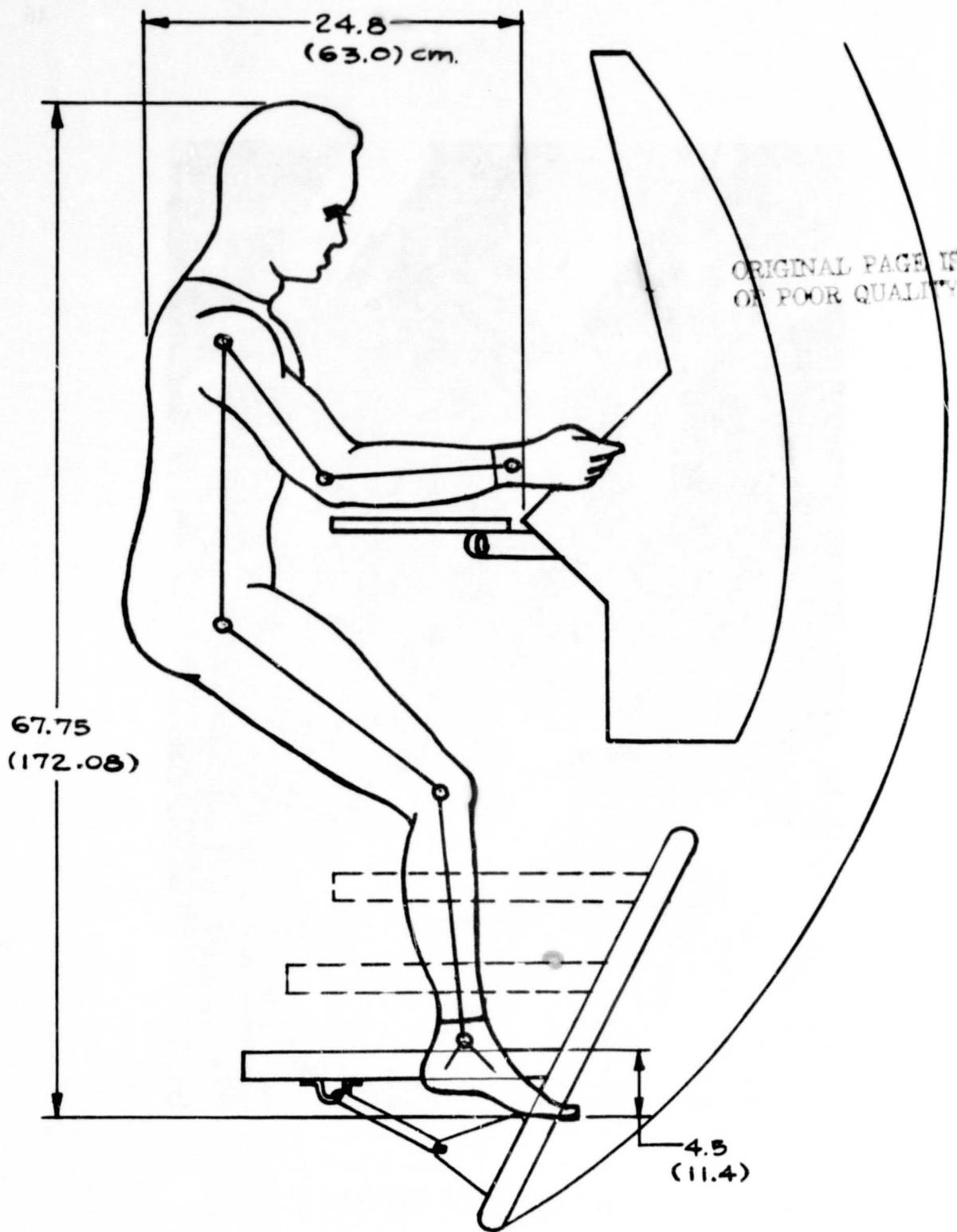
OPTIMIZED POSITION OF SMALL CREWMAN AT ATM CONSOLE

FIGURE 29



OPTIMIZED POSITION OF AVERAGE CREWMAN AT ATM CONSOLE

FIGURE 30



OPTIMIZED POSITION OF LARGE CREWMAN AT ATM CONSOLE

FIGURE 31



SL3 CDR AT ATM CONSOLE

FIGURE 32

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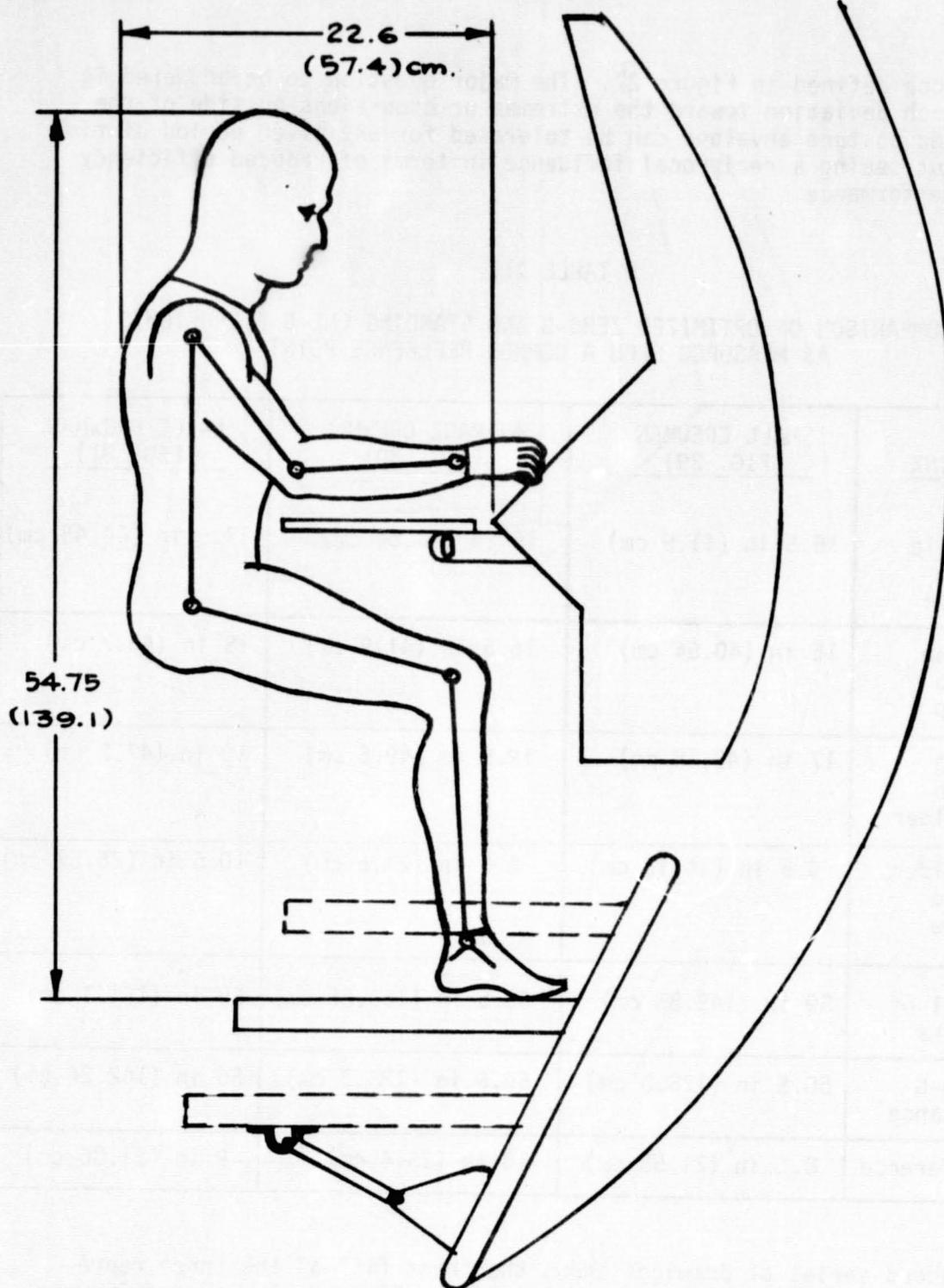
envelope defined in Figure 27. The major question to be answered is how much deviation toward the extremes or excursions outside of the defined posture envelope can be tolerated for any given period of time without seeing a reciprocal influence in terms of reduced efficiency and performance.

TABLE III

COMPARISON OF OPTIMIZED ZERO-G AND STANDING ONE-G EYE HEIGHTS
AS MEASURED FROM A COMMON REFERENCE POINT

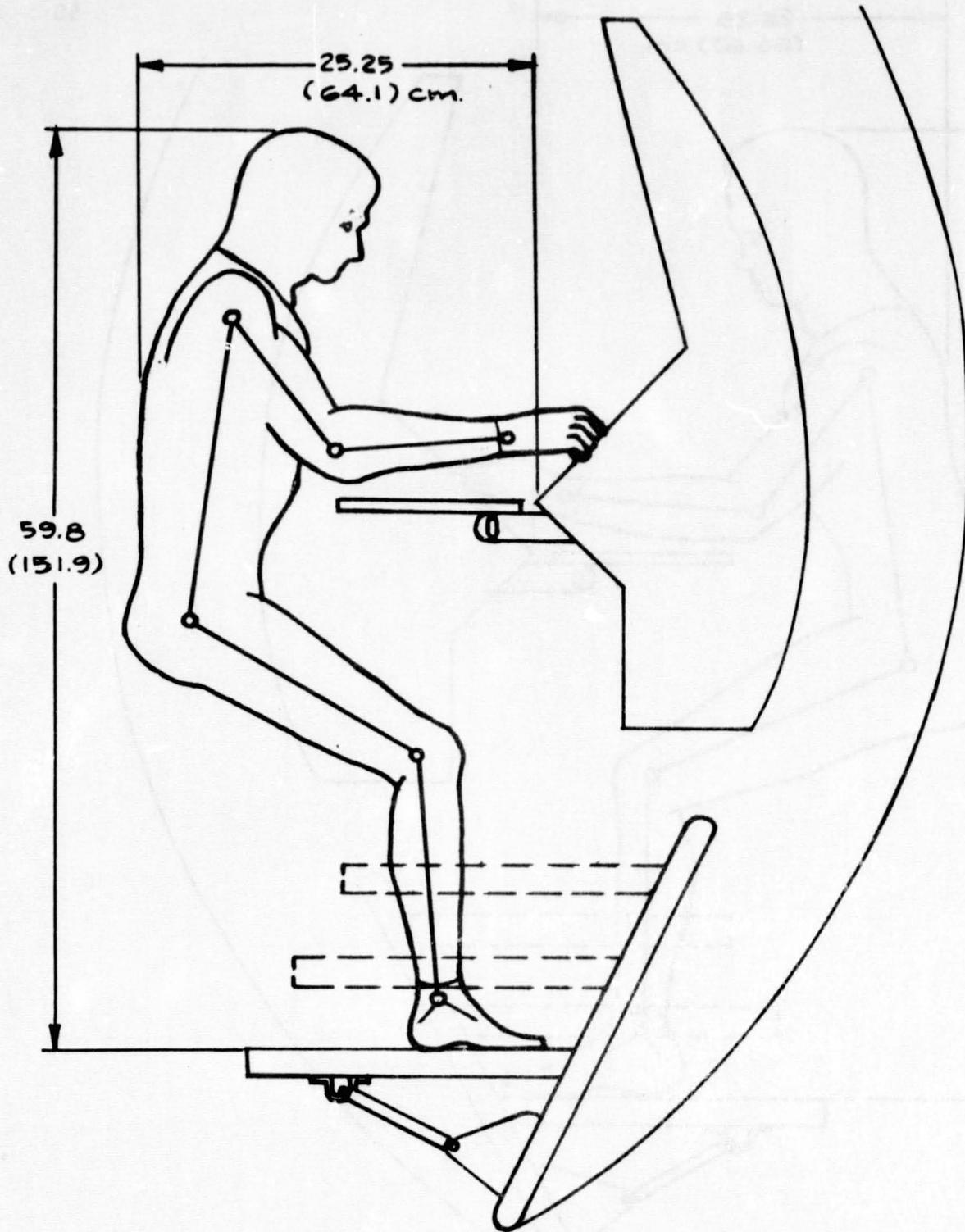
<u>LINK</u>	<u>SMALL CREWMAN (FIG. 29)</u>	<u>AVERAGE CREWMAN (FIG. 30)</u>	<u>LARGE CREWMAN (FIG. 31)</u>
Ankle to Knee	16.5 in (41.9 cm)	16 in (40.64 cm)	17.5 in (44.45 cm)
Knee to Hip	16 in (40.64 cm)	16.5 in (41.9 cm)	18 in (45.7 cm)
Hip to Shoulder	17 in (43.18 cm)	19.5 in (49.5 cm)	19 in (47.3 cm)
Shoulder to Eye	9.5 in (24.13 cm)	8.5 in (21.6 cm)	10.5 in (26.67 cm)
Total of Links	59 in (149.85 cm)	60.5 in (153.66 cm)	65 in (164.1 cm)
Zero-G Distance	50.5 in (128.3 cm)	50.5 in (128.3 cm)	56 in (142.24 cm)
Difference	8.5 in (21.58 cm)	10 in (25.4 cm)	9 in (21.86 cm)

A second series of drawings shows the "best fit" of the three representative crewmen at the ATM workstation. Figures 33, 34, and 35 were developed by "fitting" the crewmen to the console by placing the feet



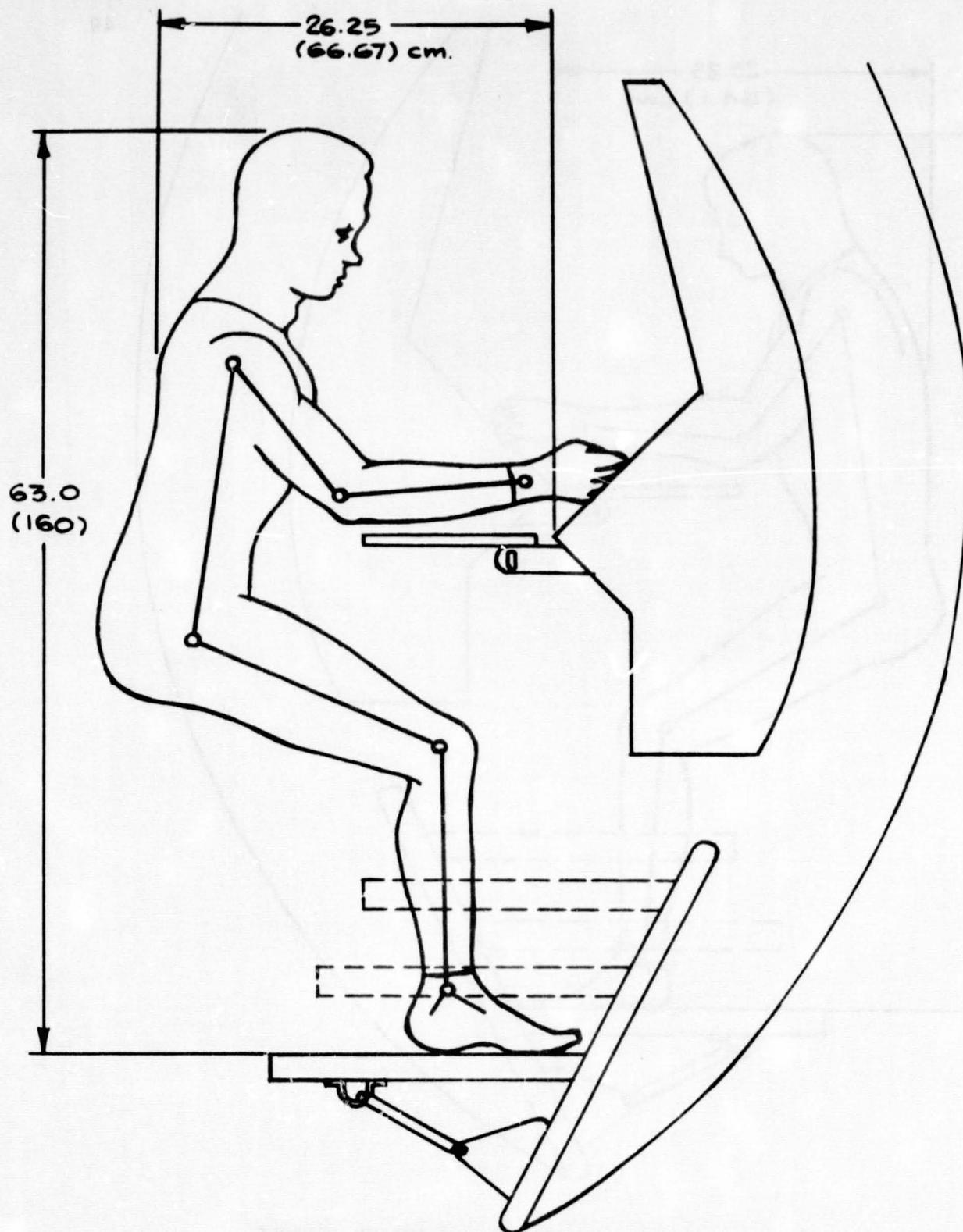
"BEST FIT" OF SMALL SKYLAB CREWMAN AT ATM CONSOLE

FIGURE 33



"BEST FIT" OF AVERAGE SKYLAB CREWMAN AT ATM CONSOLE

FIGURE 34



"BEST FIT" OF LARGE SKYLAB CREWMAN AT ATM CONSOLE

FIGURE 35

flat on the foot restraint platform (as the triangle shoes would have necessitated) and successively positioning the body links to achieve an eye position as close as possible to that defined for the "optimum fit" previously developed. Also, attention was given to the need for writing on the horizontal work surface. The various body angles were kept as close as possible to the neutral position considering the constraints of foot placement and avoiding contact with the writing board. Table IV lists the differences between the body angles in Figures 33 through 35 and the neutral position defined in Figure 27.

TABLE IV
COMPARATIVE BODY POSTURES

BODY ANGLE	FIG. 27	FIG. 33	FIG. 34	FIG. 35
Ankle	$111^{\circ} \pm 6^{\circ}$	* 93°	* 94°	* 92°
Knee	$113^{\circ} \pm 8^{\circ}$	* 117°	125°	* 115°
Hip	$128^{\circ} \pm 7^{\circ}$	* 104°	* 113°	* 105°
Body/Upper Arm	$36^{\circ} \pm 19^{\circ}$	37°	45°	46°
Upper/Lower Arm	$122^{\circ} \pm 23^{\circ}$	124°	123°	123°

*Outside neutral envelope

The geometry of the ATM workstation forced the two larger crewmen onto the lower platform position to achieve a "best fit" at the console. Since even the small crewman is "closed" toward a sitting posture when using the mid-position of the platform, no use can be seen for the top position except as a possible mount for the chair. "Closing" the body toward the seated position by reducing the angles at the hips and knees was the prime source of crew complaint about discomfort at this workstation. Achieving that posture required the use of major leg and abdominal muscle groups, and sustaining the posture left these muscles in a constant state of use. No quantitative data is available from the missions that will show directly the fatigue associated with retaining a suitable working position, but numerous crew comments do address the subject. A few are summarized here:

SL-4 CDR: "Yes, but your abdomen and your muscles tensed up and you just got tired of it. What we need to do is remember postural situation up there and the fact that it is quite natural to be standing up." (SL-4 Systems Debriefing)

SL-4 SPT: (Major Muscle Groups) - "It's a little bit harder than one-g because you don't have the gravity holding you down. So I find myself with my legs and back getting tired." (M487-2D)

SL-4 CDR: "The upshot was at the food table and at the ATM panel you had to hunch down in order to get a decent level and ..."

SL-4 PLT: "Tense your abdomen."

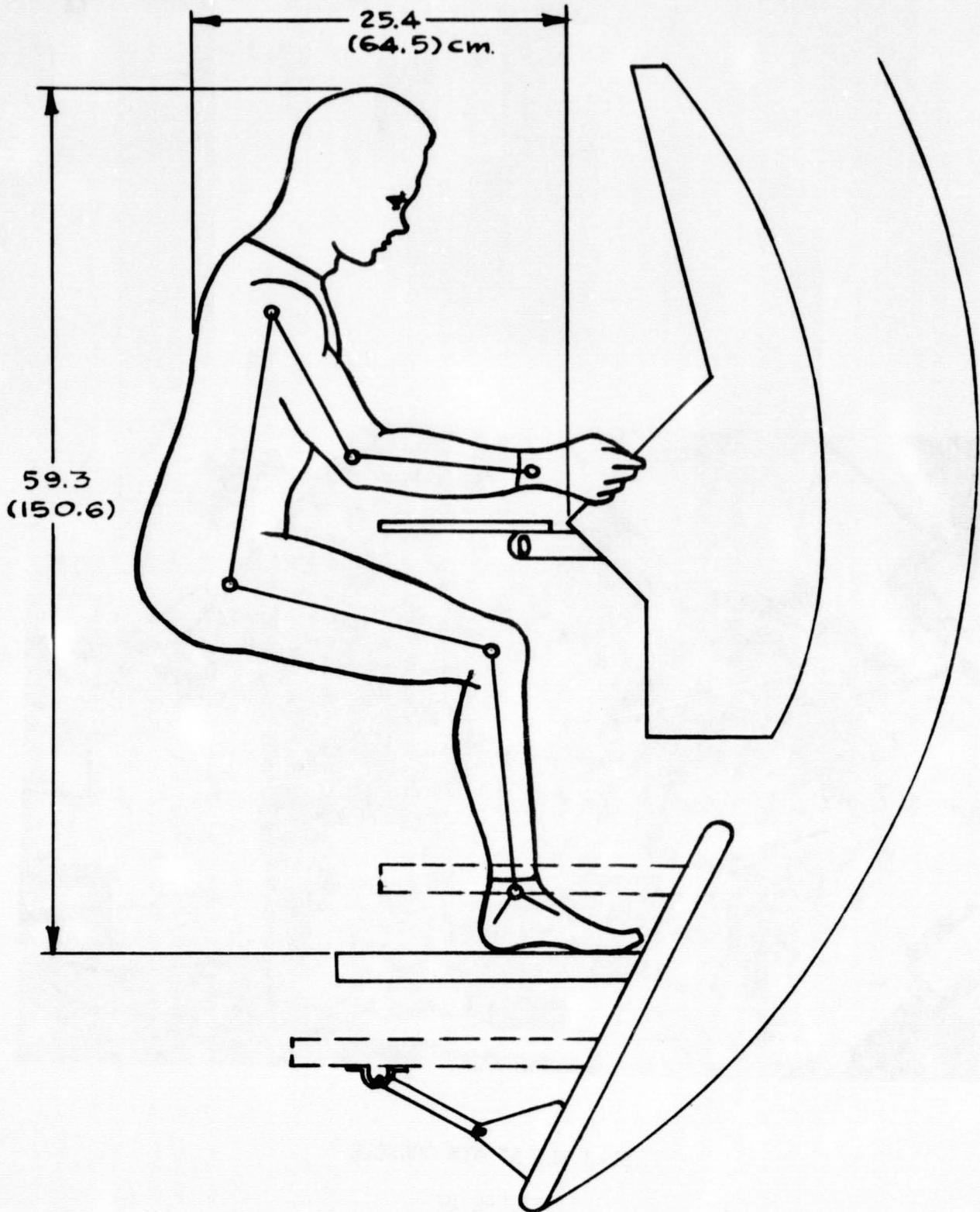
SL-4 CDR: "Yes, but your abdomen and muscles tensed up and you just got tired of it." (SL-4 Systems Debriefing)

The foregoing comments indicate that even with a "best fit" position some of the crewmen were not satisfied with the interface at the ATM console. The "best fit" positions depicted in Figures 33 through 35 are best only in the sense that they were achievable within the constraints of the geometry of the workstation layout. The average crewman fits best, but not on the mid-position, or average position, of the platform. Apparently the platform was designed more for seated use than semi-standing use, and the standing position was further complicated when the platform was not adjusted to give the crewman the best possible interface position. For instance, the SL-3 crew chose to leave the platform in the mid-position as a convenience for the two shorter crewmembers thus forcing the taller member of the crew to "close" his body angle even more. Figure 36 shows the "forced fit" of the large crewman at the console using the mid-position of the platform. His two most significant posture angles, the hip and knee, have closed the 95° and 109° , respectively, both of which are significantly outside the neutral envelope. Figure 37 verifies this data point through an inflight photo. When this photo is analyzed using the Boeman link technique depicted in Figure 38, the knee and hip angles are found to be even more closed; 82° and 90° , respectively. Figure 39 shows the Boeman technique applied to Figure 37.

Awkward postures at the ATM console were not limited to large crewmen seeking a comfortable operating position. Figure 40 shows a crewman having to assume a "hunch back" position to operate a camera located on the console. Figure 41 shows the Boeman overlay of Figure 40, and the hip angle is found to be 81° , again significantly outside the neutral envelope.

The SL-4 SPT commented on this crouched position:

"I always wished that the ATM foot restraint were lower. We all found that we were hunched over when operating the ATM. We got a little better



"FORCED FIT" OF LARGE SKYLAB CREWMAN AT ATM CONSOLE

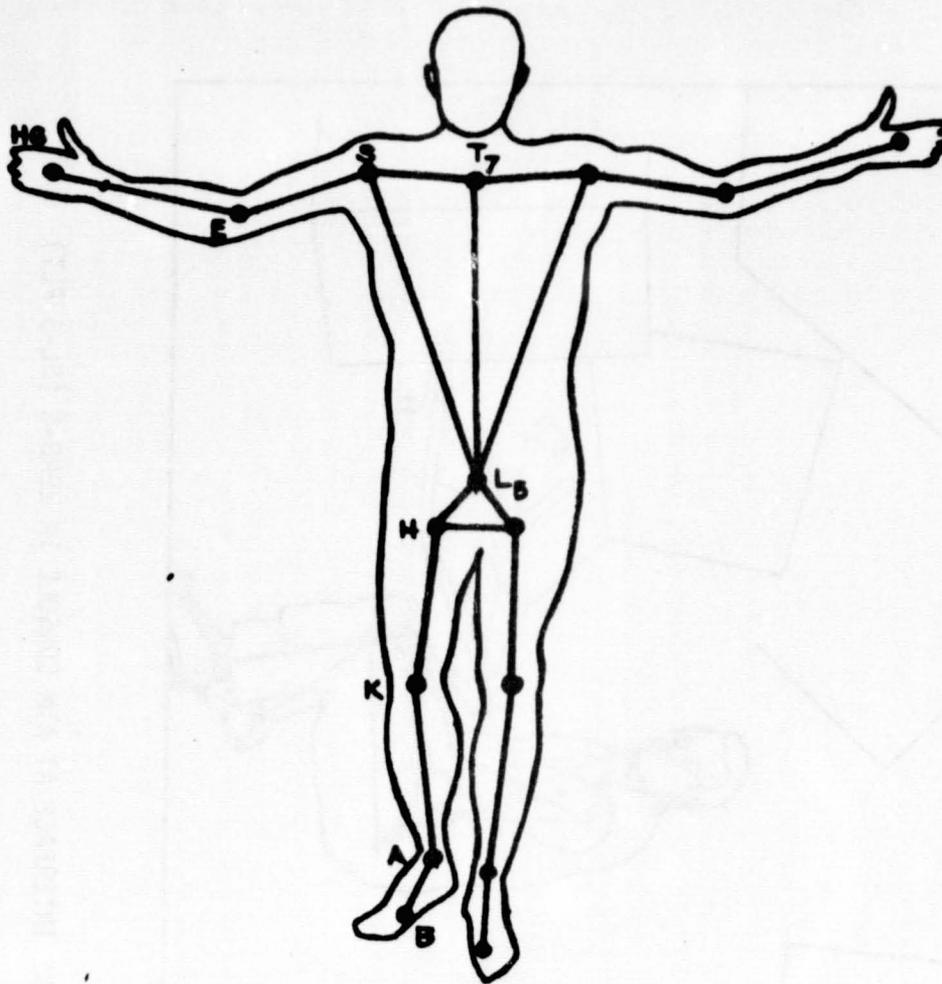
FIGURE 36



SL-3 PLT AT ATM CONSOLE

FIGURE 37

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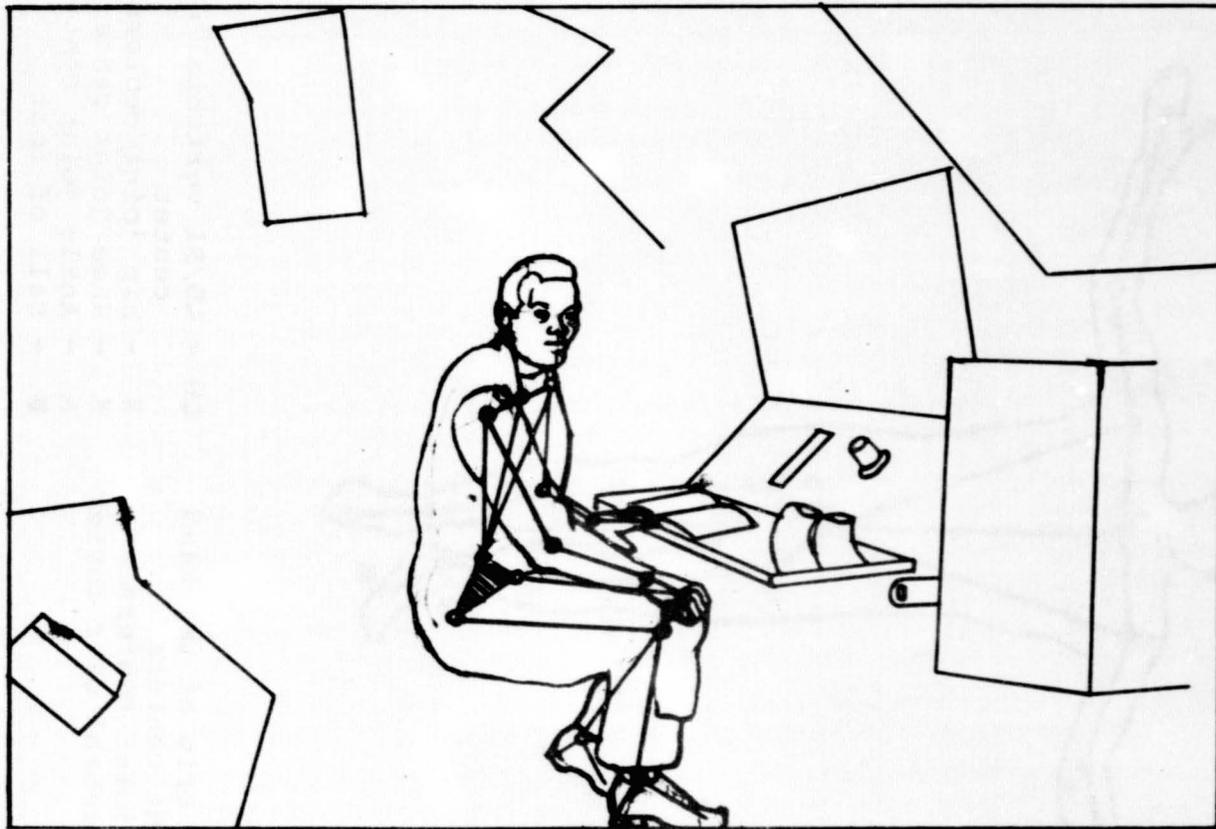
Notation:

HG - Center of grip of the hand
E - Elbow joint centers
S - Shoulder joint centers
T7 - T7/T8 vertebral disc center

L5 - L5/S1 vertebral disc center
H - Hip joint centers
K - Knee joint centers
A - Ankle joint centers
B - Ball of foot

BOEMAN LINKAGE REPRESENTATION

FIGURE 38



MAN/MACHINE INTERFACE AT ATM CONSOLE IN ZERO-G (SL-3 PLT)

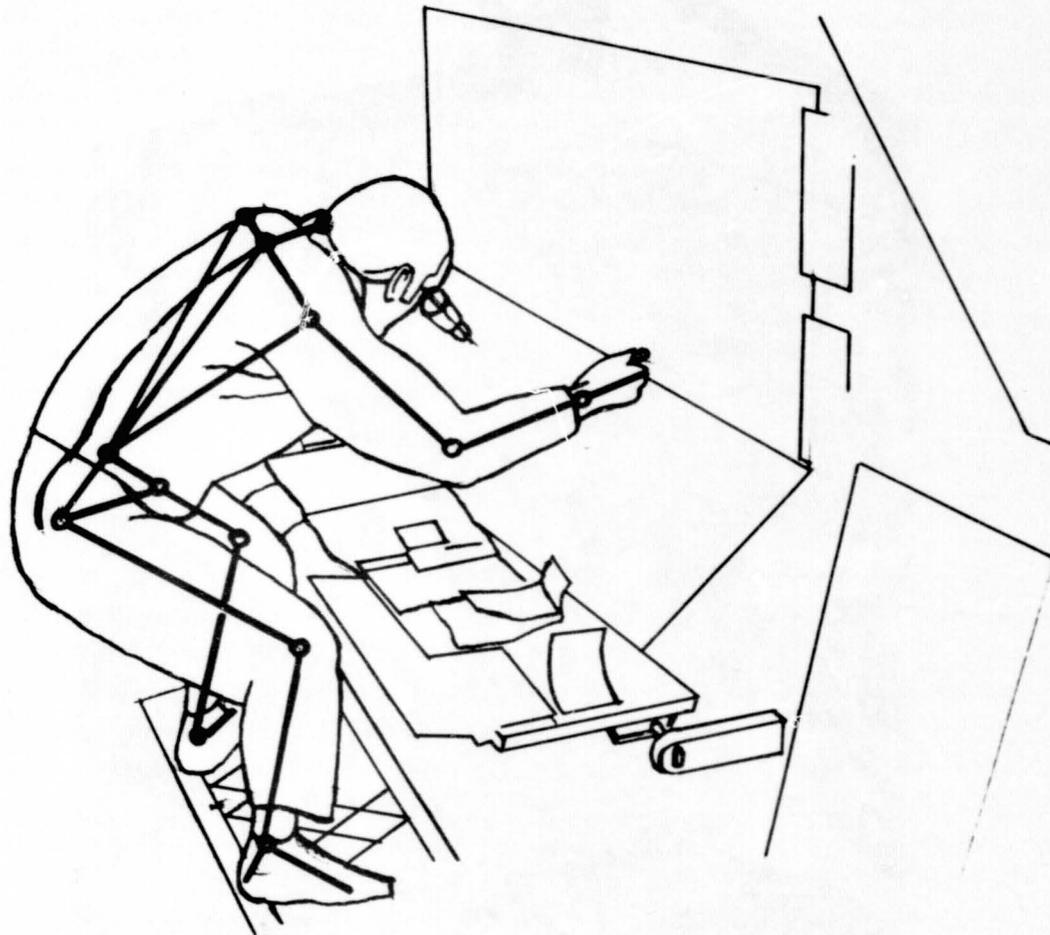
FIGURE 39

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SL-3 CDR OPERATING POLAROID CAMERA ON ATM CONSOLE

FIGURE 40



MAN/MACHINE INTERFACE AT ATM CONSOLE (SL-3 CDR)

FIGURE 41

as we got used to having a higher head position relative to the panel but we always seemed too high on the panel. I would much rather have that thing gone down about 6 to 10 inches. (SL-4 Technical Debriefing)

One unexplainable anomaly developed with respect to the ATM console operator's position. Some crewmen felt strongly that they could not achieve a proper eye position at the workstation, even with the foot restraint platform in its lowest position. The following excerpt from the SL-4 Systems Debriefing addresses this situation:

Query: "You commented in the debriefings on the ATM foot restraint position and the fact that it generally was too high for all of you by about 8 or 10 inches. Did you move the ATM foot restraint from its position and what position did you use?"

SL-4 CDR: "It was all the way down, as far down as it could get."

Query: "It was all the way down?"

SL-4 CDR: "Yes."

It is impossible to support this complaint when the two-dimensional layouts are drawn. Even with the midrange crewmen standing erect when the platform was in its lowest position, their eye positions would not exceed what could be considered reasonable. Consequently, it is assumed that the seated simulator eye position had become so well accepted that it overly influenced the zero-g perception of what was actually achievable in flight.

No attempt is being made here to make a case against the ATM workstation for mission experience certainly reflects that many hours of highly significant data were acquired through its use. However, it did present a recognizable man-machine interface problem which was in many ways quantifiable. The two-dimensional techniques used are in no way intended to supplant three-dimensional full-scale evaluations; they are simply intended to serve as a firm base upon which to build better design techniques for zero-g workstations. No firm quantitative case can be built concerning the performance decrement that might be associated with forcing an operator's posture outside the neutral body envelope until inflight data on muscle activity and fatigue can be acquired and correlated with appropriate task analyses. However, it is not unreasonable to suggest that some portion of the error count described in Reference No. 6 could be ascribed to the operator's position at the console, and that a more optimized design of that interface might have improved performance.

5.2.2 Scientific Air Lock (SAL)

As noted in Section 4.1.2, the SAL workstation in the OWS forward compartment was used in a standing mode since that posture was required to maintain restraint contact with the grid floor while installing, operating, or removing equipment at that workstation.

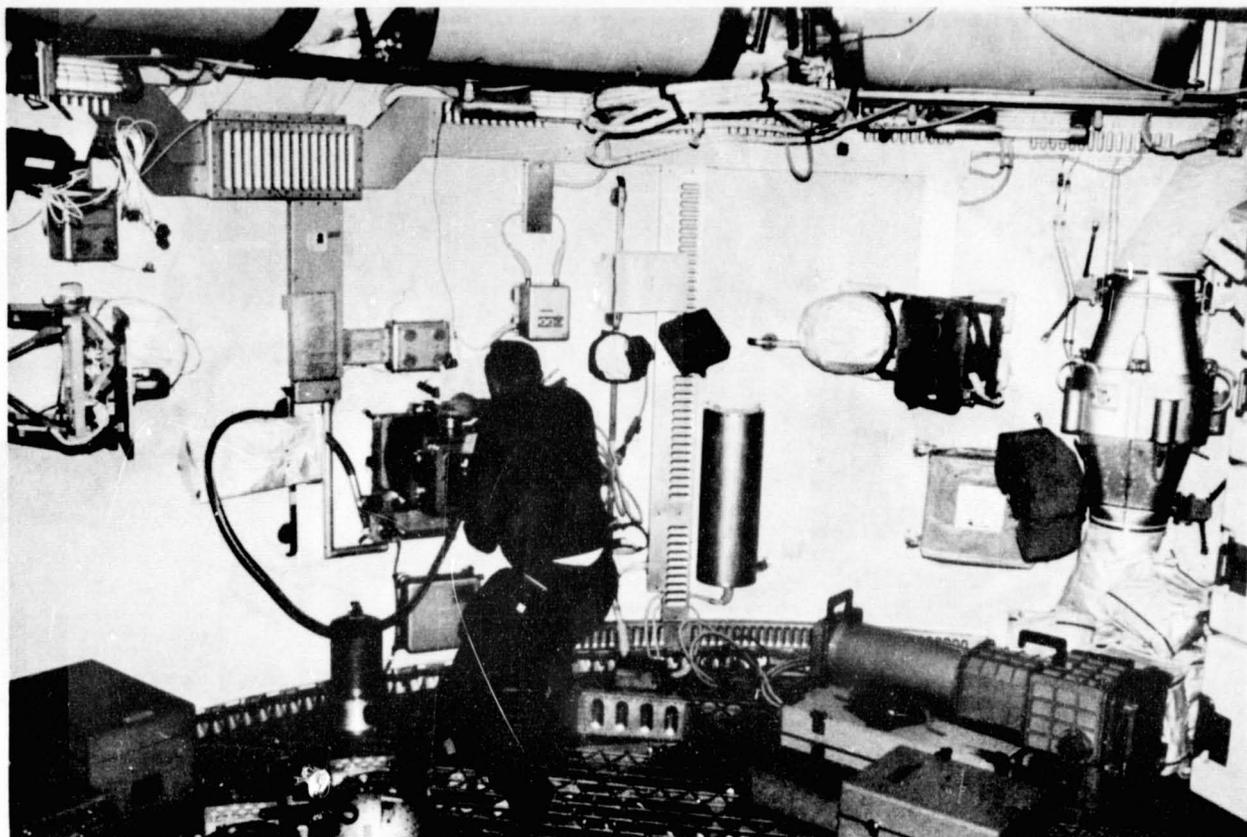
Figure 42 shows the SL-3 PLT using the grid floor for restraint while working at the SAL. It is interesting to note that he has one foot free of the grid, probably to provide stability and possibly as a convenience to keep from using the time to insert both shoe restraints in the grid. Numerous TV and 16mm motion picture films show him using this positioning method at numerous workstations.

The squat depicted in Figure 42 is indicative of two things: first, that a position was required that placed the upper body and arm muscles near the centerline of the experiment to achieve proper installation and removal forces for SAL hardware and second, that zero-g provided a convenient medium for assuming any position required for a short-term task. However, for the long-term monitoring and operation functions required once an experiment was installed, the same positional implications were present as for the ATM console. The closer one was able to approach his own particular neutral body position, the more comfortable, and probably more efficient, he would be at the workstation.

Figure 43 shows the SL-3 CDR at the SAL. Since his feet are not visible in the photo, we can only assume that he is locked into the grid floor. However, his posture doesn't appear to be too awkward for the task he is performing. Although the photo does not show enough of the crewman's legs to accurately determine the hip angle, it can be measured at approximately 150° , about 15° outside the neutral envelope on the "open" side. However, the "open" side of the envelope approaches an erect stance as opposed to the "closed" side approaching a seated position. If we assume that less effort and muscle action is required to straighten up in zero-g than to bend over, then for the average size crewman, the SAL was fairly reasonably located for applying mounting and demounting forces as well as for positioning the eye for monitoring and operation. Location of controls and displays on the experiment hardware could unduly complicate the vision and access tasks which were otherwise tolerable.

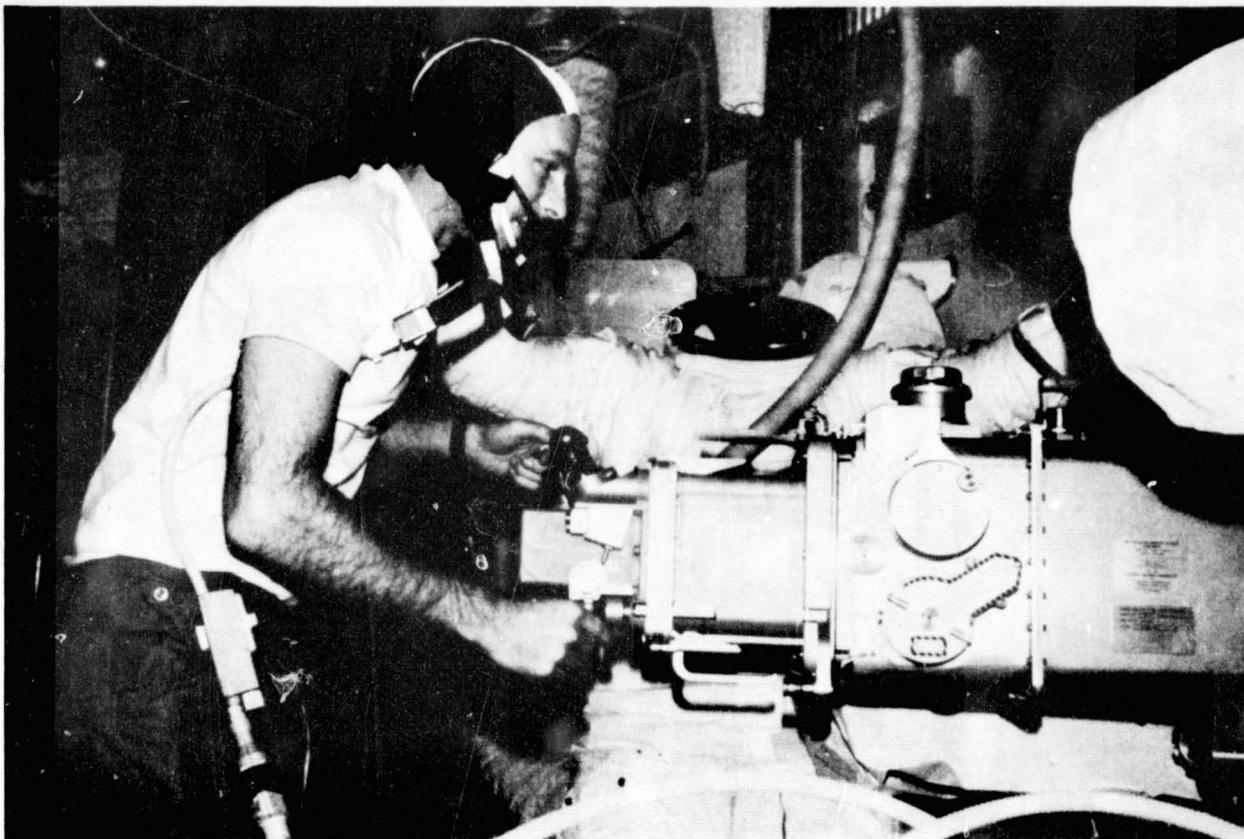
In contrast, Figure 44 shows the SL-2 SPT interfacing with the Earth Terrain Camera at the SAL. Some difference can be seen between the man-machine interfaces shown in Figures 43 and 44. The larger crewman towers over the hardware item and must bend at the waist to see or reach certain elements of the device. Again, it must be assumed that his feet are restrained in the grid floor.

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SL-3 PLT AT SAL WORKSTATION

FIGURE 42

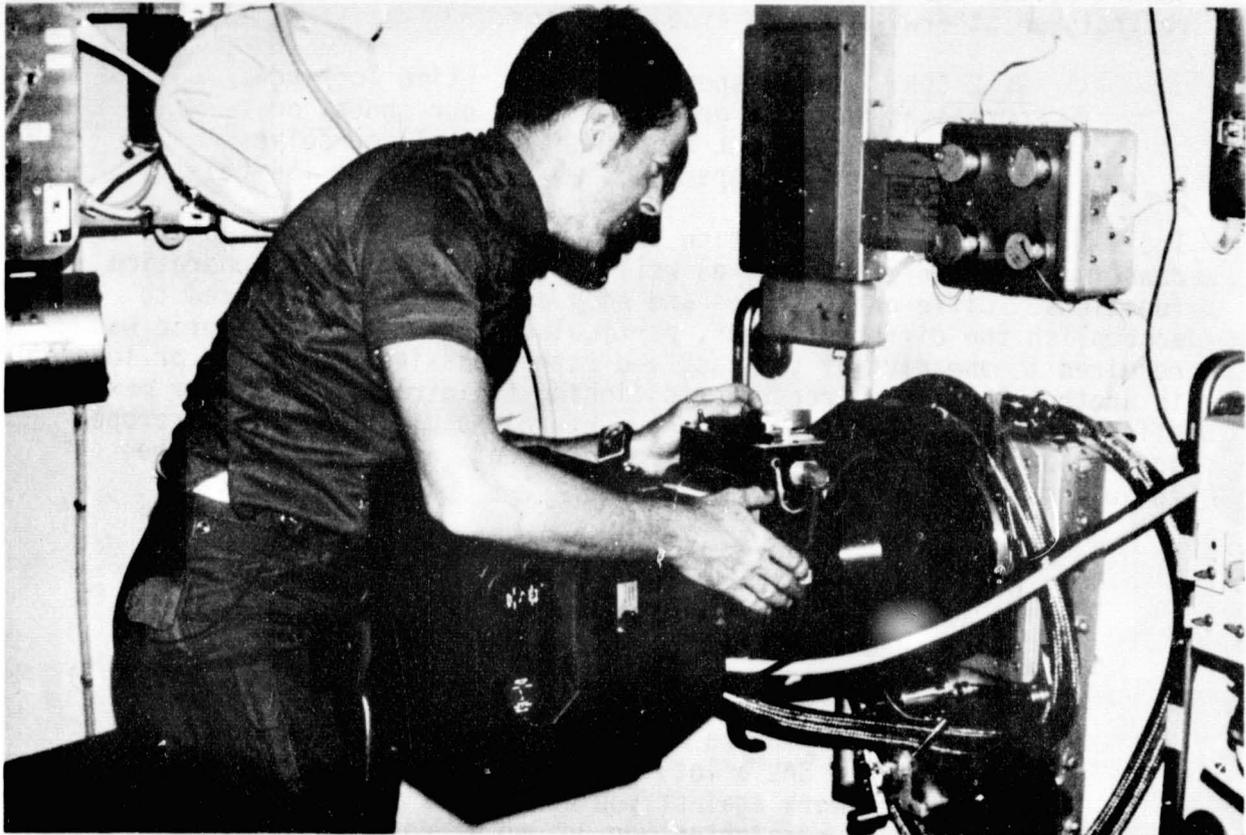


SL-3 CDR AT SAL WORKSTATION

FIGURE 43

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SL-2 SPT AT SAL WORKSTATION

FIGURE 44

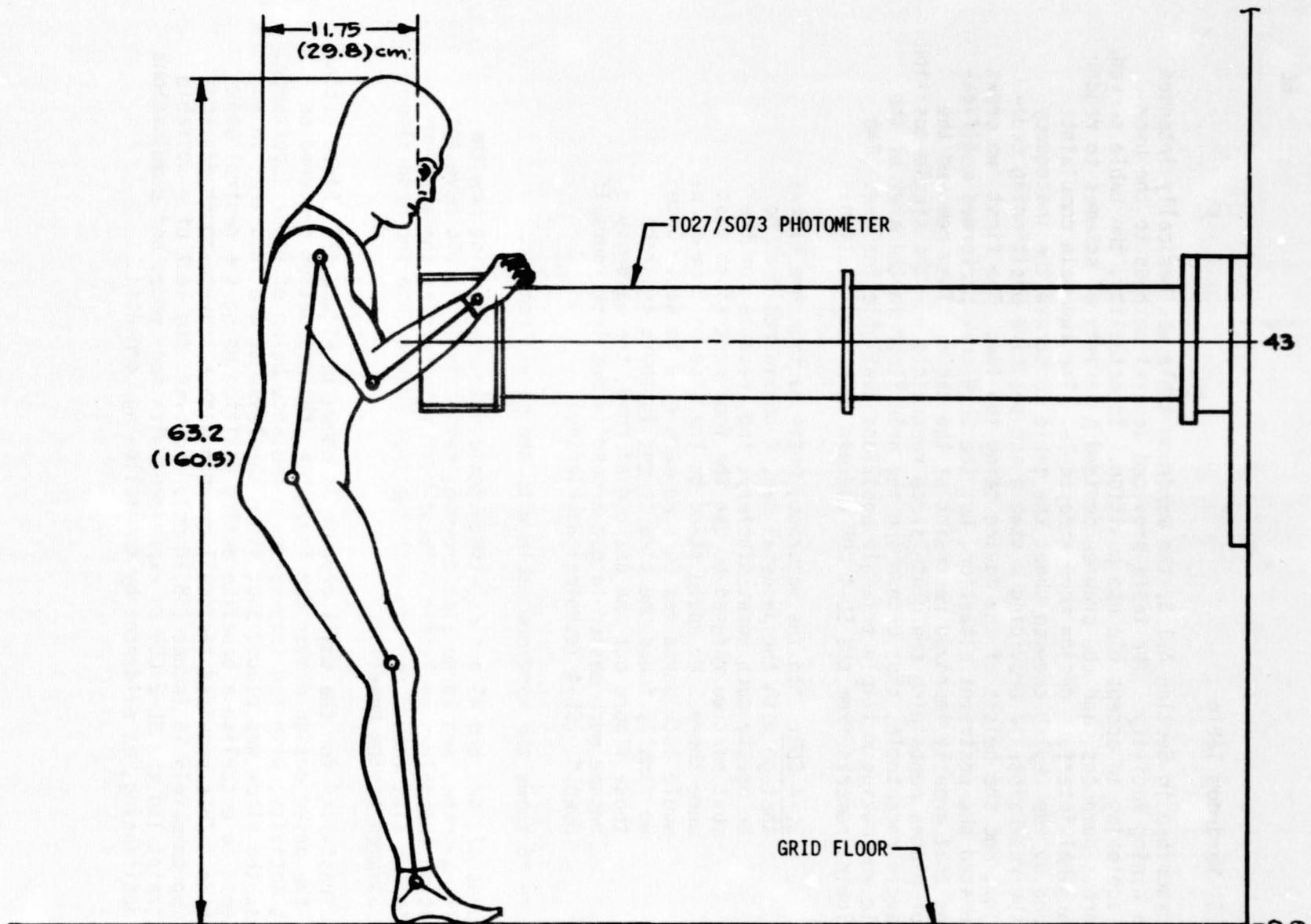
Since no photograph was available showing the representative small crewman at the SAL, a one-tenth scale drawing was developed to depict the position he would have to assume to maintain restraint and operate a SAL installed experiment. Figure 45 shows the interface that confronted the small crewman. He found his body forced toward the upright "open" position outside the neutral posture envelope if he were going to maintain an acceptable eye-to-control and display distance. Even when assuming a fairly erect posture, as in Figure 45, the crewman still was faced with an eye position only 8 inches (20.32 cm) above the top of the experiment, where controls and displays were often located. Obviously, some sort of elevation was needed to properly position small crewmen at the SAL so they could take advantage of the neutral body position. Without such a device the experiment itself was often used as a handhold to restrain an otherwise unrestrained operator.

SL-2 CDR: "We've spent most of our time locking ourselves into the grid floor with our shoes, or holding onto the SAL experiments to hold ourselves in place while we operate them." (Dump Tape 154-06)

The SAL was a unique workstation in that both mechanical setup and take-down functions were required as well as the monitoring and operation functions. Different postures and body positions were required to accomplish the different tasks, particularly where physical force was required in one part of the task and rather passive monitoring or logging in another portion. Properly positioning the airlock itself for maximum efficiency in installation and setup exercises did not insure a proper operation position of the installed equipment, as evidenced by the following comment:

SL-4 PLT: "Discuss both the beneficial and the detrimental effects of zero-g on the following types of activities. Individual work activities while restrained at a specific work location. Okay, if you're restrained in zero-g, the only disadvantage of zero-g is the upright preference of the body posture. If you are hunching over an object like we do at the SAL a lot, that's an awkward posture. Zero-g can work against you as well as for you. It tends to straighten you up, so if your work posture is a crouched over or bent over position at the waist, then you're expending extra energy and zero-g is hurting you." (M487-2C)

Future workstations that will require this type of dual-mode activity should be designed with inherent flexibility in operator positioning devices to allow the most efficient posture to be brought to bear on each portion of the overall task.



"BEST FIT" OF SMALL SKYLAB CREWMAN AT SAL

FIGURE 45

5.2.3 Wardroom Table

As described in Section 4.1.3, the wardroom table was basically intended as a dining facility. The table provided several methods to the user for achieving an acceptable use position. In actuality, the table served numerous purposes, and the crewmen devised a variety of schemes to render a marginal interface design more acceptable. The two main complaints voiced by the Skylab crewmen about the table concerned the inadequacy of the restraints in providing a stable and positive positioning capability, and the height of the device being too low. The first two crews tolerated the restraint situation, but the SL-4 crew performed modifications that greatly improved restraint at the table. They removed the floor plates containing the cloth strap restraints and the single-position triangle receptacle, thus uncovering the grid floor in the area of the table and making multiple triangle positions available for use. The following remarks from the SL-4 CDR address this modification:

SL-4 CDR: "In the wardroom, until we took the floors that go with the pedestal out, I considered that to be pretty much unsatisfactory, too, because for the most part we refused to use the foot restraints that were there. We would stand to the side of them or we would lock ourselves in somewhere else to eat. Once we finally found the time to get in there and take those floors out and get rid of them, the wardroom became much easier to get around in and lock yourself down." (SL-4 Technical Debriefing)

Figure 46 shows the wardroom table with the panels removed.

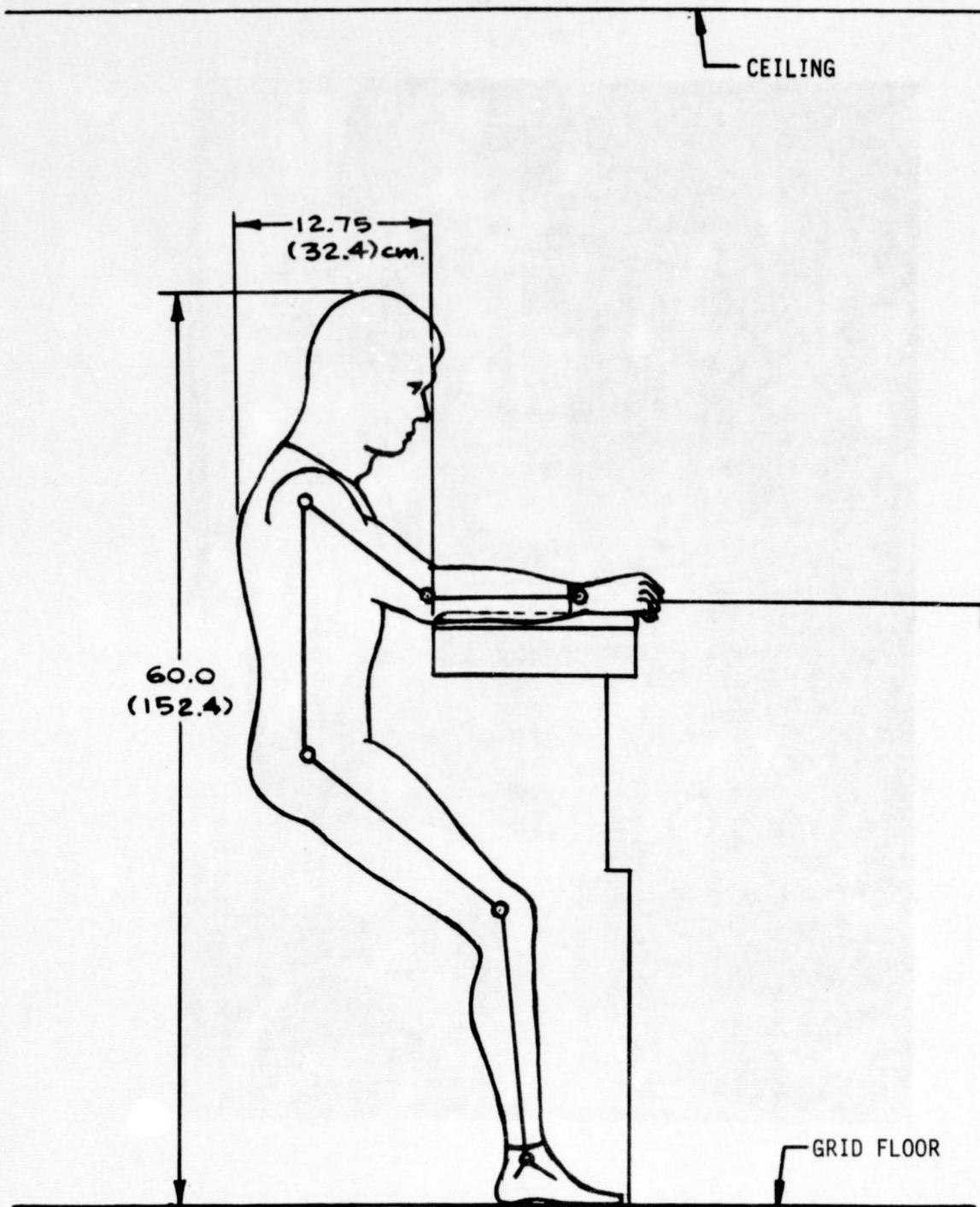
Figures 47, 48, and 49 are one-tenth scale drawings showing how the small, average, and large size crewmen, respectively, would have to position themselves to attain a "best-fit" interface at the wardroom table. A flat footed posture with the shoe locked into the grid floor was assumed as the baseline.

The "best-fit" for the small crewman is shown in Figure 47. Since eating was the prime design driver for the table, the evaluation centered on this activity, with the tray-to-mouth distance being of major importance. Thus, the elbow was placed just above the level of the food tray in an attempt to establish a baseline eating position using the neutral body posture. This provided the small crewman with a tray-to-mouth distance of approximately 15 inches (38.10 cm). However, the lack of a suitable restraint led the SL-2 CDR to experiment with many modes and combinations of positioning, as evidenced by the following comments:



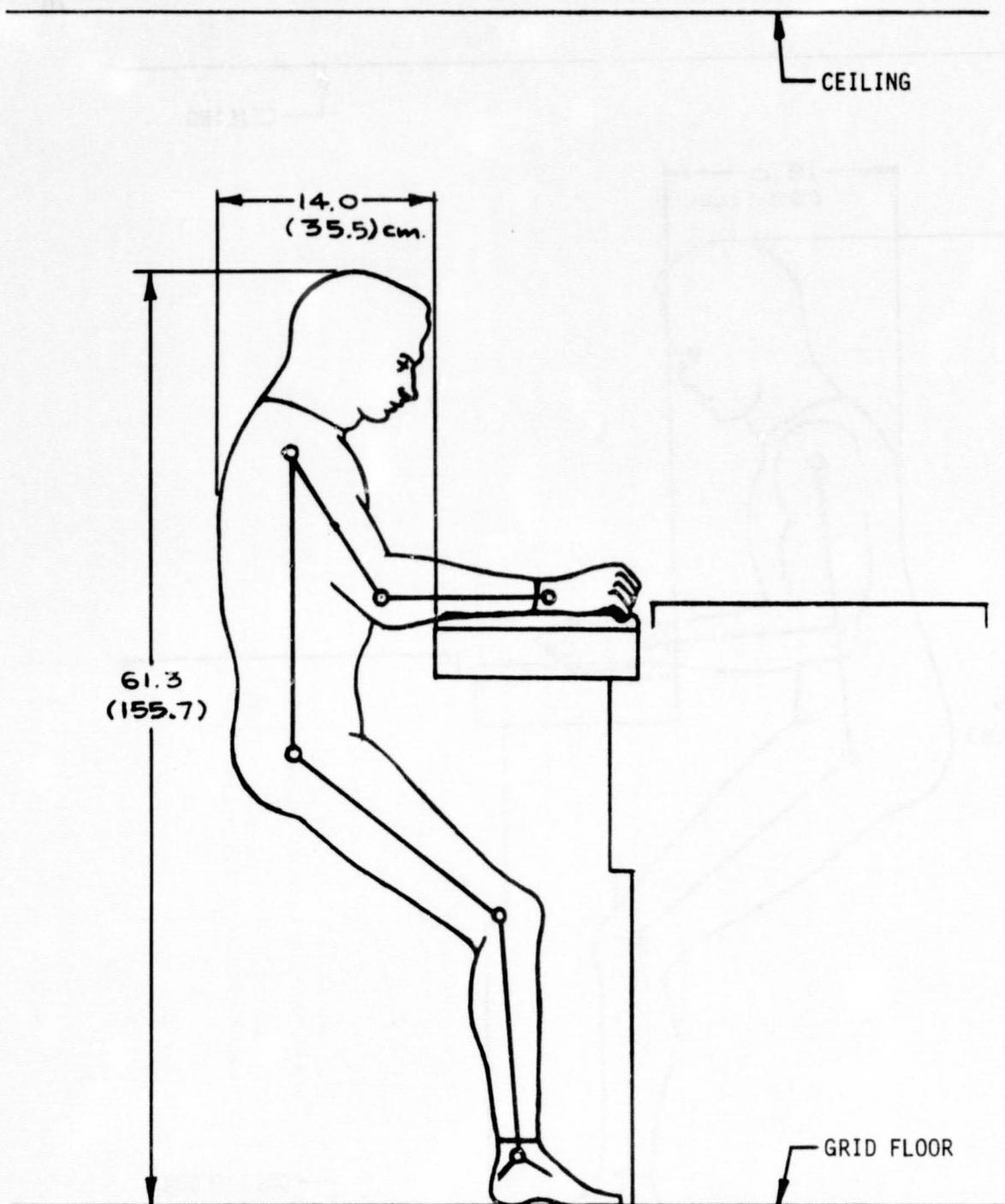
WARDROOM TABLE WITHOUT FOOT RESTRAINT PLATES

FIGURE 46



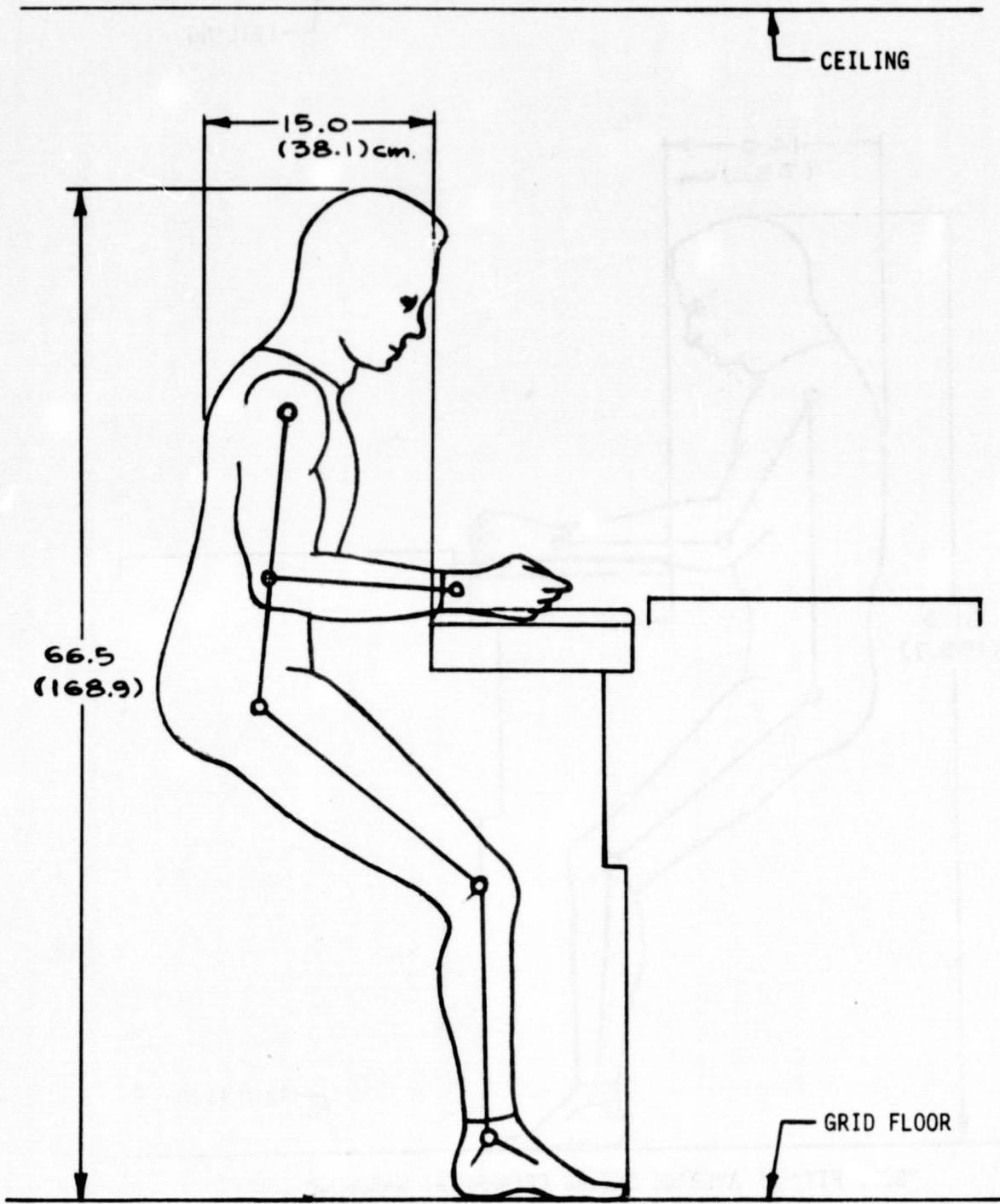
"BEST FIT" OF SMALL SKYLAB CREWMAN AT WARDROOM TABLE

FIGURE 47



"BEST FIT" OF AVERAGE SKYLAB CREWMAN AT WARDROOM TABLE

FIGURE 48



"BEST FIT" OF LARGE SKYLAB CREWMAN AT WARDROOM TABLE

FIGURE 49

SL-2 CDR: "I used the triangles to lock in and sometimes used the thigh restraints when I was eating; but you are in the mode of holding yourself forward with your stomach muscles when you're eating. There was another mode I got into in those thigh restraints where I would get locked into them just the way I am now. Just crossed my feet, free from the floor, and I would read there and I would just take a moment to stabilize myself so I wouldn't rotate. I was actually just free floating with that pole between my legs and I'd just hold the book out here, and once you could stabilize with your elbows you could get the roll out of it, and after that you could relax completely. And your feet would lock in and your back would curve back, and that was a nice reading position." (SL-2 Corollary Debriefing)

The "best-fit" for the average crewman is shown in Figure 48. It becomes slightly more difficult to fit the average size crewman to the workstation while retaining all the desirable positioning traits for the eating task. His tray-to-mouth distance lengthens to about 17.5 inches (44.45 cm).

The "best-fit" for the large crewman is shown in Figure 49. In this instance the tray-to-mouth distance increases to almost 20 inches (50.80 cm) and the arm angles at both the shoulder and the elbow begin to close.

Various solutions were adopted by different crewmen to solve the problem of positioning at the table. An analysis of Figures 50 and 51 revealed that the SL-3 PLT stood to one side of the wardroom table at an approximate angle of 45° to the food tray centerline while eating. In an apparent attempt to adapt to a less than optimum interface, he also straddled the pedestal in a "forced-fit" as illustrated in Figure 52. The "one-foot" restraint method illustrated is typical of his preference for restraint at all the standup workstations aboard Skylab.

Another difficulty at this workstation is illustrated in Figure 51, which shows the SL-3 CDR reconstituting one of his drinks. The reconstitution station was much easier to reach and operate from a position between the food trays rather than to reach over the tray while restrained in an eating position, especially for the smaller individuals with shorter reaches.

One of the common solutions to the problem of excessive tray-to-mouth distance is illustrated in Figure 53 where the food can has been removed from the tray and held close to the mouth. This was an acceptable practice but did limit the meal to a single item at a time or numerous retrievals and replacements of cans.

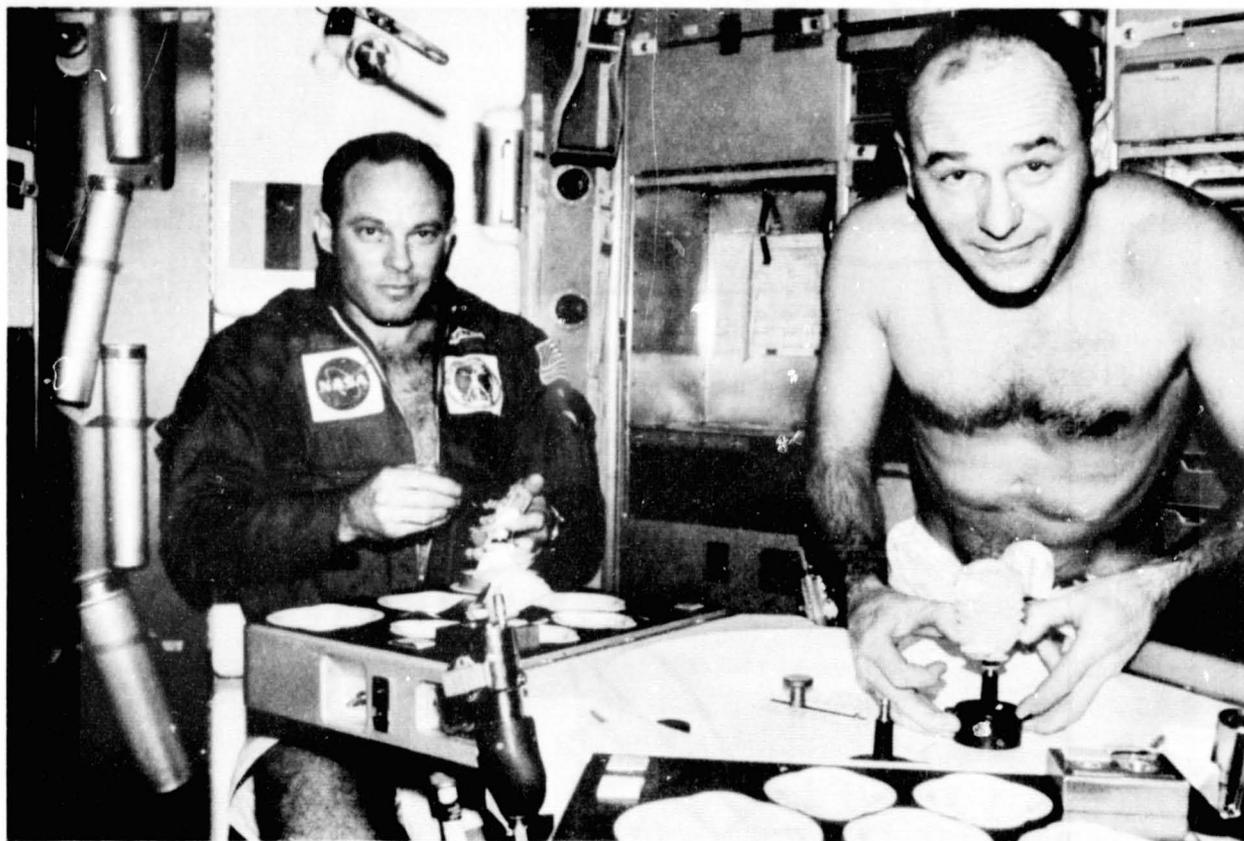


SL-3 PLT AT WARDROOM TABLE

FIGURE 50

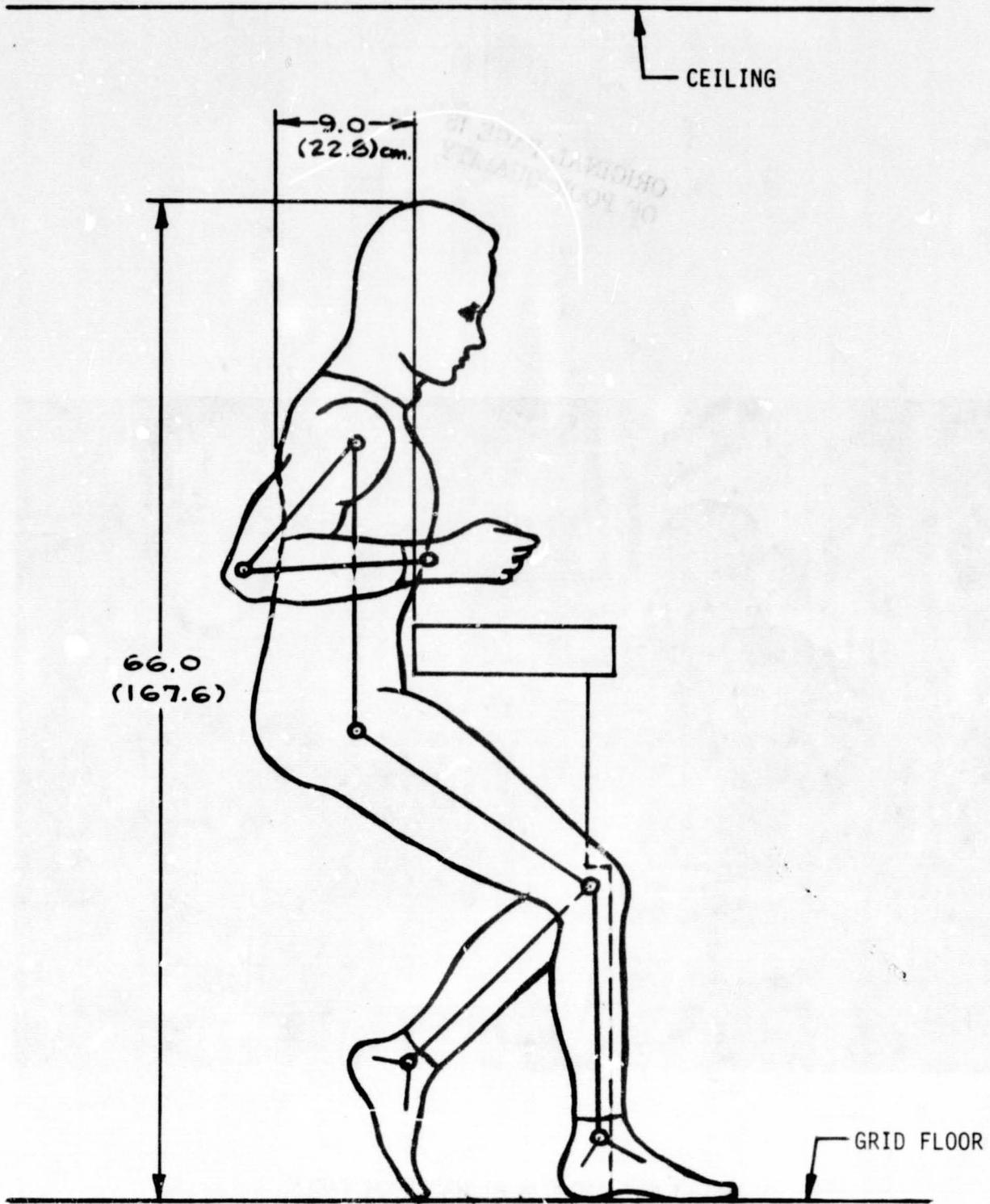
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SL-3 PLT AND CDR AT WARDROOM TABLE

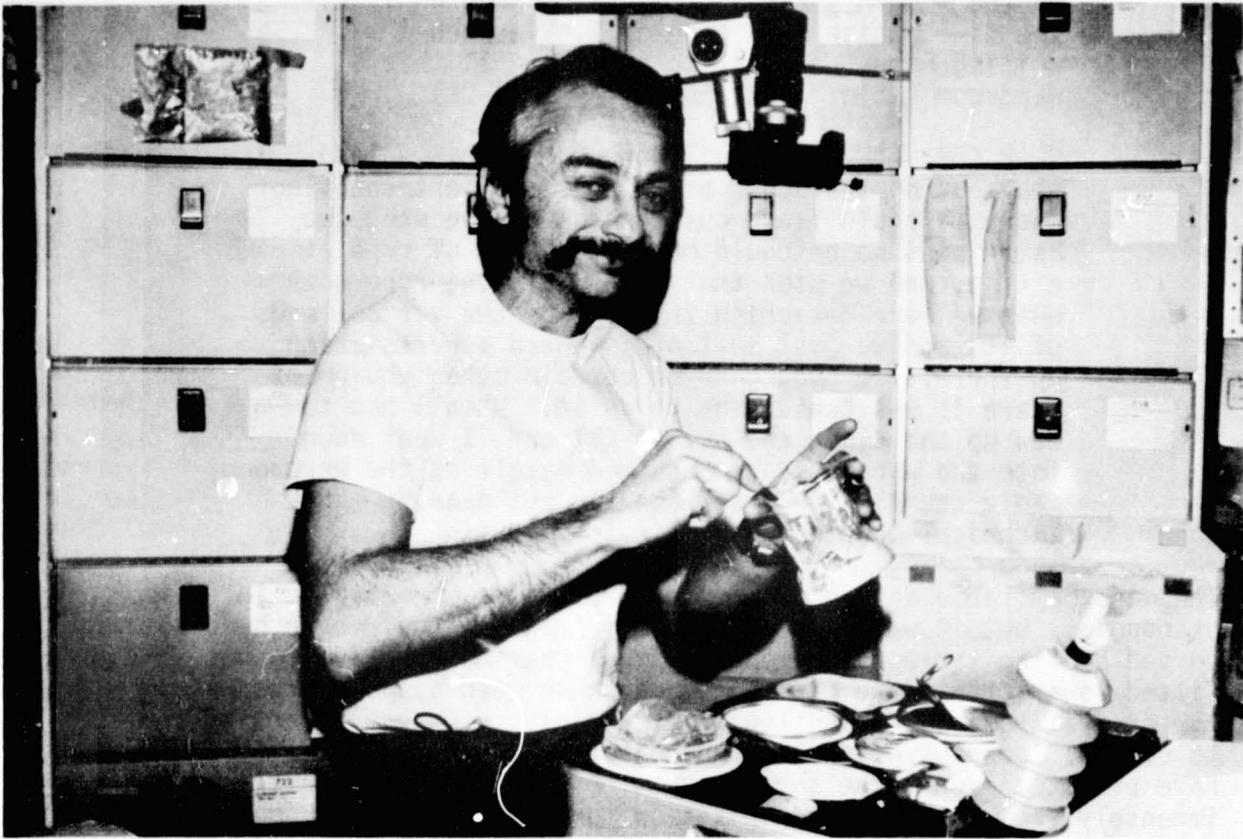
FIGURE 51



"FORCED FIT" OF LARGE SKYLAB CREWMAN AT WARDROOM TABLE

FIGURE 52

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SL-3 SPT AT WARDROOM TABLE

FIGURE 53

The wardroom table was also used as a desk (with the food tray cover installed) and as a general support work surface. The following crew comments are indicative of non-eating uses for the table:

SL-2 PLT: "I have, on occasion, put the cover on my tray and used it as a desk. I think we're looking at the ideal world, what you would want in a desk, you'd want a larger flat area with things on it, a light, a good light. And things on it to hold a number of papers, to hold it down while you're using it. You know, like your checklist there and your notebook there and you'd want someplace to put it so you wouldn't have to hold your hand on it all the time, which is a problem I have when I'm writing notes, or copying something at this wardroom table. (SL-2 Dump Tape 160-01)

SL-2 CDR: "When we built the EVA gear, we laid that out on the upper experiments compartment floor where we could flake out the rope. Joe used two astro pins so he could measure 5 feet of rope at a time, and we used that to tow all the rope down when we were detaching things from the various ends of it, and we just sort of invented a workstation up there. We hung gear on certain other equipment where it was convenient to do it. When I had to sew up the cloth and cut it all out, I went down into the wardroom and anchored myself at the wardroom table where I could sew and lay out gear." (SL-2 Technical Debriefing)

The wardroom table design was acceptable from a man-machine interface standpoint, but it was far from optimum. Eating could have been better served had the table been higher and had the individual trays been tilted toward the user. Writing could have been supported better by larger flat surfaces, lighting, and multiple, portable restraint devices to control loose paper, pens, and pencils. Various other uses would have profited from these same changes. All users would have profited immensely from a better body positioning arrangement in support of the table, plus the foresight in requirements definition to recognize the many potential uses of the device and to design it accordingly. Future designs should profit from these lessons.

5.2.4 Structural Transition Section (STS)

The STS was a prime example of an open and unrestrained crew station, containing handrails to assist in mobility and one-handed retention

but no restraint devices. Consequently, tasks at this workstation had to be performed by either free-floating or partially restrained crewmen. Figure 54 shows the SL-4 PLT performing a task in the STS. The photograph clearly shows the normal mode of operation at this station: hanging on with one hand while manipulating controls with the other. This type of design is certainly not suitable for long-term tasks. Fortunately, however, most of the tasks called for at this workstation were momentary, such as checking an instrument reading or setting a switch to a different position. Nevertheless, the difficulties associated with operating in a completely open volume without adequate retention and positioning devices is reflected in the following comments from the SL-4 PLT:

SL-4 PLT: "Number 2, what postural adjustments have you had to make in order to accommodate task performance in zero-g? The STS and the MDA are very difficult locations in which to work with tools, because of the great lack of foot restraints and body restraints. And this means that you end up use--using your body against whatever things--whatever pieces of hardware are available. And I have experienced numerous cuts and bruises and so forth in trying to stabilize myself while I'm working with tools or just with installations."
(Dump Tape 022-03)

In addition to the difficulties associated with properly positioning themselves to function efficiently at the STS workstation, the crewmen quickly noted one other major design deficiency of the area. It was located along a primary traffic route, traveled numerous times every day by each crewman. Consequently, there were continued opportunities to interfere with someone trying to work at the station, and each passage exposed the D&C panels to inadvertent contact. The following conversation between the CAPCOM and the SL-2 PLT addresses this point:

SC: "You know Crip, we're not sure any of these switches; any of these switch breakers on the STS panel. There's always a potential for inadvertently opening those darn things, and I was thinking about that last night, and we probably ought to pass on to the 487 people. I guess I'll put it on B channel. But if you got exposed breaker panels with the switch breakers on, you got to cover them. The guard is not enough. You got to flat cover them with something."

CC: "Roger. Do you think there's a change that you might accidentally pop that one open?"



SL-4 PLT AT STS WORKSTATION

FIGURE 54

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SC: "That's what -- That's my message really. Any breaker on panel 200, 201, or 202, always has a potential for having been inadvertently opened by one of three or four people up here."

CC: "Okay, Paul. We copy, thank you."

SC: "May I add: We've been running with the lights out up there a lot and I've made a lot of trips to the command module yesterday, plus changing that tape recorder paper and around there and its very easy - you get to hanging on with one hand, you get floating around on the (garble) to get in there and knock something off and you'd never know it."
(SL Air/Ground Tape MC416)

Any workstation supporting tasks that require full attention to perform should be located outside areas of potential interference by other crewmen and should have adequate body positioning devices included as an integral element of the design.

5.2.5 Earth Resources Experiment Package (EREP)

The EREP workstation accommodated two crewmen in the forward end of the MDA. One of the two worksites was equipped with a foot restraint platform while the other left the operator to his own devices to properly position himself for the task. Figure 55 shows an SL-2 crewman using the foot restraint platform to interface with the EREP C&D panel. His partner at the Vertical Tracking System (VTS) station had no such luxury. The favorable crew comments concerning the EREP C&D station with the restraint platform speak well for its acceptance as an efficient workstation.

SL-3 CDR: "On a space station, you've got to have some way to connect yourself to the floor. One of the nice things about the EREP C&D panel was that you could use your triangle shoes, so it gave you both hands free." (SL-3 Technical Debriefing)

Figure 56 illustrates that the use of the foot restraint platform allowed the operator to have both hands free. Without such a device, one hand was required to maintain stability. Additionally, crewmen had to position and retain themselves by wrapping their legs around vehicle structure when using the VTS station. The following crew comments address this problem:

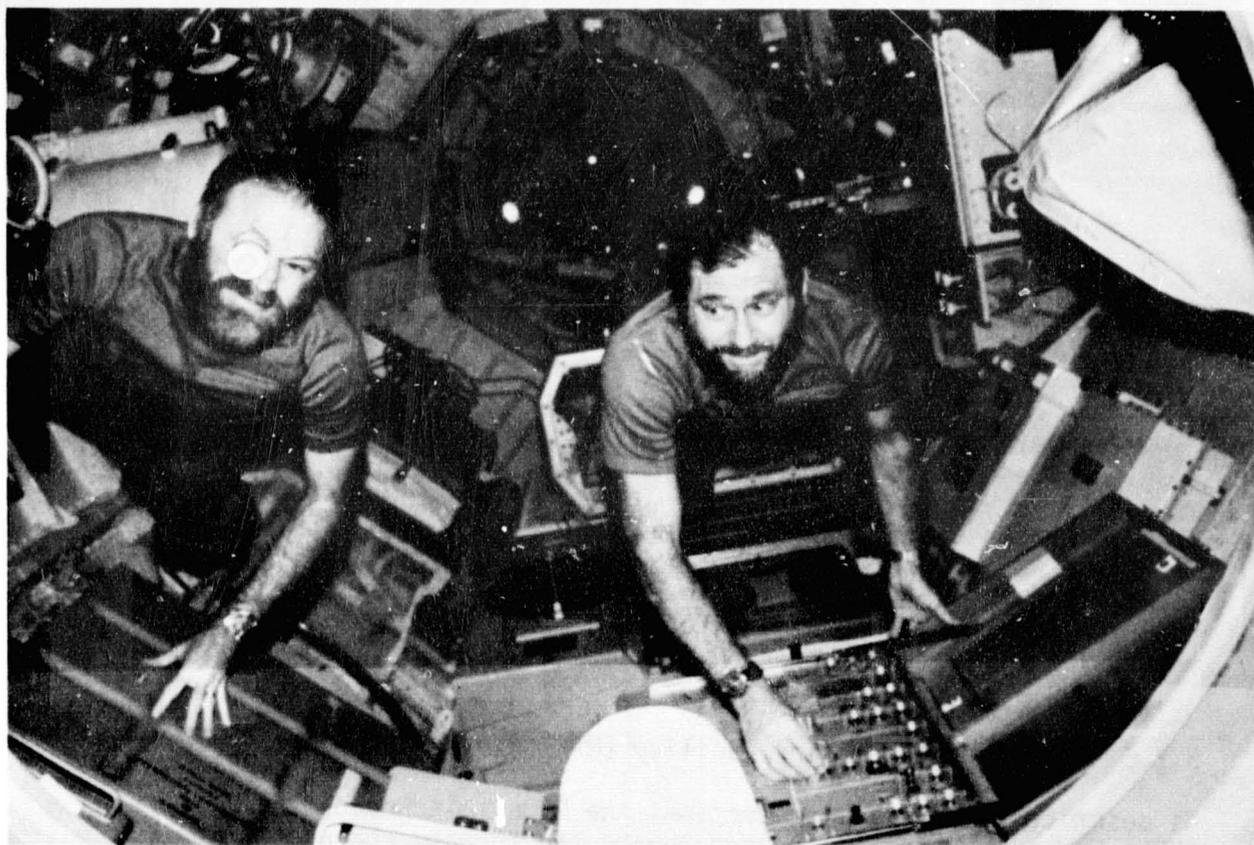


SL-2 CREWMAN AT EREP C&D WORKSTATION

FIGURE 55

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SL-4 CREWMEN AT EREP C&D WORKSTATION

FIGURE 56

SL-4 CDR: "The foot restraints for the C&D operator were very good, but the VTS operator's feet were just free to float. Both of us would just jam our feet underneath that tray holding the interchange duct that brought the air down into the command module. So I think better personal restraints are needed for the VTS operator." (SL-4 Earth Resources Experiment Debriefing)

SL-3 CDR: "One of the disadvantages of the VTS was that you didn't have any foot restraint and you were always trying to put your legs around something else or hold on with your hands which meant your hands weren't free to hold something else. I think maybe in future applications we ought to try to always have some sort of foot restraint at every station. That allows you to move your body and do work with your hands." (SL-3 Technical Debriefing)

SL-4 PLT: "It was very difficult to do some of the tasks which were required. In fact, I put up long straps, and ended up tying my ankles to single handholds, in order to have a good stable body position for doing some of the early work in the coolant servicing loop in particular and for some of the EREP instruments' calibrations." (SL-4 Technical Debriefing)

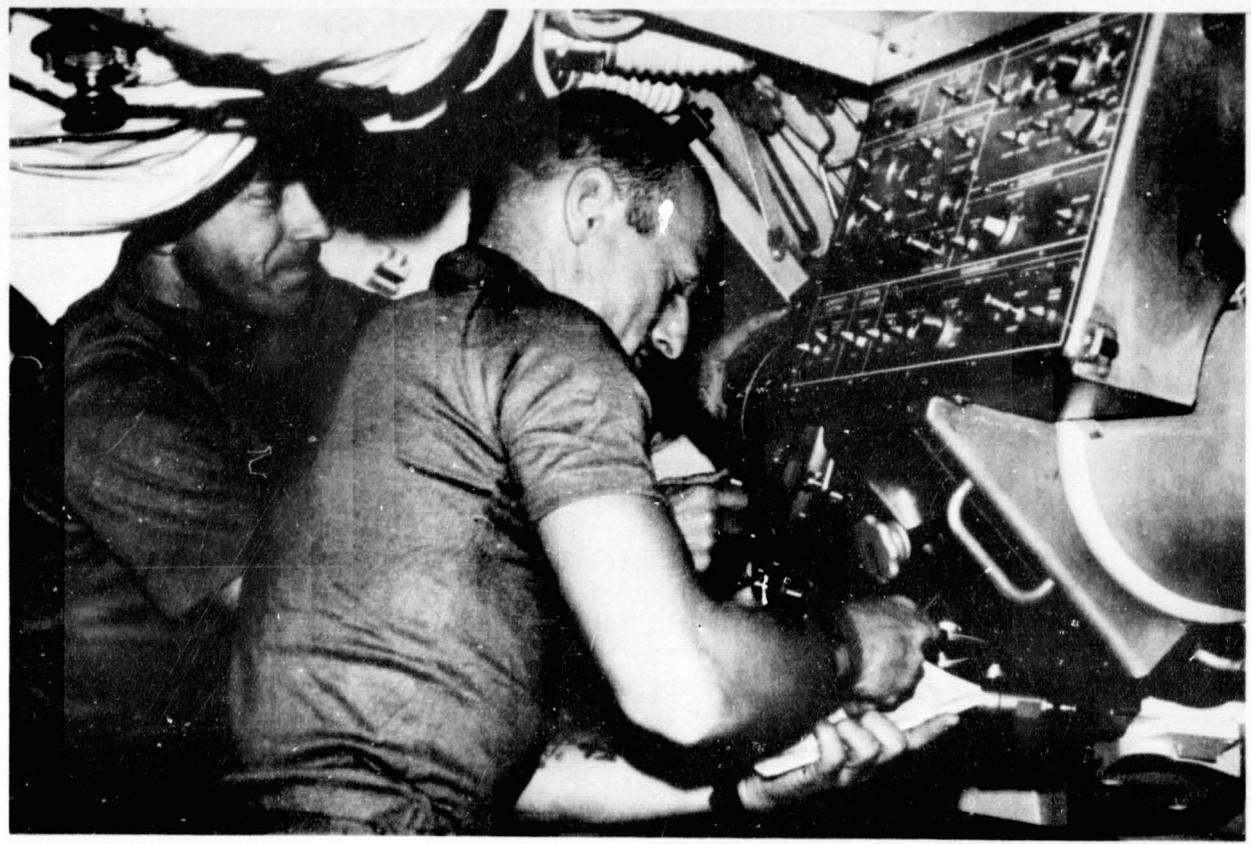
The discussion in this section once again makes the points that proper body positioning and restraint devices are essential to the functional interface of a zero-g workstation, and that requirements recognizing this fact must be integrated into the basic design to insure that inherent inefficiency is not designed to the system through omission.

5.2.6 Materials Processing Facility (MPF)

As described in an earlier section, the Materials Processing Facility (MPF) was a workstation located toward the forward end of the MDA and consisting of multiple components. The design called for a single foot restraint platform to serve the entire facility. This one item turned out to be the most glaring flaw in the design of the workstation: only portions of the facility could be reached and operated from the positions allowed by the restraint platform.

Figure 57 shows the SL-2 crewmen performing a task at the MPF workstation. The SL-2 CDR is assumed to be restrained by the foot platform as he reads the checklist in front of the C&D panel. The SL-2 PLT is assumed to be

unrestrained, holding the work chamber with one hand while leaving the other free to accomplish the task.



SL-2 CREWMEN AT MPF WORKSTATION

FIGURE 57

The following crew comments address operations at the MPF workstation:

SL-4 CDR: "For 479, I used the one triangle in the upper left-hand corner, because that was the closest one. It was poorly placed for the furnace work."
(SL-4 Technical Debriefing)

SL-4 PLT: "When you use the foot restraint for the 512, it's not very good. In fact, I stopped using it yesterday, it was so bad. I could get along better without the thing. It holds your body in the wrong position." (SL-4 Dump Tape 356-06)

The following exchange from the SL-4 Systems Briefing sums up the adequacies and inadequacies of the man-machine interface at the MPF:

Query: "Bill, you mentioned that the M512 foot restraint was a little bit off for some of your work with the furnace, that you had just used one triangle I believe, and you felt the body position was a little wrong."

SL-4 PLT: "Yes; now Jerry, I think, used it all right."

SL-4 CDR: "No, I had the same problem though; all I could anchor was my right foot. The other one was off --"

SL-4 PLT: "Okay. I ended up not even using it for the 512, because the 512 work was so limited. Now the flammability, that was another matter entirely, because that required the continual presence there at the panel, and Jer spent several hours doing that. So on 512, it wasn't even worth the problem."

SL-4 CDR: "The work chamber, the furnace chamber was here. And the floor started here at my right foot and went off that way. So I could anchor - The most comfortable thing was to anchor my foot in the forward left-hand corner, and then the rest of me was hanging out over the end, and I was working with one foot restraint. We just didn't have it in the right place, that's all."

Query: "Apparently they - when it was originally planned, it was organized for --"

SL-4 CDR: "The C&D panel."

Query: "And for the activity back there in the back and the preparation and not actually for ..."

SL-4 PLT: "Oh, for all that stowage and everything."

SL-4 CDR: "Yes."

Query: "Yes. For handling all the other stuff. And maybe that is why, because of the particular type of experiments that were flown on your mission, we didn't have any comment about it on either of the other two missions."

SL-4 PLT: "You know, thinking out loud and not trying to redesign, but, I guess, really suggesting it; you could have something like that foot restraint there, but where you had different levels of the triangles that would telescope and slide out, giving you a longer - which could be rigidized by tethers, maybe. But the idea was excellent. The triangle - when that thing was moved around for C&D work, it was great when - as long as you were right at the C&D panel. But that's all it was good for. But it was excellent for that." (SL-4 Systems Debriefing)

The discussion in this section emphasizes the point that simply placing a body positioning device in the general area of a workstation is not adequate; the device must be designed as an integral part of the overall layout to produce desirable results.

5.2.7 Other Workstations

For the purposes of this report, Skylab was considered to contain four types of workstations or worksites: (1) standing, restrained at the feet; (2) seated; (3) free floating; and (4) improvised. The previous sections have dealt in detail with the standing and seated stations, and somewhat with the free floating stations. This section will address the free floating and improvised stations in sufficient detail to cover their Skylab uses and build a base of experience data for future applications. The discussion will be based upon the efficiency of the man-machine interface of these various workstations under actual off-line operational inflight conditions. First, a series of inflight maintenance (IMF) tasks will be addressed as they occurred aboard Skylab, and a case will be made for having a dedicated IFM workstation where these types of activities can be conducted more efficiently. Skylab had no such workstation; therefore, the crewmen had to improvise when performing off-line maintenance tasks. Following the IFM discussion, other worksites will be addressed and examples shown of the good and bad aspects of zero-g on improvised workstations.

During the SL-2 mission, the docking probe troubleshooting, verification, and checkout tasks required the services of all three crewmen: one to hold the probe, one to read the procedures, and one to perform the work (which required both hands). A worksite capable of restraining the object of interest, retaining the tools, and holding the checklist would have freed two crewmen for other activities. The following comments from the SL-2 CDR address this subject:

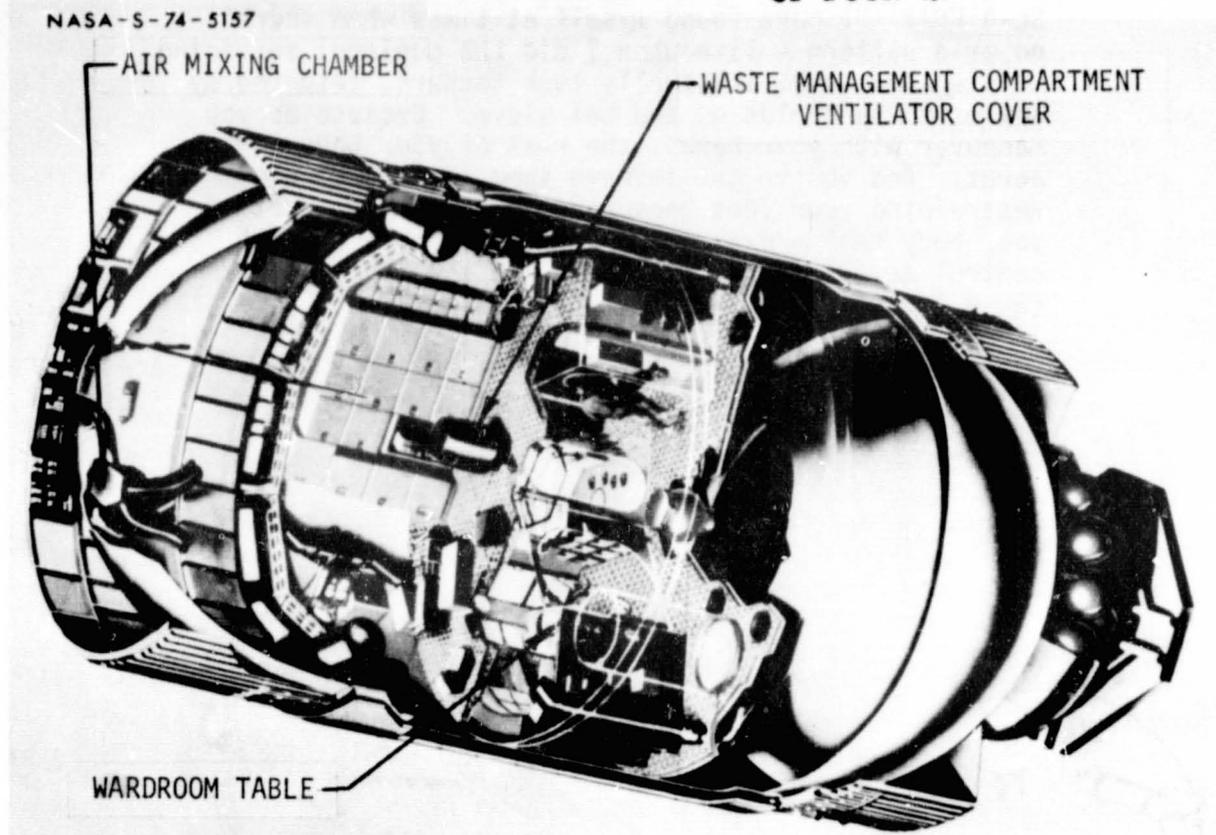
Speaker: "Did you tend to find that the general work area served as a maintenance station? Or did you repair various items either online in their use position or at random locations?"

SL-2 CDR: "We took the probe down to the lower experiments area where we had enough room to get all three of us around it. It was also a good place to lock ourselves in while we were working on it. We started our troubleshooting S019 up in the experiments compartment the best that we could, but when it was time to work on that, I believe you took it down to the corner of the experiments area over by that same pile of 600 lockers where the tool boxes are." (SL-2 Corollary Debriefing)

The SL-3 crew sometimes chose to work on the top surface of the ventilator cover that housed the ventilator fan and filters for the waste management compartment. This unit protruded approximately 3.281 ft. (1 m) above the surface of the grid floor in the forward compartment (Figure 58) and was located approximately 3.281 ft. (1 m) from the front of the rack of food containers, thus presenting a nearby surface for use as an interim stowage area. Pieces of tape were looped to form an adhesive outer surface when affixed to the food containers, thus providing for retention of small parts such as screws, nuts, and bolts. The SL-3 PLT considered this to be a "reasonably good place to work" as reflected in the following comment:

SL-3 PLT: "And I worked on the tape recorders there. Also at the top of the waste management vent filter cover is another reasonably good place to work until we have better ways to hold things down. It's a nice flat surface and about desk height. Fasten yourself down next to it and go to work there." (SL-3 Dump Tape 250-07)

A most effective worksite was improvised by the SL-4 crew. They took many of the small off-line repair and servicing tasks to the air mixing chamber return-air vent screens in the dome of the OWS (Figures 58, 59, and 60). The air flow through the air mixing chamber did collect things (see Figure 60) and the SL-4 SPT used this phenomenon to create a workstation at this site. The 60-mesh screens had an air velocity of approximately 4.9 ft/sec (1.5 m/sec) across the surface and were approximately 0.98 ft² (0.3 m²) in area. This combination of aerodynamic retention and available useable surface area provided a suitable work bench. A small bin was created by taping cardboard sides approximately 3.94 in. (10 cm) in height to the screen, thus reducing the tendency of small loose items to be dislodged from the screen by either air flow turbulence or an inadvertent bump by the working crewman. This principle of aerodynamic retention should find application in the design of a work bench for future vehicles.

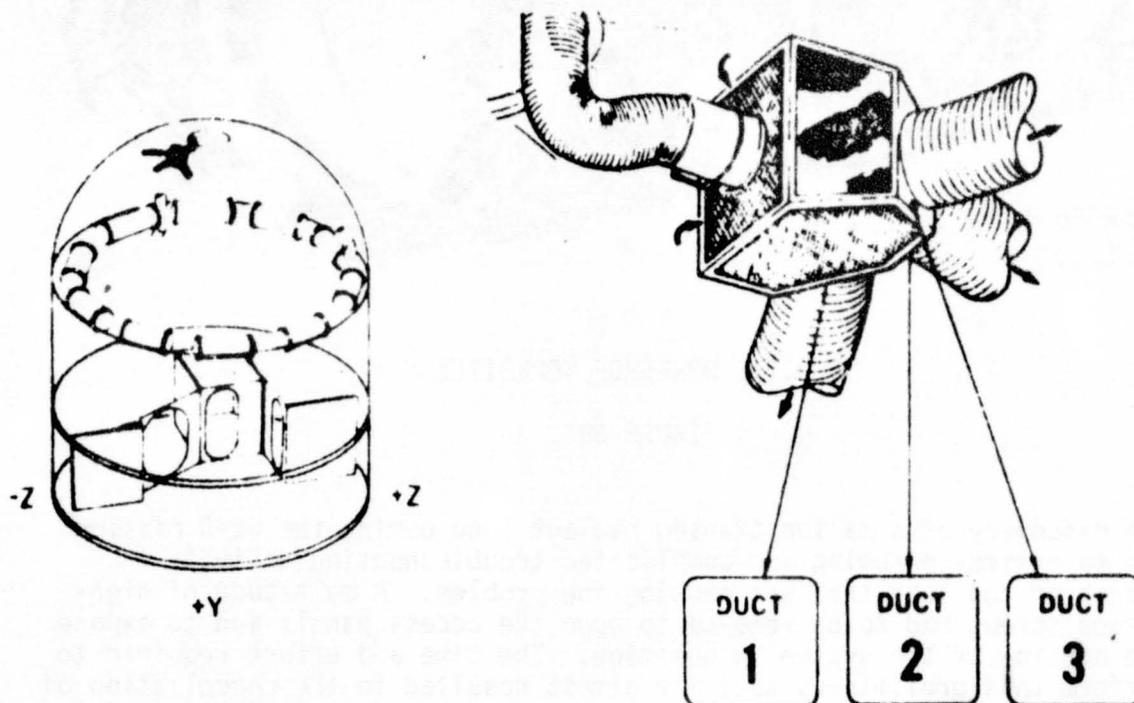


ORBITAL WORKSHOP WORKSITES

FIGURE 58

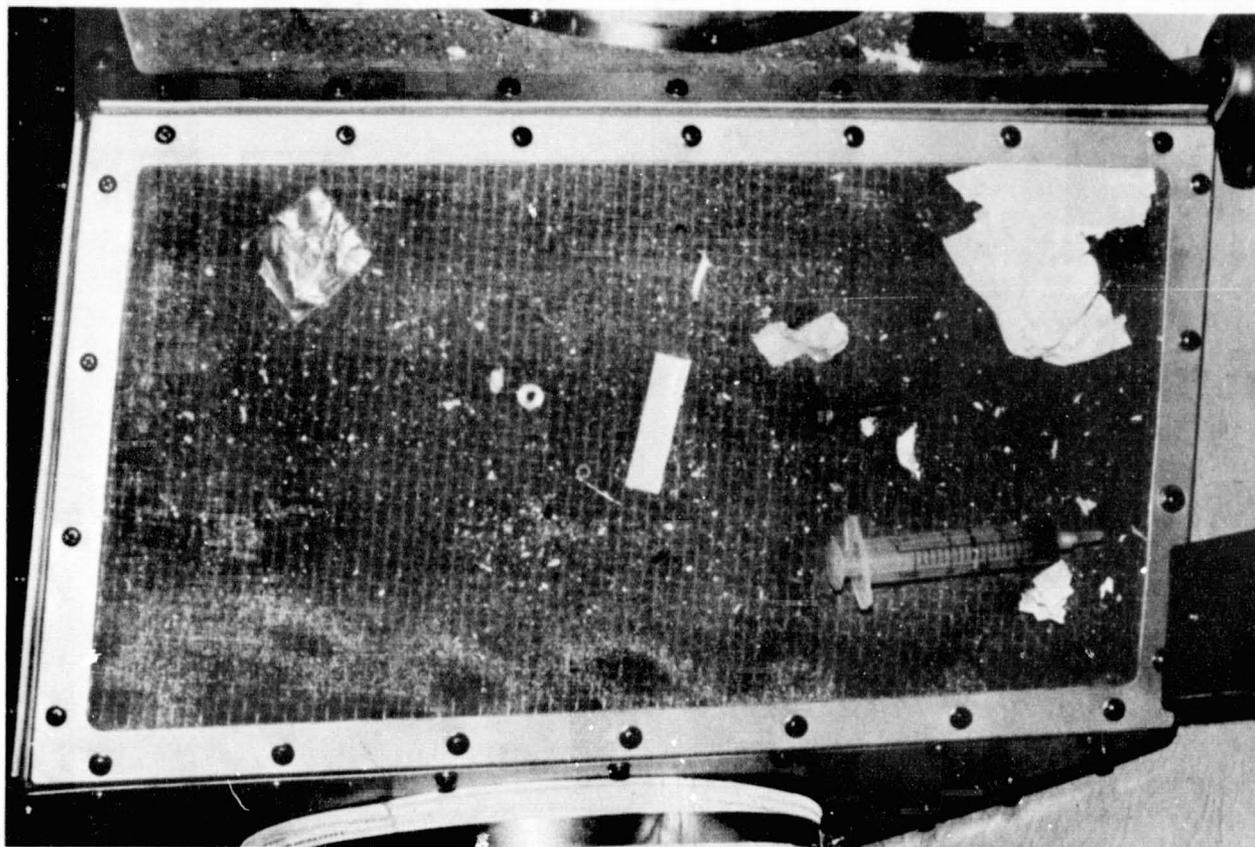
The discovery of a malfunctioning coolant loop during the SL-3 mission led to a time-consuming and complicated troubleshooting activity in search of the leak that was causing the problem. A multitude of high-torque screws had to be removed to open the access panels and to expose the portion of the system in question. The time and effort required to perform this preliminary activity almost resulted in the cancellation of the actual troubleshooting task. With the access route cleared by the SL-3 crew, the SL-4 crew was able to service the coolant loop with replacement coolant in a very routine manner, thus not only rendering the subsystem usable again but also demonstrating the feasibility of such servicing operations in weightlessness. The coolant servicing task could not be accomplished until the SL-4 SPT tethered his ankles to handholds on the mol sieve because as he maneuvered with his hands, the rest of his body torqued about as he indicated in the following crew comments:

SL-4 PLT: "I have found myself at times when there's no grid pattern - like when I did the coolanol servicing maintenance task, I actually took tethers, tethered my ankles to handholds on the mol sieve. Because as you maneuver with your hands, the rest of your body torques about. And you've got to have some - some way of restraining your feet because this is the one part of your body that - over which you do not have as much control as, of course, the arms and the upper body."
(SL-4 Technical Debriefing)



AIR MIXING CHAMBER

FIGURE 59



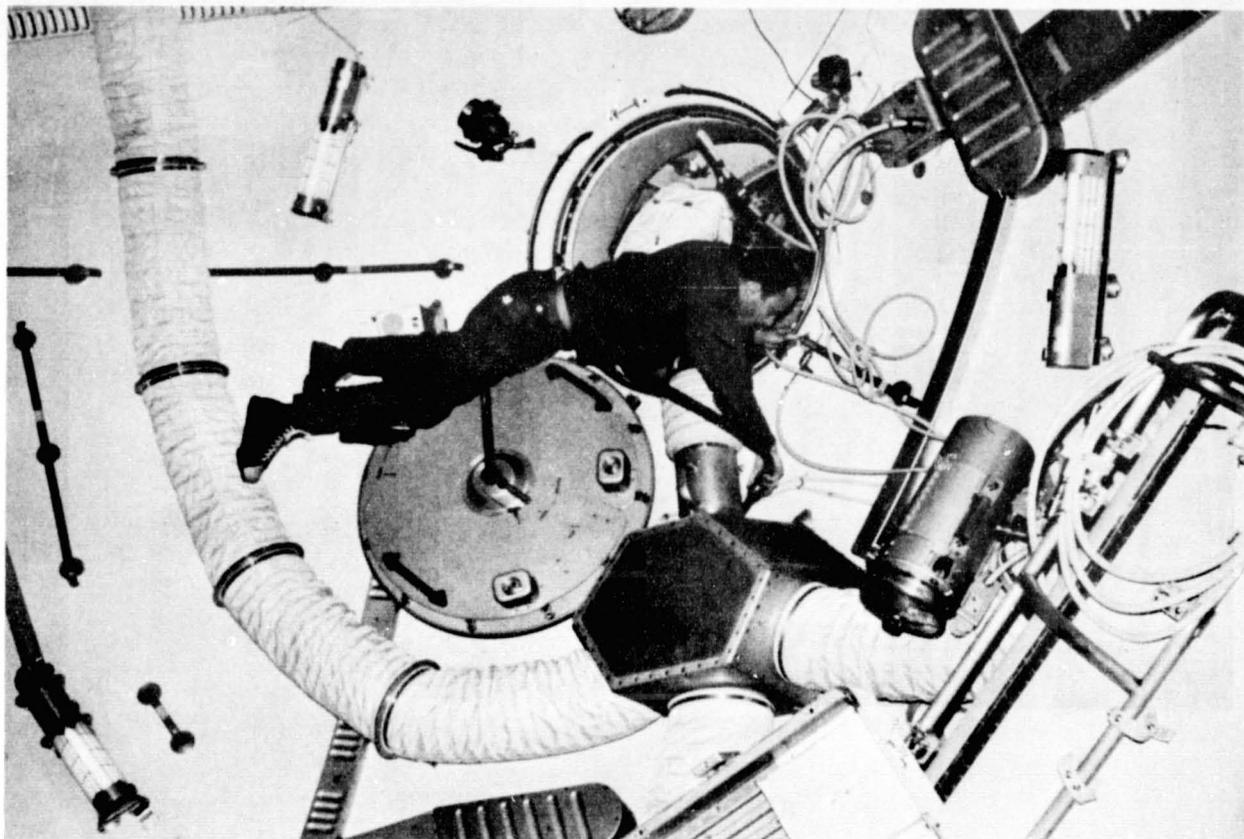
AIR MIXING CHAMBER SCREEN

FIGURE 60

Figure 61 shows the SL-3 PLT at the dome air mixing chamber using the vacuum cleaner, a good example of a required chore without specific restraint provisions. The crewman is holding onto a handrail with his left hand while vacuuming an air duct screen with his right hand. He is using his left hand and wrist to remove the forces imposed by the vacuum cleaner. The SL-3 PLT used only the one hand for restraint; however, the SL-2 PLT used the ducts for footholds; i.e., wrapped his legs around them to stabilize himself while he was vacuuming the screen as reflected in the following comments:

SL-2 PLT: "And on occasion, for example, yesterday I vacuum cleaned the plenum inlet screen at the top of the dome, I found the ducts themselves very handy

for footholds. I'd wrap my legs around them and use that to stabilize myself while I was vacuuming the screen." (SL-2 Dump Tape 151-09)



SL-3 PLT AT AIR MIXING CHAMBER WORKSITE

FIGURE 61

Figure 62 shows an example of a man-machine interface that is both efficient and inefficient. Work tasks with difficult access were in some instances made easier by the complete freedom of body positioning allowed by zero-g. Unfortunately, when the crewman is not properly positioned and restrained to do a job, some of the benefits of zero-g are lost in the energy expended to attain and retain a suitable work position. The photograph shows the SL-2 PLT reading the M509 checklist with his legs locked to the parasol deployment container for stability. The SL-2 CDR is using his right hand for stabilization with the left

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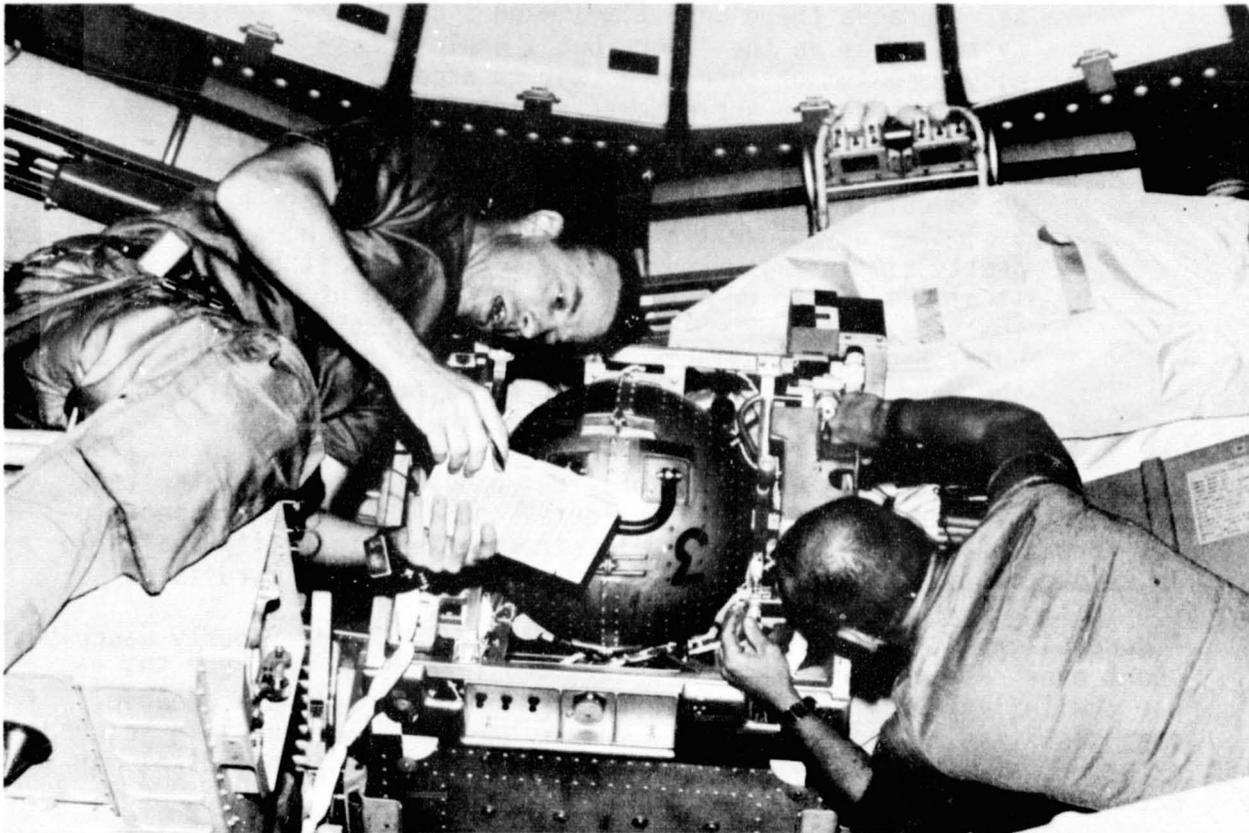
hand free for task operation. However, the SL-2 CDR is unrestrained, using body momentum to accomplish the task. The SL-2 CDR's experience was that he did quite well without restraint and was more efficient in many respects as indicated by his comments:

SL-2 CDR: "There's two things that are overriding in my mind that I want to make sure that you appreciate. One of them is the fact that we did so well without restraint, and the less restraint you've got to provide, the more efficient in many respects a guy is going to be. Because there were times when I could have locked my triangles in the floor, but I would choose to use body momentum or some other way to accomplish it to frankly save the unpleasant task of having to go through the exercise of locking in, do a very simple thing when I was locked in, and then unlock again to go someplace else. There were occasions where I had a simpler way of restraining myself. Those shoes were pretty simple. You know, I would have done it because it almost got to be a tradeoff; the amount of time was the same. It took me longer to do it unrestrained, but I had the satisfaction of not having to go through the exercise of restraining and unrestraining myself." (SL-2 Corollary Experiments Debriefing)

Figure 63 shows the SL-3 SPT with his feet wedged between a water tank and a dome locker support. He is oriented upside down with respect to the forward compartment, but this illustrates the versatility available in zero-g if suitable restraints are provided or can be improvised.

Figure 64 depicts the adverse posture (similar to the previously described "bent over" ATM posture shown in Figure 40) imposed on the SL-2 SPT to use the Inflight Medical Support System (IMSS) microscope, a generic type task that may appear often in future vehicles carrying life science experiments. This posture should be avoided if the most efficient man-machine interface is to be developed.

Figure 65 shows the SL-4 CDR at the trash airlock (TAL). He observed that operating the TAL without a set of restraints was not always an easy task: "You pull on the handle; you open the door; and pull on the handle to push the trash out and your body goes the opposite way, and you find yourself having to lock your legs down around the trash airlock and just grab it with your legs." This situation was further complicated during the SL-4 mission by the protocol the crew adopted for dumping trash. On the average, they made TAL dumps about once every three days. If the well was full of trash bags (which is where they were temporarily stowed awaiting dump), there was no room for the operator to anchor

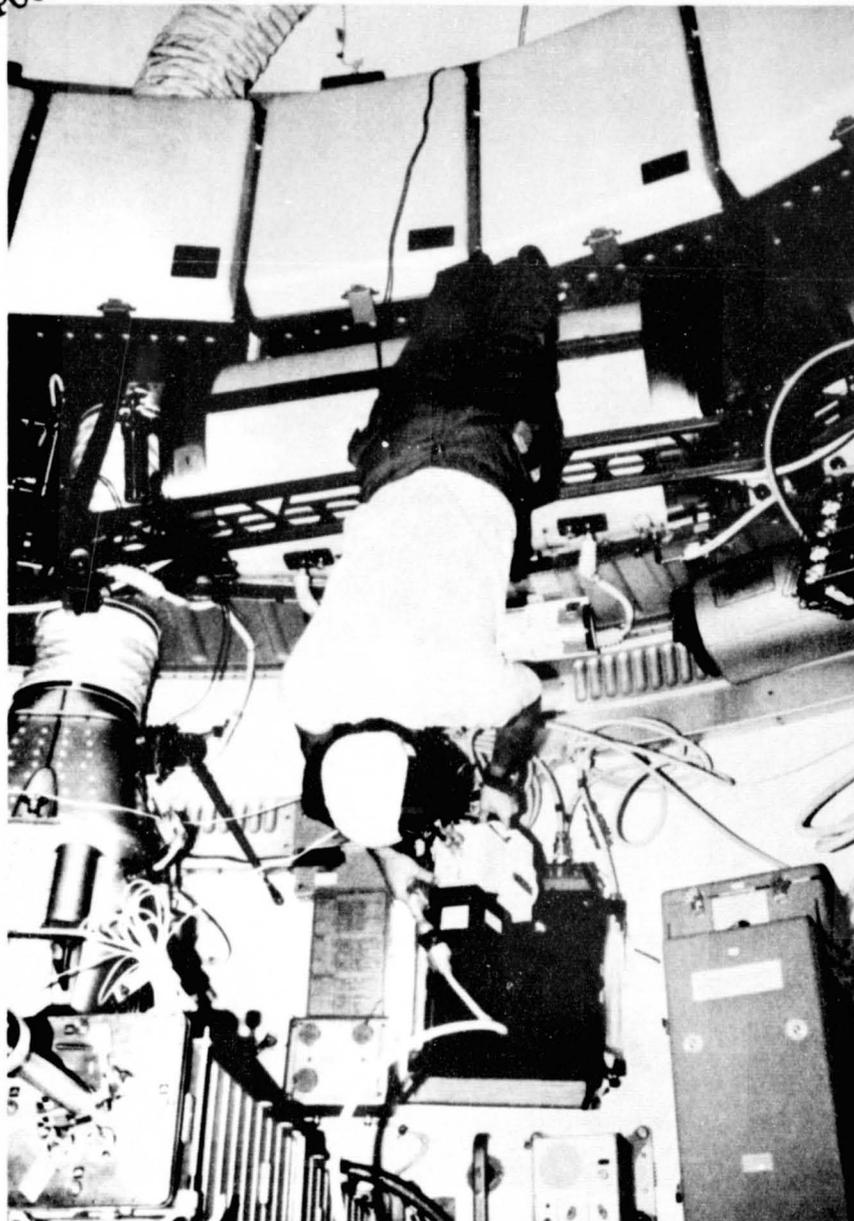


SL-2 OFF-LINE WORKSITE

FIGURE 62

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SL-3 SPT AT WORKSITE (FORWARD COMPARTMENT)

FIGURE 63



SL-2 SPT USING MICROSCOPE

FIGURE 64

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SL-4 CDR AT TAL WORKSITE

FIGURE 65

himself by putting a leg down into the well as depicted in Figure 65. An additional difficulty was imposed on TAL operations by the accidental bending of a portion of the mechanical linkage used to operate the device. This caused the SL-3 and SL-4 crews to adopt a two-man TAL operation where it became necessary for one crewman to stand on the lid, brace his hands on the hatch in the floor above, and force the lid downward, while the operator threw the latching handle up over the lip of the cover and locked it down. The following crew comments address the problems associated with this worksite:

SL-3 CDR: "Essentially the trash airlock has been operating real well the whole mission. We decided that we just let one person do it and that's me and we've been shooting them out of here with no trouble at all. We've been using usually two urine bags correct on that, two urine containers per urine bag and no more for every once in a while we'll throw all three urines in the urine bag, but we've found out that's the only one that really swells in there. The only thing that we've noticed wrong was the other night we noticed that the little rod that interconnects the lock handle to the safety mechanism for the eyelid open and close and which also - the handle also includes the depress and press valves. That little link, was bent. My opinion of how it got bent, I've been closing the lid myself and as I closed the lid I'd push on it and then flip the handle over. My opinion would be that I didn't flip it far enough over and when I moved the iris handle or the eyelid handle whichever you want to call it, depress handle that it would cause it to put a load on that (garble) that rod. And the rod is slightly bent. It still works great - we just use two persons, two people now to do it, one to stand on it and the other to lever it."
(Dump Tape 251-01)

SL-4 CDR: "Trash airlock, problem here for the operator of the trash airlock, there is no really good way of anchoring yourself or restraining yourself while you're trying to use the trash airlock. You pull on the handle; open the door; and pull on the handle to push the trash out and your body goes the opposite way, and you find yourself having to lock your legs down around the trash airlock and just grab it with your legs. And I think there could be a better way to restrain the operator of the trash airlock." (M487-3B)

SL-4 CDR: "We had been warned by the SL-3 crew that the operation of the trash airlock shutter was no longer a one-man operation. I could do it at the beginning of the mission, but apparently the system changed, warped, or was modified in some way because I couldn't do it later. It became necessary for one man to stand on it, brace his hands in the hatch on the floor above, and force the lid to the trash airlock downward, while the commander, as trash airlock operator, threw the latching handle up over the edge of the lip of the cover and locked it down. We have some movies and photos that will demonstrate the two-man trash airlock operation. On the average, trash airlock dumps were necessary only about once every three days. As trash accumulated, we would put it down in the well between the trash airlock and the floor of the experiment compartment until we had five or six bags. Trash dumps were usually done in the evening before retiring. A problem in the airlock operation was the lack of mobility restraints for the operator. If the well was full of trash bags, there was no room for the operator to anchor himself by putting a leg down into it." (SL-4 Technical Crew Debriefing)

The Waste Management Compartment (WMC) was not an efficient worksite from a man-machine interface standpoint for most of the Skylab crewmen because of the lack of good foot restraints. The SL-2 CDR felt that the room was small enough that the lack of foot restraints did not create a problem. He was able to bounce off the walls slowly enough to not upset his stability completely. However, the SL-3 and SL-4 crewmen strongly desired good foot restraints and there were many crew complaints.

Figure 66 shows the SL-3 PLT shaving and illustrates the point that without proper restraint interfaces in the WMC, the best way for a large size crewman to use the hygiene station was the wedge mode, which certainly seems less than optimum. The following comments address this point:

SL-3 PLT: "Getting in and out of the waste management compartment is sort of a stunt because once you get in there - getting in and out is okay, but getting in there is not too good because there's nothing to lock your feet into. Your feet just slide all over the floor; you sort of bounce and ricochet from wall to wall. And you know the best way to restrain yourself in there is to - in front of the sink to put your knee up against the little handrail there and your back against the tissue wipe dispenser area and kind of wedge yourself in there to



"WEDGE MODE" RESTRAINT IN WMC

FIGURE 66

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do whatever is necessary. Other than that, you just drift around in there. And you have to wedge yourself with your feet and hands between the walls in order to stabilize yourself. So it's getting in and out is all right, but once you get in there it's anybody's guess as to how you're going to handle the situation." (SL-3 Dump Tape 232-05)

SL-4 CDR: "The big problem, I would say, in the waste management compartment is lack of proper foot restraints. We kind of boxed ourselves in, literally speaking, when we put the sheath over the floor and - thereby dealing ourselves out of the gridwork available for locking your seat down. An unfortunately, we didn't do much to remedy the situation once it was done. The designed foot restraints that are in front of the urinal and the pot interfered with the drawers; so we've had a lot of design modifications and a lot of fiddling around. And the final upshot of that is that we've ended up with nothing. And changing out a urine drawer in the morning is pure hell because you've got no way to lock yourself down to do the work that you need to do. And you're forever trying to jam yourself up against the wall or lock your feet here or there and get yourself in position so that you can do the urine sampling and the urine bag changeout. The same goes for when you're finished using the commode, the fecal collector. You find yourself in a tough situation with a tough cleanup job left to do and no way to lock yourself down so that you can stabilize yourself and do the cleanup you need to do. You've also got to weigh the feces, put in a new bag, mark the feces label, get it into the oven. And so then during the whole period of time, you're just ricocheting around in there with really not much of anything to lock into, nothing but a couple of handholds. That's the most serious problem in there. The - the mirrors, I think-." (SL-4 Dump Tape 333-02)

SL-4 CDR: "The waste management compartment was terrible."

SL-4 SPT: "You were just like a ping pong ball inside of a little cup; you bounced around in there. You never really restrained yourself. You just ricocheted off the walls."

SL-4 CDR: "Of all places, where body wastes are handled is no place to be unable to control body position. That was just absolutely ridiculous. The folks who designed that did a nice job of making sure that all the smells were retained, and that you had privacy. Unfortunately, when they did that, they eliminated all opportunities to properly restrain yourself."

SL-4 PLT: "The restraints that were in there got in the way when the urine drawers were pulled out. They weren't very good for really holding your feet in."
(SL-4 Technical Debriefing)

This section had addressed several different workstations and makeshift worksites. Some were planned and some were not, and therein lies the point to be made in this discussion. Not all work needs can be anticipated prior to flight, thus a versatile system of crew positioning and retention devices must be developed to allow the most efficient possible conduct of chores that arise unannounced. The following crew comments sum up the situation:

SL-3 CDR: "I don't think there's any way that you can tell before you fly just where you're going to need to position yourself to do different tasks. One, you can't think through everything just as planned; and two, plans change at the last minute. So it means that, really, all over the spacecraft, you have to position yourself from time to time to do work. Sometimes it's possible just to float by and do it. Sometimes it's possible to get your buddy to hold on to. Most of the time, to do real constructive work, you've got to be stabilized, and these triangle shoes seem to be able to do the job real well. My only thought would be, on a future space station, that we ought to have a similar-type device. Now maybe there's an improvement - magnetic shoes or some sort of grippers or something. But we're going to need a device that can be used almost anywhere and have it accomplish the business of tethering the - the man, himself, so he can do a job." (SL-3 Dump Tape 222-01)

5.2.8 Extravehicular Activities (EVA)

Extravehicular operations were performed during all three manned Skylab missions. These operations included planned nominal tasks (ATM film retrieval), major contingency operations Solar Array System (SAS) deployment and twin-pole sail deployment), and several other minor

tasks. A thorough treatment has been given to Skylab EVA in Reference 7, and no attempt will be made here to duplicate that effort. Our purpose in addressing EVA workstations is to simply acknowledge their place in the overall topic and to call attention to the fact that they should not be overlooked in the design of future spacecraft.

5.2.8.1 Planned EVA Workstations

The pre-planned tasks, performed at workstations designed to facilitate those tasks, were easily and routinely accomplished. ATM film changeouts became very ordinary chores as the Skylab missions progressed. The workstations described in Section 4.2 were well conceived and adequately laid out to accomplish the assigned tasks. Visibility and reach parameters were efficiently accounted for and led to numerous favorable crew comments concerning these workstations. A typical comment follows:

SL-2 CDR: "Okay, the other thing is - is that EVA station - the FAS station - is super. It's so much - it's so easy to work in there, it's unbelievable. You guys did great work designing it.

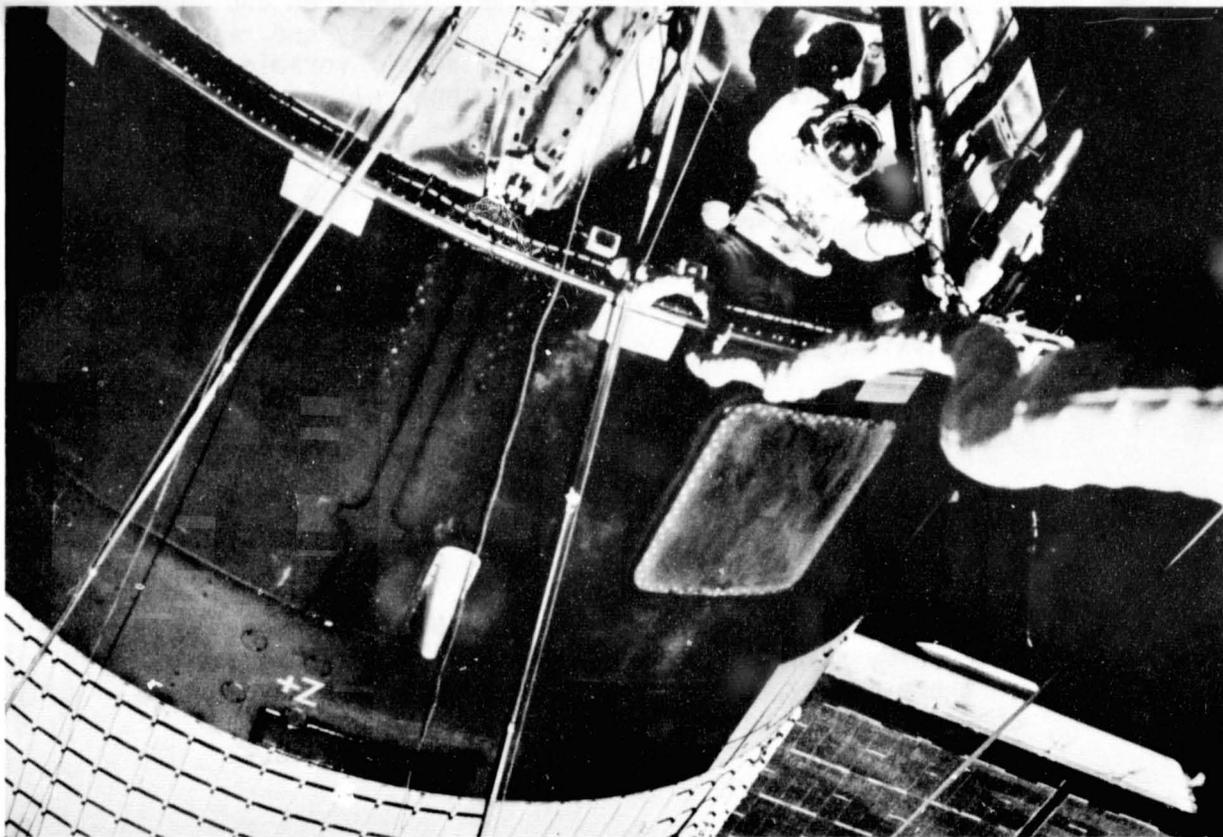
You mean even for a little guy, you can reach all those things, huh?

Even for a little guy; I didn't complain about you one time." (SL-2 Dump Tape 160-02)

Figure 67 shows a crewman in place at the FAS workstation. The adequacy of the positioning and retention devices at the FAS workstation is evidenced by the following comment:

SL-2 PLT: "Anything, if you're in a bind for room, because my normal mode in the FAS was only one foot in there anyway, which gives you more room to move about. Then if you're in a place where you're room limited, even one foot restraint is enough." (SL-2 Corollary Debriefing)

The other EVA workstation also received favorable crew comments, and the overall EVA system showed the results of years of testing, evaluation, and application of lessons from previous missions and programs. One of the major planned activities was the transfer of the ATM film from the various use stations to the airlock and vice versa. A mechanical boom system devised to accomplish this chore worked extremely well. The various workstations were also well designed to position the crewmen to send and receive cargo on the boom, as shown in Figure 68. The following comments address the ease of boom operations:

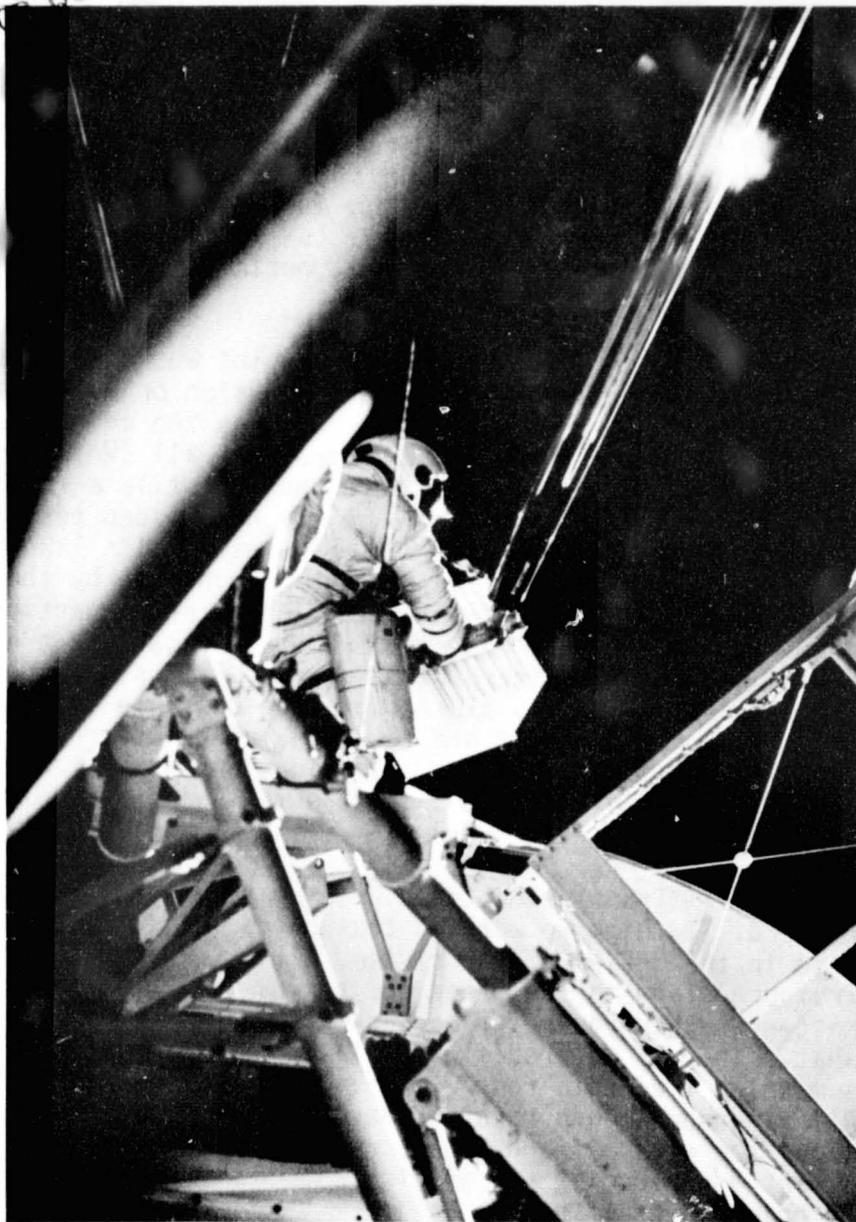


CREWMAN AT FAS WORKSTATION

FIGURE 67

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EXTENDIBLE BOOM OPERATION

FIGURE 68

SL-4 CDR: "Boom operation - The booms just worked like champs. We found them to be superior to the clothesline operation because you didn't have the tangle, the intertwining problem, that you had with the clothesline. I think our modes of operation were the right way to go. The boom is the prime mode and the clothesline is the backup mode if the boom fails. The clothesline mode is a good mode of operation. It's quite useable but it takes more time and it's a little more trouble."
(SL-4 Technical Debriefing)

Even though crewman translation from point to point would not ordinarily be considered suitable to be included in a discussion on workstation design, the subject does have application. Just as the point was made in the concluding portion of Section 5.2.7 that not all IVA worksites can be anticipated preflight and, therefore, as versatile a restraint system as possible is needed to accommodate the unforeseen task in a peculiar location, so is the need for EVA translation aids likewise general in nature. Since the IVA environment is confined by the boundaries of the vehicle, locomotion to the job is not a particularly significant factor. But simply being able to gain access to the task in the EVA environment is a major part of the job. Thus, ease of locomotion and abundance of mobility aids to provide passable translation paths to worksites (wherever they are located) is an integral part of designing the EVA workstation. These provisions are demonstrated in use during a Skylab EVA in Figure 69, and the following comments address their adequacy:

SL-4 SPT: "Translation techniques - are very straight forward. I think we worried that one a little bit too much in the design of the system. It's so easy to get from one place to the other out there. It doesn't matter whether you're going backward, sideways, or what. There's no problem translating yourself. With something tied onto your wrist is also very easy. All you need is one hand and maybe one foot to stabilize yourself and you can work your way along almost anywhere, if you go slow enough." (SL-4 Technical Debriefing)

5.2.8.2 Contingency EVA Workstations

Several requirements arose during each Skylab mission which was unforeseen and required EVA tasks to be performed. Some were relatively simple, like striking an electrical housing to release a hung relay, and some were major program drivers, such as the release of the jammed solar wing.

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EVA TRANSLATION

FIGURE 69

Two major items contributed to the difficulty of these tasks, the lack of mobility aids to gain access to the proper area and the lack of restraints at the worksite once it was reached.

An extreme example of a contingency, unplanned EVA task, is the freeing of the solar panel wing from its jammed position during the SL-2 mission. The jammed solar array wing was easily freed by the SL-2 crew after they gained access to it. Two of the crewmen spent the major part of an EVA period trying to position one of them to cut the strap that was holding the wing. An access path to the area would have made the task routine.

During another EVA period, the SL-4 crew encountered the same situation when trying to position themselves to troubleshoot and repair a malfunctioning antenna within the Earth resources array of experiment equipment. They finally accomplished the task but only after expending considerable time and energy. A path to the worksite and proper restraints in the area of the task also would have rendered this task routine.

A manned maneuvering unit would greatly assist in solving the locomotion and access problems, and some sort of portable workstation with suitable provisions for restraining personnel and equipment would render any worksite attainable as serviceable.

6.0 APPLICATION OF SKYLAB RESULTS

Based on the foregoing evaluations of selected Skylab workstations, this section applies the results to ongoing and future programs, with special emphasis on the correlation of neutral body posture in zero-g to workstation design.

6.1 SHUTTLE ORBITER

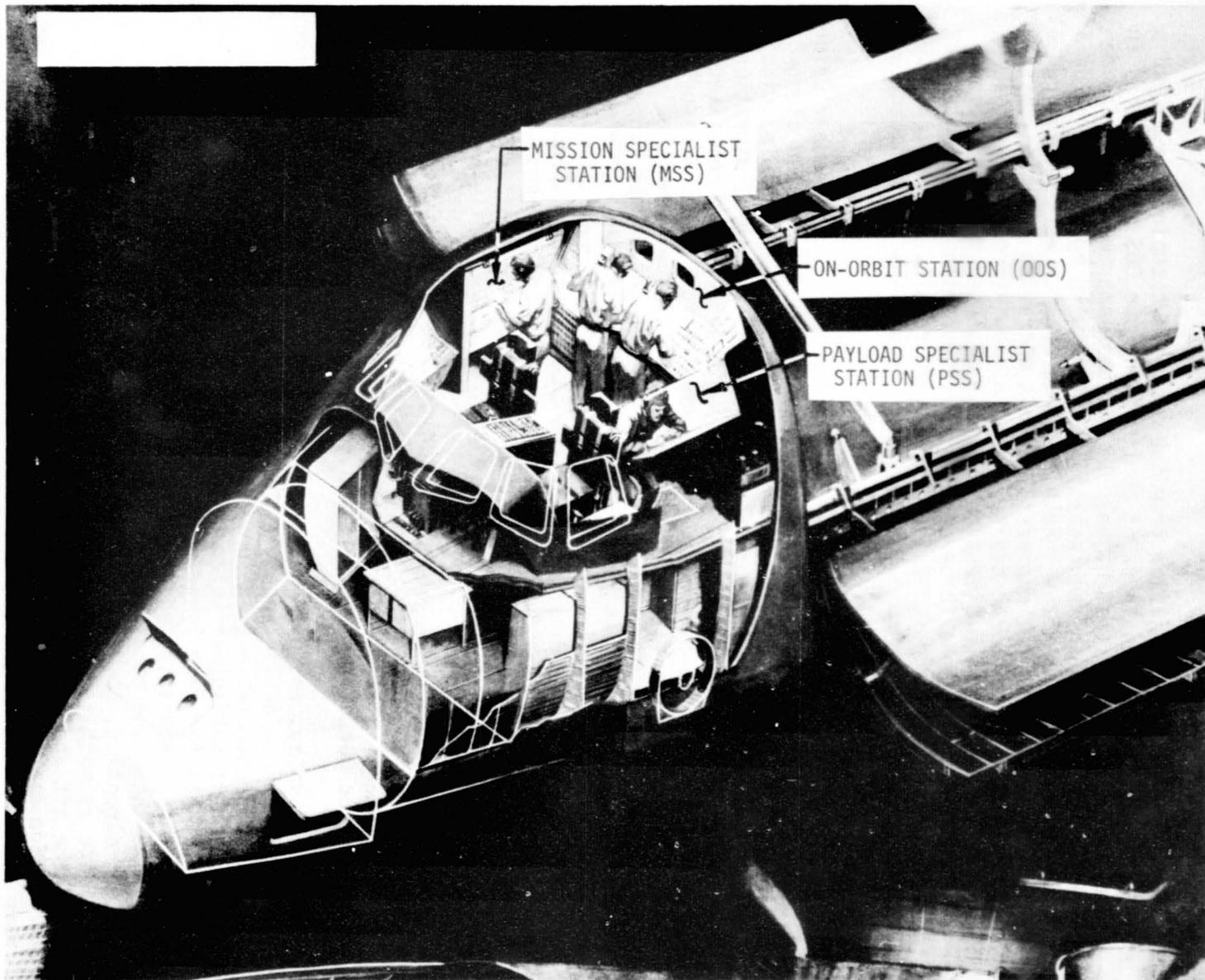
The Shuttle Orbiter represents the basic Space Transportation System for the next decade or longer, and much of the conceptual design work was accomplished prior to the publication of this report. However, the various workstations anticipated as being needed will be evaluated in their baseline configuration to determine compatibility with neutral body position and to insure the highest possible integration between the machine and its operator for better user efficiency.

The Orbiter aft flight deck crew stations were designed as integrated on-orbit modular workstations for payload support operations. Fixed facilities, common to all missions, were also provided: e.g., communication panels, lighting controls, TV monitor and controls, standard electrical interfaces, etc. Figure 70 depicts a four-man crew conducting on-orbit operations at the aft flight deck crew stations. Artistic license shows some of the crewmen in one-g standing positions rather than the operational zero-g neutral body position. Two crewmen (Orbiter CDR and PLT) are shown at the on-orbit station with the Mission Specialist and the Payload Specialist manning their respective stations. Each station will be evaluated, as will the general mid-deck operational area and the proposed EVA workstation.

6.1.1 On-Orbit Station (OOS)

The on-orbit station is located at the aft flight deck wall and contains the D&C needed for conducting orbiter rendezvous and docking operations, manipulator operations, and some limited payload operations. This station, as were those flanking it on either side, was designed using inputs from numerous full scale mockup exercises with subjects being employed in dynamic situations. Programmatic tradeoffs in terms of weight, schedule, and cost led to the final design product.

The OOS was the first orbiter workstation to undergo man-machine engineering analysis using scaled replicas of known crewmen and accounting for neutral body posture. The interfaces analyzed included design eye points, functional reach, restraint, interferences from surrounding equipment locations, and workstation layout.



ON-ORBIT OPERATIONS AT ORBITER AFT FLIGHT DECK CREW STATIONS

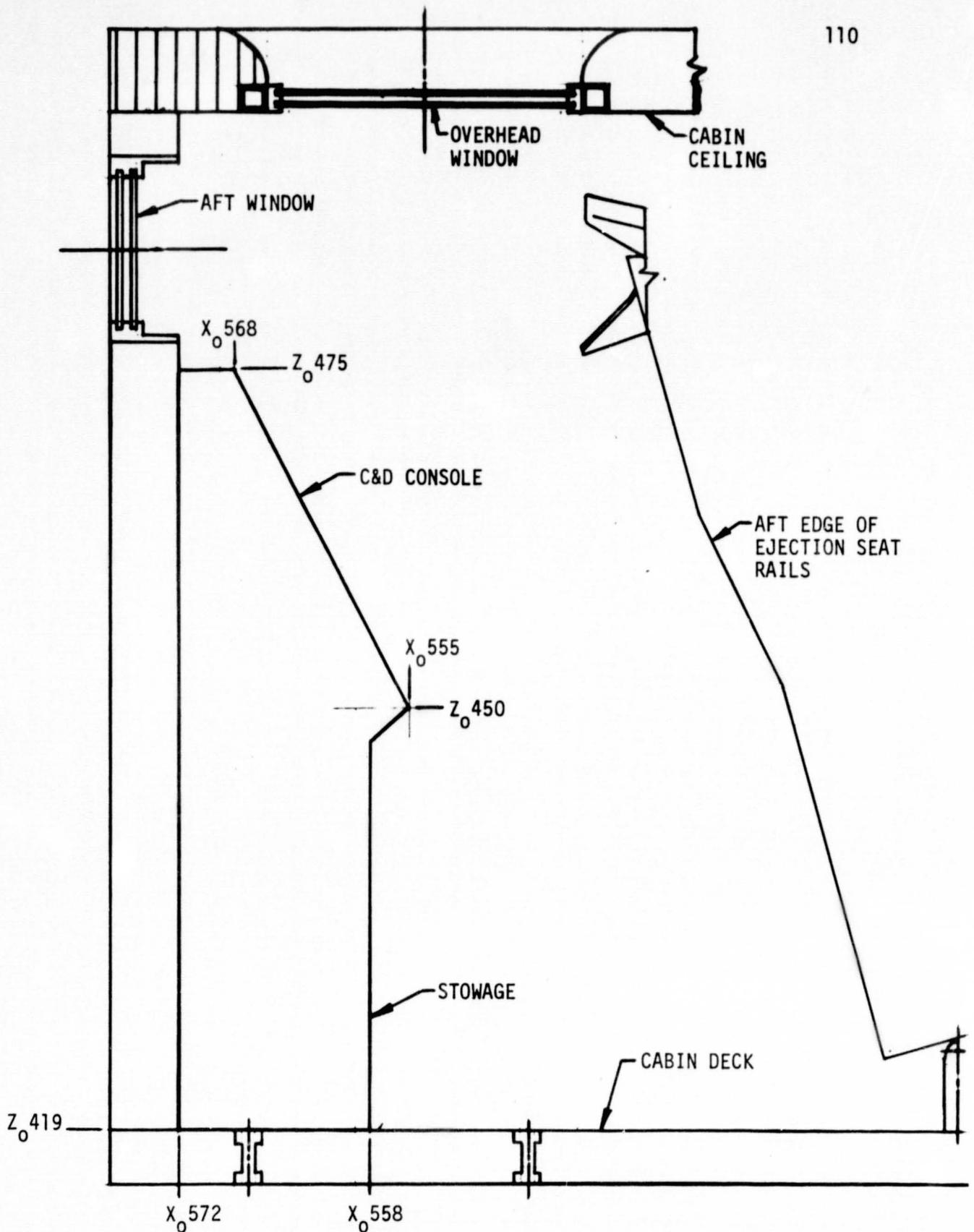
FIGURE 70

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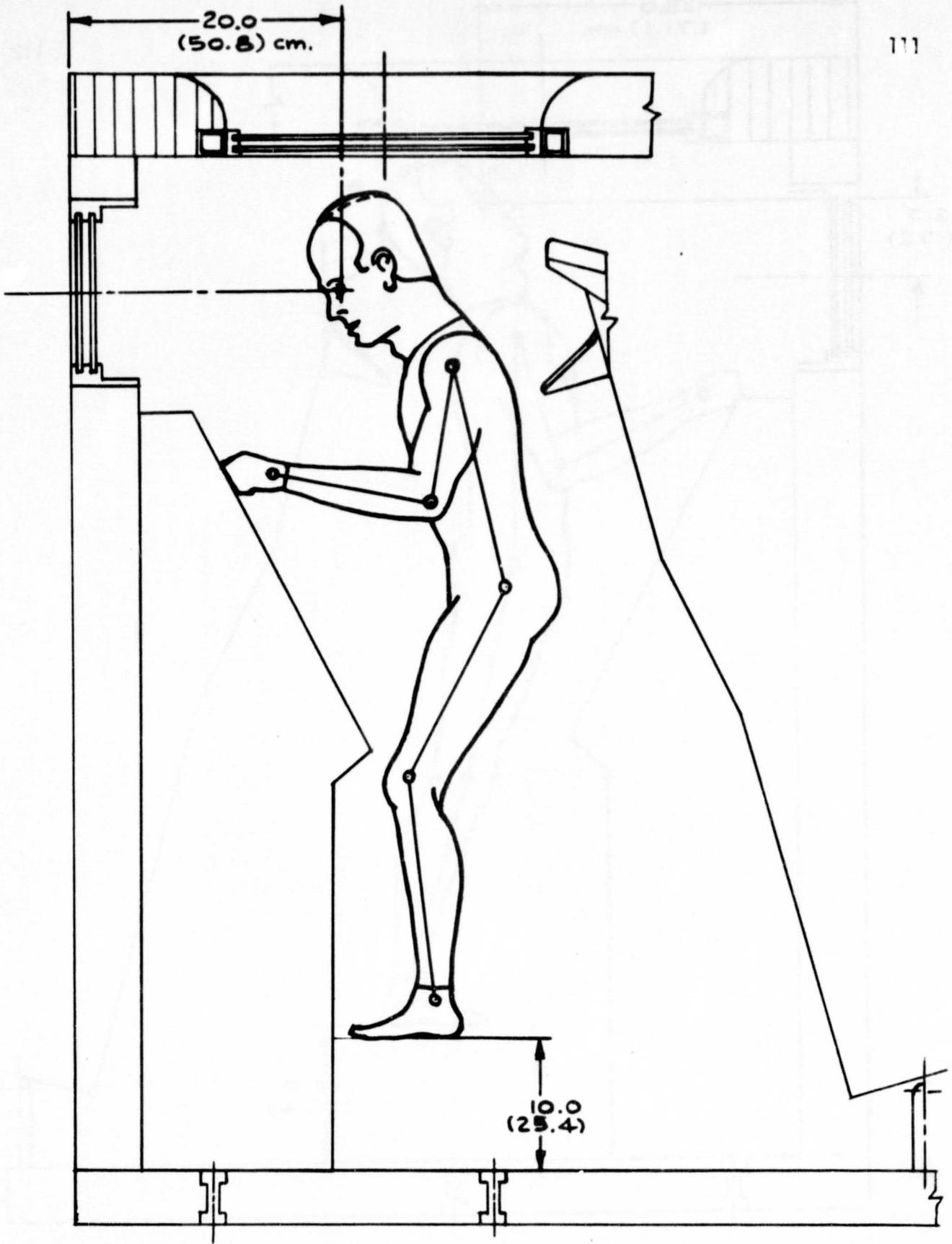
In order to smoothly transition from the analysis techniques employed earlier in this report to those of application, the OOS was laid out in one-tenth scale profile (see Figure 71) and the same two Skylab crewmen (small and large) used in the analysis sections were again used to define an envelope of operator sizes. Both of these crewmen were positioned at the OOS in three different manners: console operating position, aft window viewing position, and overhead window viewing position. Using these individuals for two dimensional layout analyses had the obvious advantage over using generic percentile representations of being able to eventually verify and validate the analytic results with actual human subjects in a three-dimensional situation. Such plans are underway but incomplete as of this writing.

Figure 72 shows the work position selected for a small crewmember which allows a good view of the console while having the eye located along the centerline of the aft window, giving the best view possible coincident with console use. The posture shown assumes a natural migration of the body toward the neutral, relaxed, zero-g body position consistent with posture requirements imposed by the workstation, task, and surrounding environment. This figure places the bottom of the crewmember's bare feet (no restraint devices considered) at a point ten inches (25.39 centimeters) above the deck, clearly making the point that some method of elevated restraint will be required and that it will need to be adjustable to accommodate a range of potential users consistent with specified anthropometric possibilities. Such a system has been baselined but not defined in detail. The difficulty encountered by a small crewman trying to operate the manipulator (for instance) and use the aft window while restrained at the floor, even if extended to full stature, becomes evident. The ejection seat rails, which will impose volume constraints on the OOS operator during the orbital flight test missions, are shown in Figures 72 through 79. Eventual removal of these devices is anticipated, at which time the operating volume of the workstation will increase significantly.

Figure 73 displays the difficulty encountered in viewing out the overhead window with the ejection seats in place (worst case condition). Assuming that a foot restraint will be desirable in this instance to achieve a reactive point sufficient to arch against, the resultant posture cannot be comfortable for very long. The ejection seat rails severely limit the positioning flexibility needed to make optimum use of the overhead window. Figure 73 shows the head high in order to get the best possible view in the aft direction, to intersect the viewing cone out the aft window and eliminate as much as possible of the blind spot caused by structure between the aft and overhead windows. Program needs have generated cost and design trade studies resulting in such situations as those described here, but the operational acceptance of such trades renders them acceptable options.

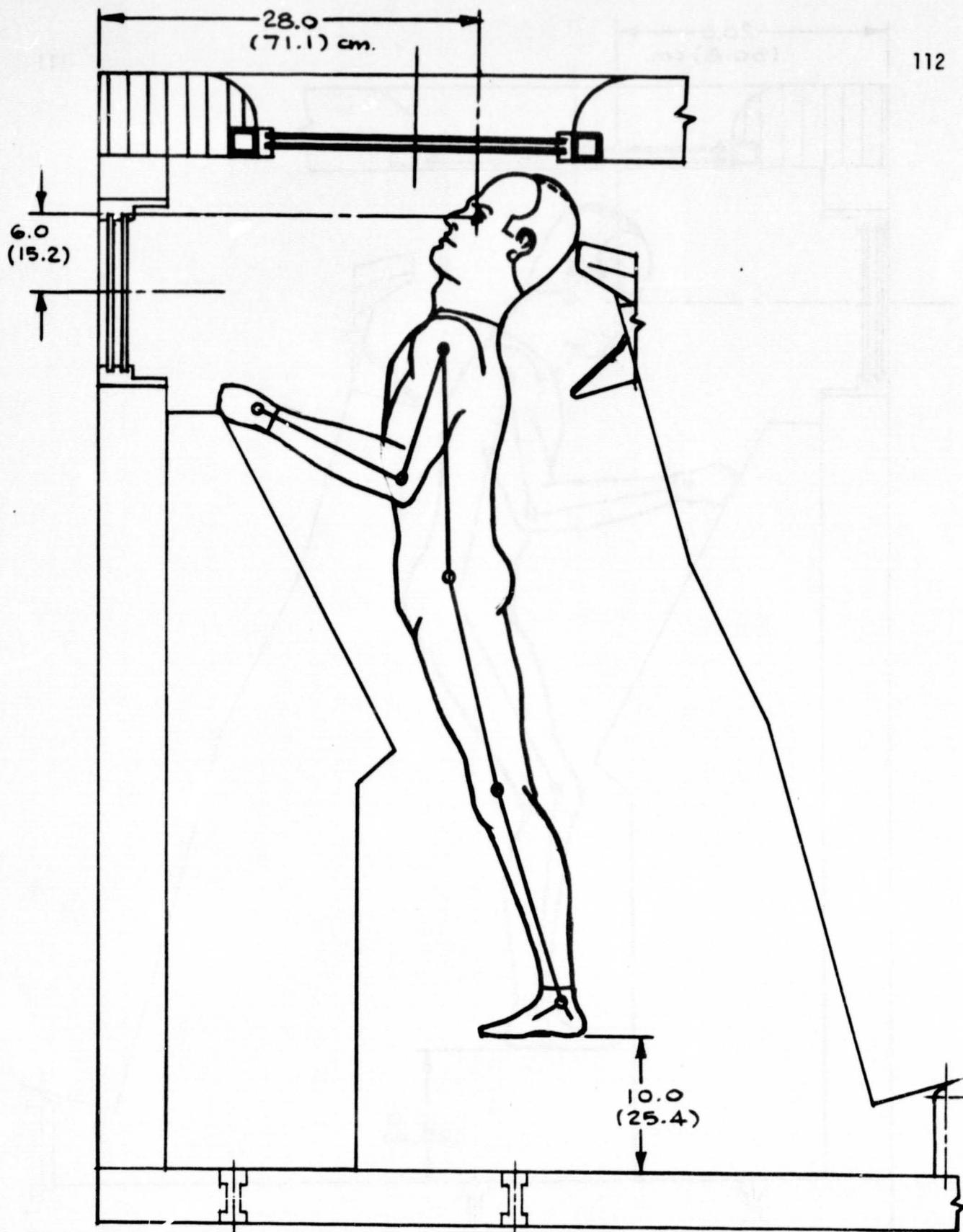


ONE-TENTH SCALE PROFILE VIEW OF OOS AND SURROUNDING EQUIPMENT
 FIGURE 71



OPTIMIZED OOS OPERATING POSITION, SMALL SKYLAB CREWMAN

FIGURE 72



OVERHEAD WINDOW VIEWING FROM OOS, SMALL SKYLAB CREWMAN
FIGURE 73

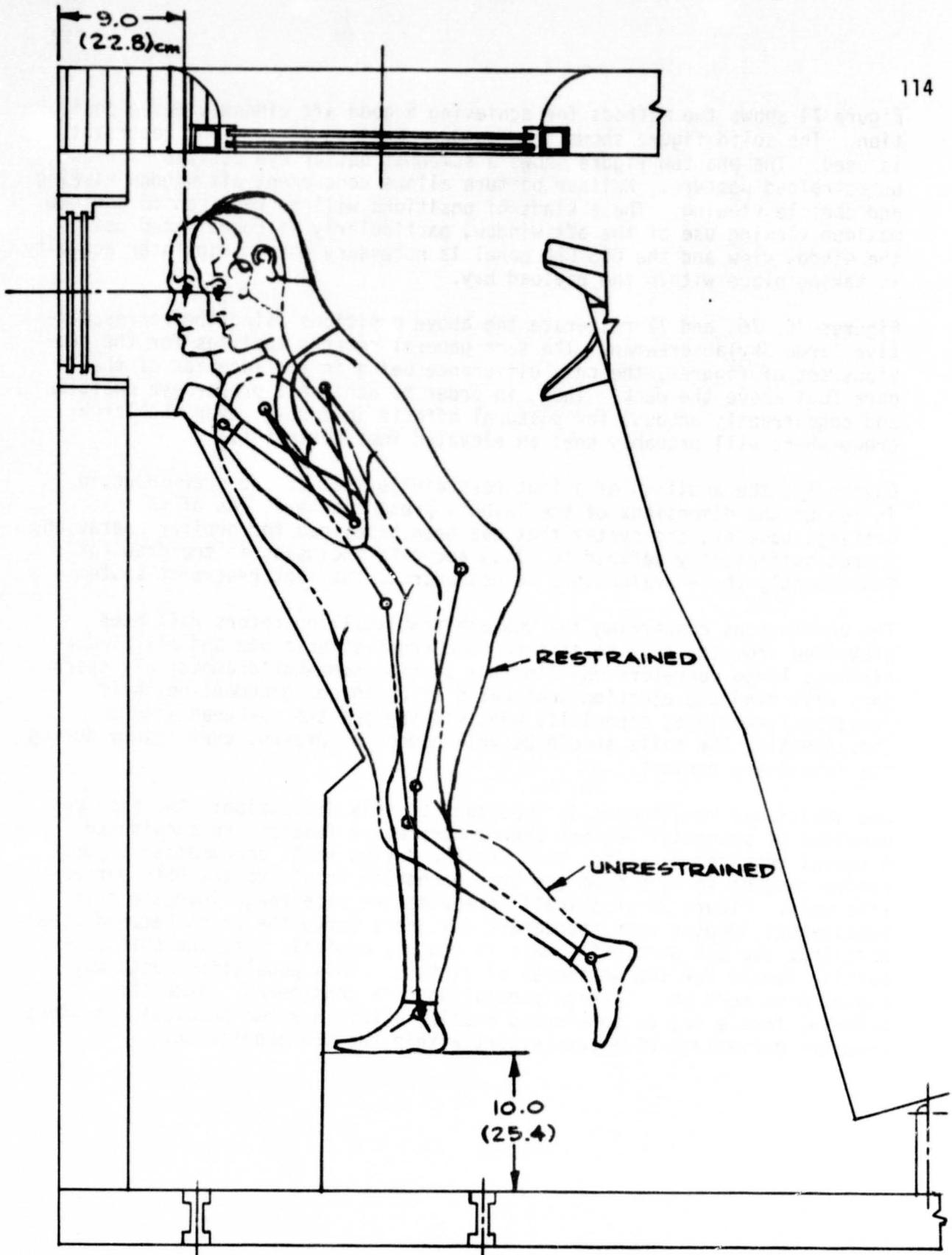
Figure 74 shows two methods for achieving a good aft window viewing position. The solid figure shows the posture required if the foot restraint is used. The phantom figure shows a somewhat better eye position for an unrestrained posture. Neither posture allows concurrent aft window viewing and console viewing. These kinds of positions will be required to achieve maximum viewing use of the aft window, particularly if coordinated use of the window view and the OOS C&D panel is necessary when manipulator activity is taking place within the payload bay.

Figures 75, 76, and 77 reiterate the above positions using the representative large Skylab crewman. The same general remarks apply as for the previous set of figures, the only difference being in the location of the bare foot above the deck. Thus, in order to achieve a proper eye position and concurrently account for postural effects in zero-g, even the large crewmembers will probably need an elevated foot restraint.

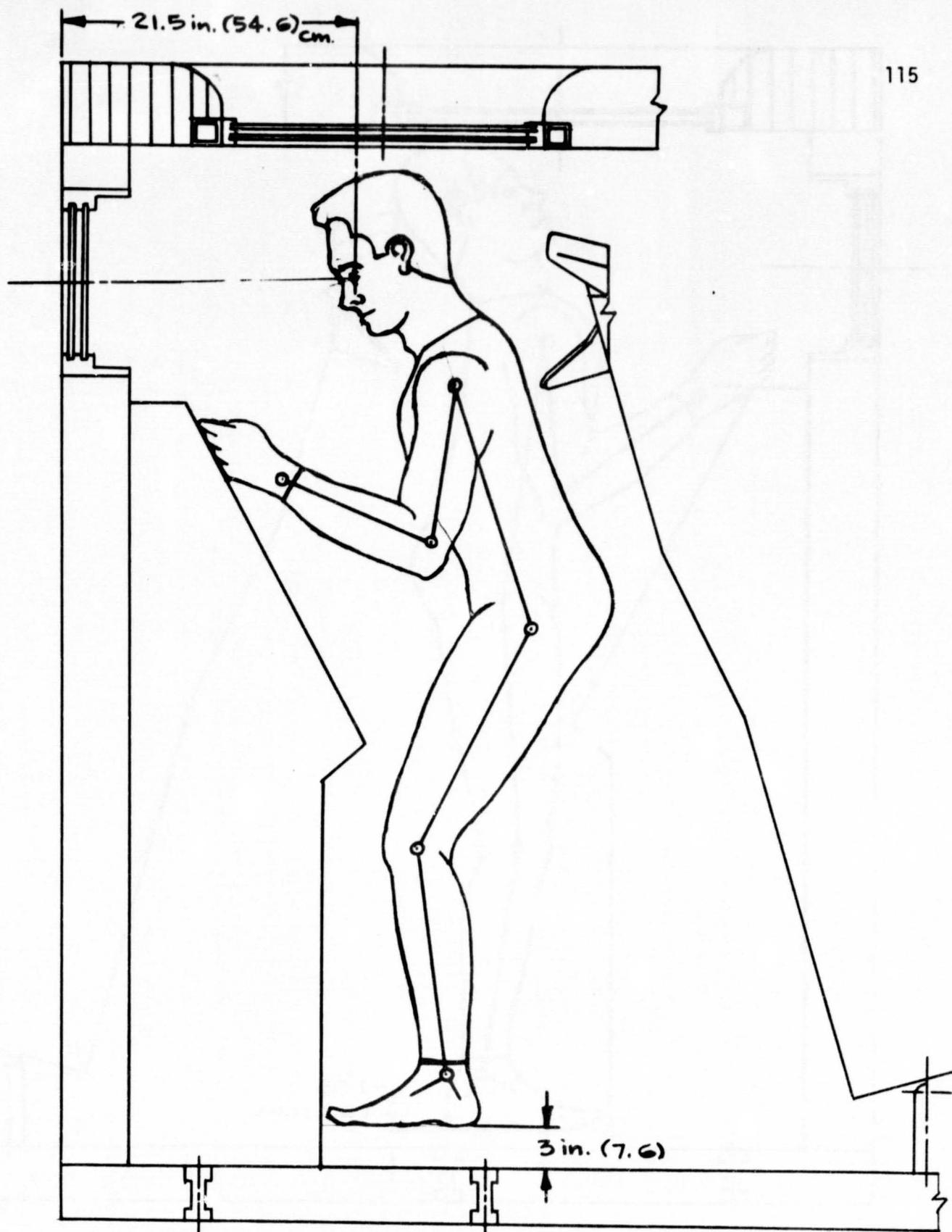
Obviously, the addition of a foot restraint system to the crewman would influence the dimensions of the layouts presented here. As of this writing, however, the system that has been baselined for orbiter operations is not sufficiently defined to allow accurate inclusion in the drawings. Consequently these evaluations do not address the foot restraint system.

The conclusions concerning the OOS are that small operators will need elevation from the deck to achieve concurrent console use and aft window viewing; large operators may find the station somewhat cramped; all operators will find the ejection seat rails to be an encroachment on their functional envelope, especially when viewing out the overhead window. Consequently, the rails should be well padded to prevent crew injury during the inevitable contact.

One additional requirement is important to this discussion: the expanded envelope of potential Orbiter crewmembers where females are considered. A recent requirement states that Orbiter design shall accommodate a population ranging in size from the 5th percentile female to the 95th percentile male. Figure 78 graphically presents the size range increase this requirement imposes upon spacecraft designers (note the cross hatched area). Note that the 5th percentile male is roughly equivalent to the 60th percentile female for the parameter of stature. This population range may expand even more when foreign populations are considered, since the oriental female may be considered smaller within her own population segment than her percentage-wise counterpart within the USA population.

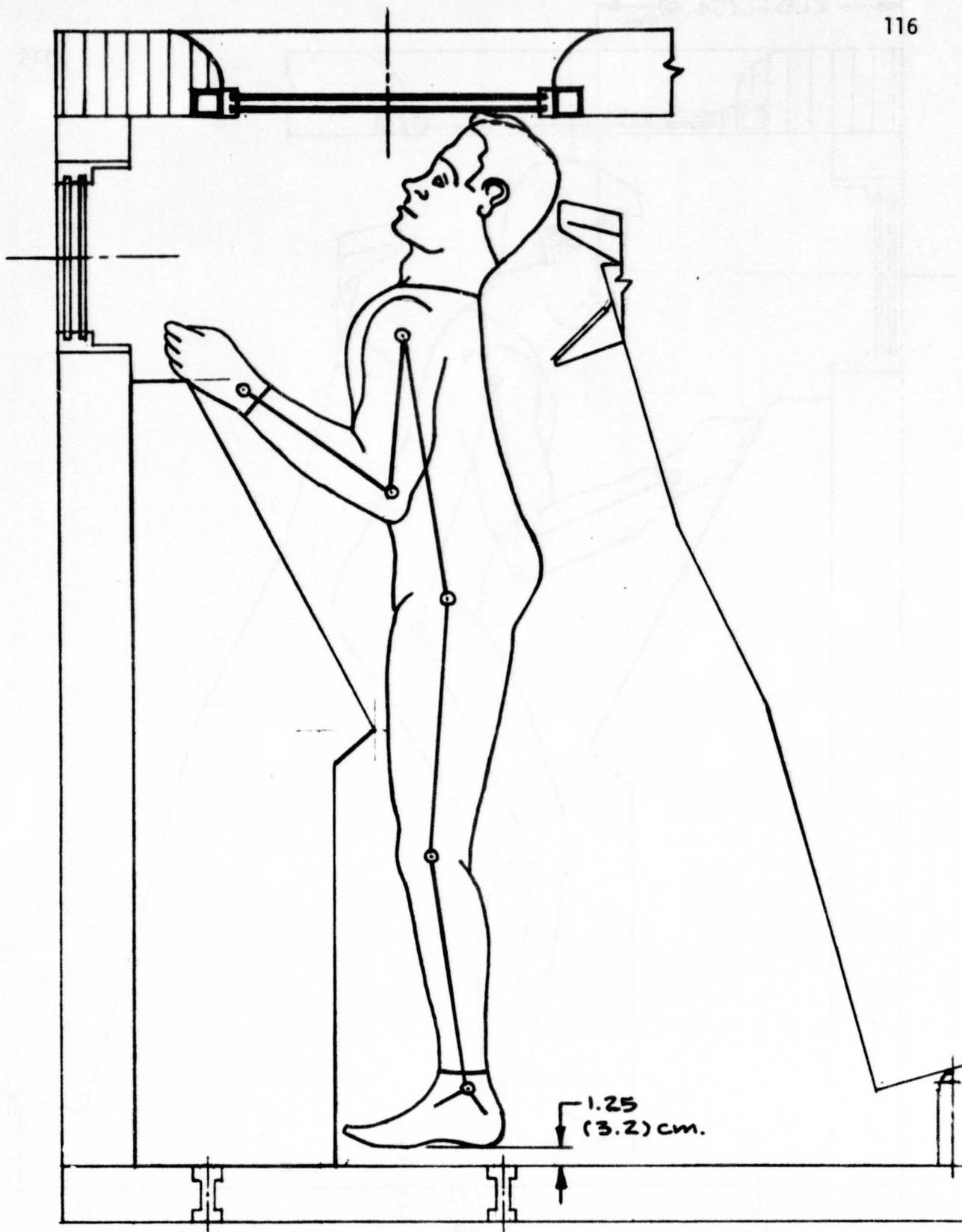


TWO POSSIBLE AFT WINDOW VIEWING POSITIONS, SMALL SKYLAB CREWMAN
FIGURE 74

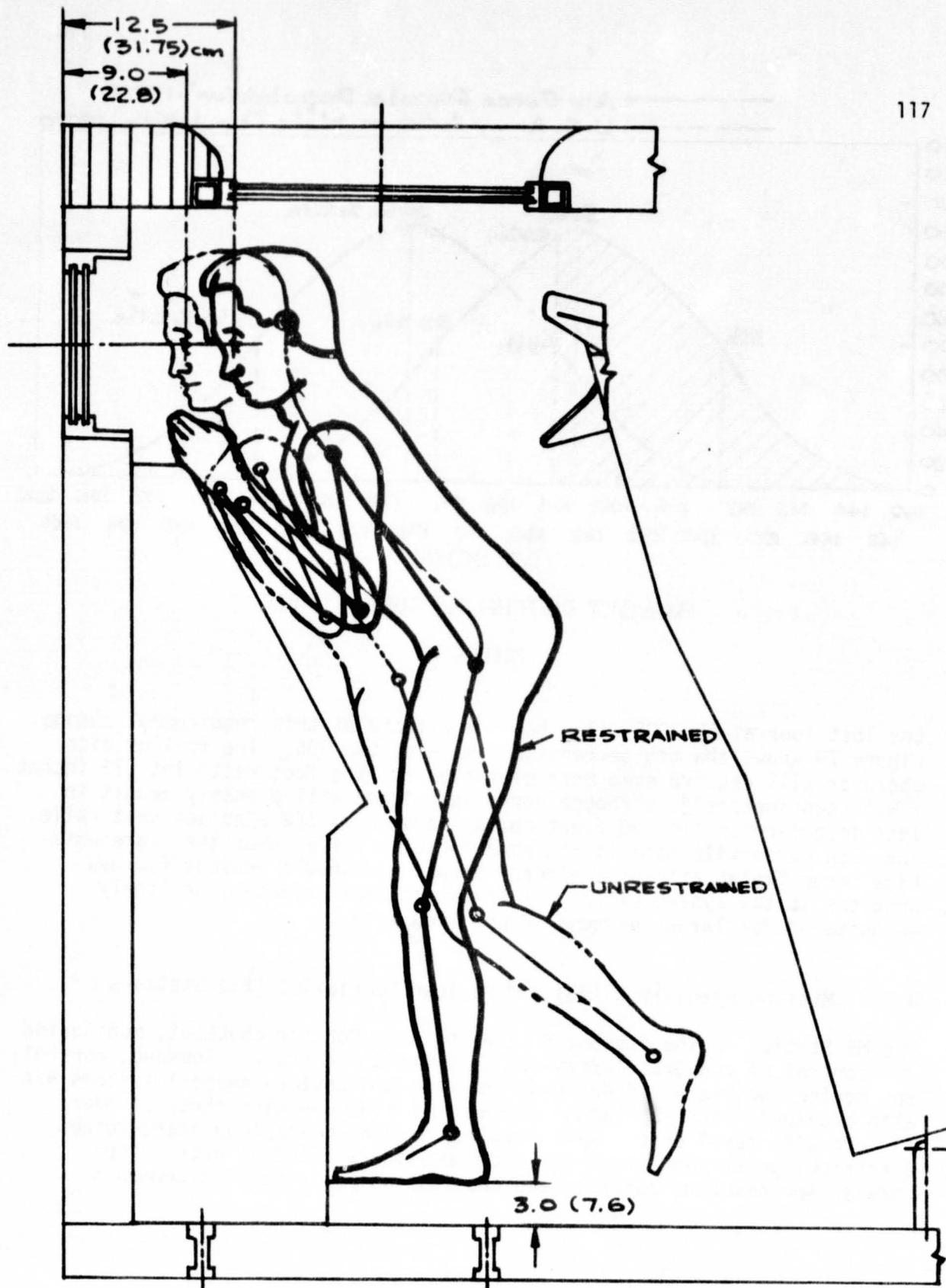


OPTIMIZED OOS OPERATING POSITION, LARGE SKYLAB CREWMAN

FIGURE 75

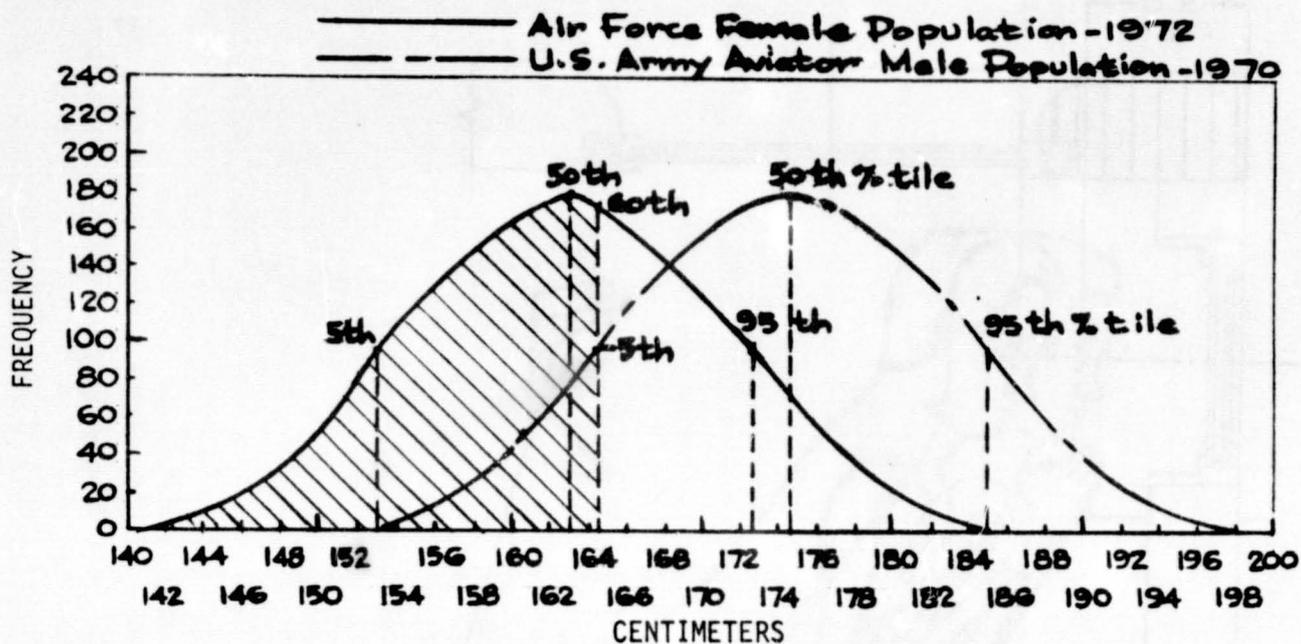


OVERHEAD WINDOW VIEWING FROM OOS, LARGE SKYLAB CREWMAN
FIGURE 76



TWO POSSIBLE AFT WINDOW VIEWING POSITIONS, LARGE SKYLAB CREWMAN

FIGURE 77



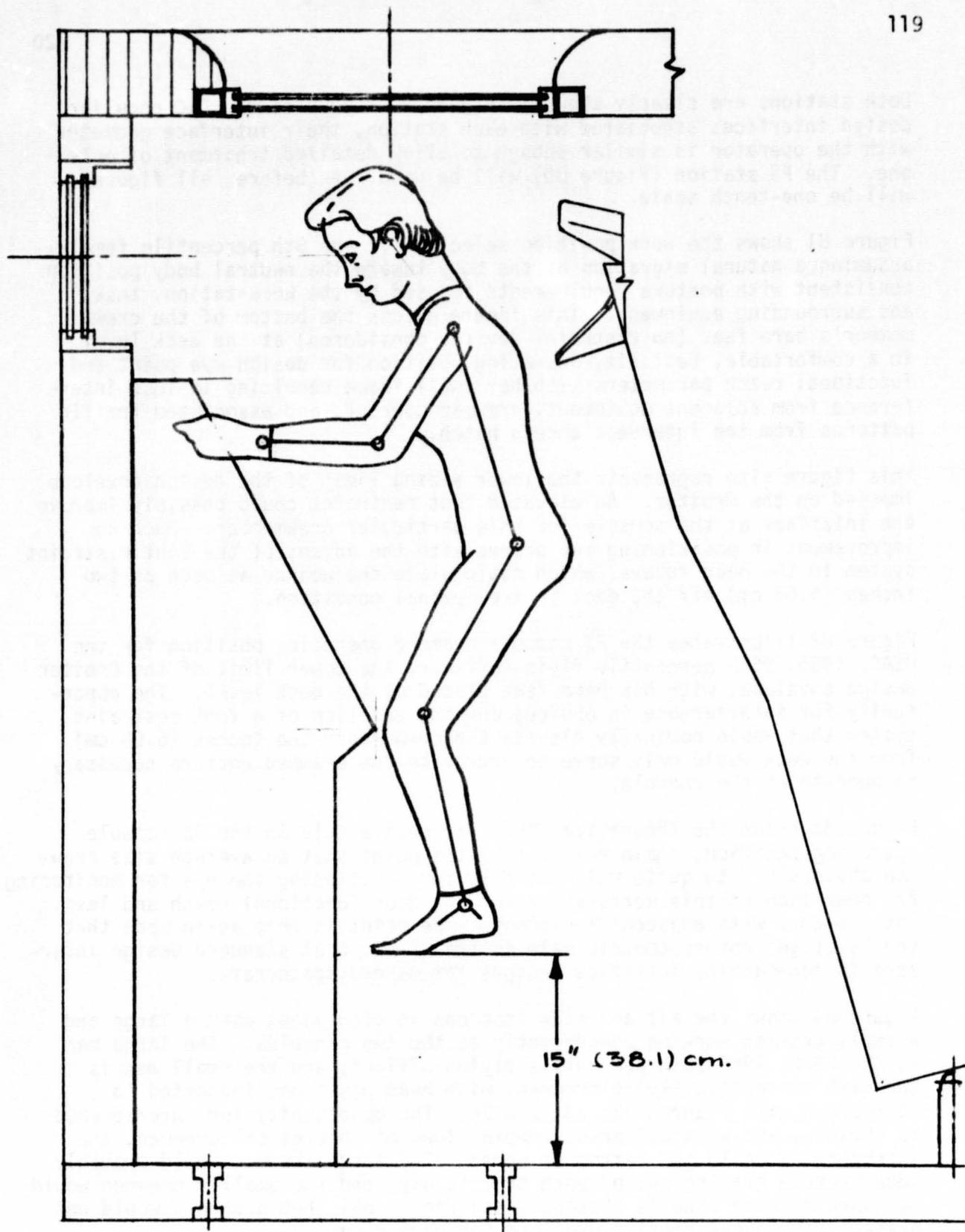
FREQUENCY DISTRIBUTION CURVE-STATURE

FIGURE 78

One last look at the OOS will show the effects of this requirement change. Figure 79 shows the 5th percentile female at the OOS. The smaller size operator will require even more elevation for the foot restraint [15 inches (38.10 centimeters)], although her slight frame will probably result in less interference from adjacent obstacles such as the ejection seat rails. The 95th percentile male is not significantly larger than the representative large Skylab astronaut already shown, and should present few new problems to the system except for the additional crowding inevitably encountered for larger persons in confined areas.

6.1.2 Mission Specialist (MS) and Payload Specialist (PS) Stations

The MS Station on the starboard side contains D&C for checkout, monitoring, and control of the Orbiter/payload subsystems interface. Command, control, and monitoring via RF of deployed and detached payload support systems are also provided. The PS Station on the port side contains three standard 19-inch wide panel spaces with required Orbiter-to-payload standardized electrical power connectors for accommodating GFE and/or user unique modules for command, control, and checkout of experiment instruments.



OPTIMIZED OOS OPERATING POSITION, 5TH PERCENTILE FEMALE

FIGURE 79

Both stations are clearly shown in Figure 70. Despite the D&C peculiar design interfaces associated with each station, their interface geometry with the operator is similar enough to allow detailed treatment of only one. The PS station (Figure 80) will be used. As before, all figures will be one-tenth scale.

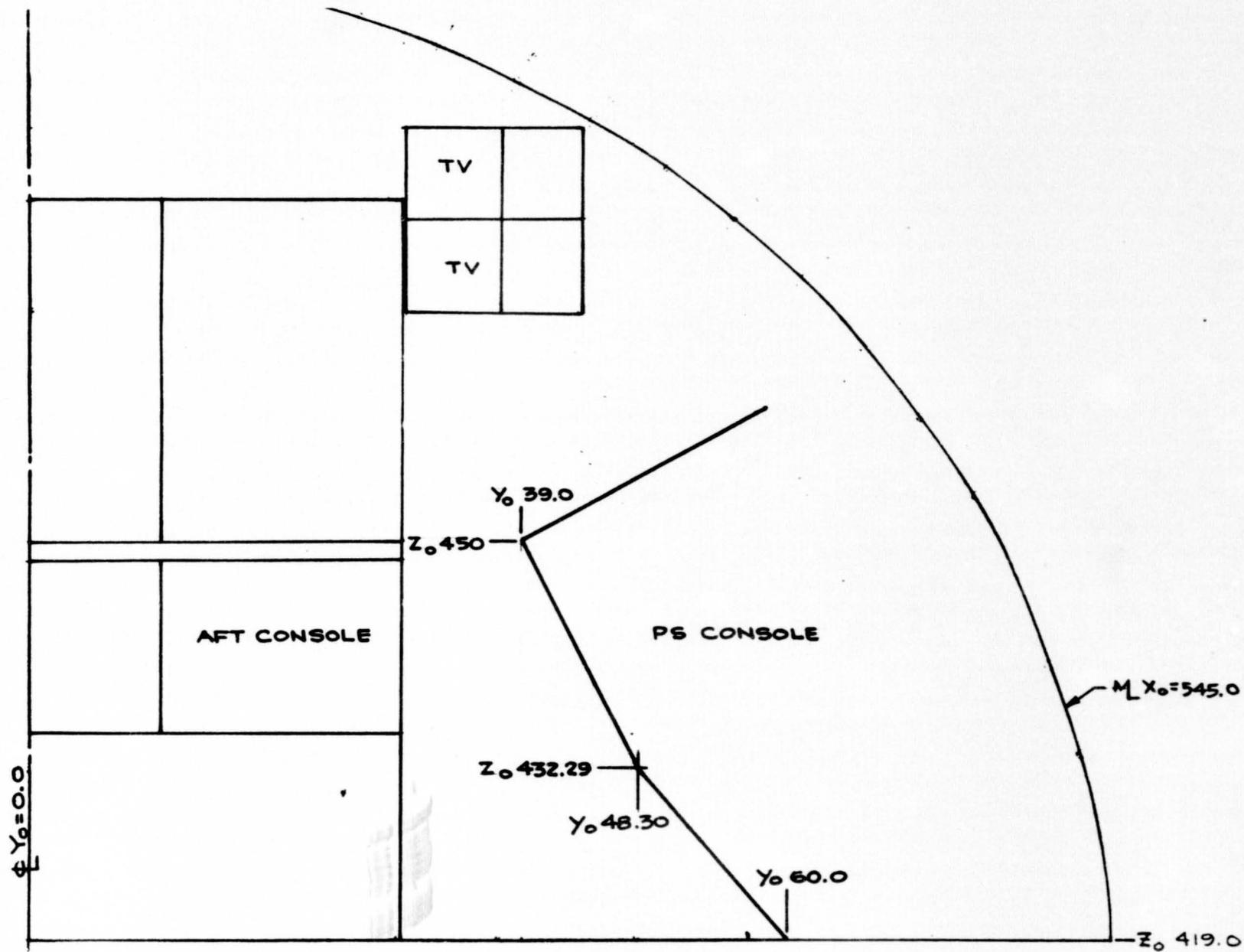
Figure 81 shows the work position selected for the 5th percentile female, assuming a natural migration of the body toward the neutral body position consistent with posture requirements imposed by the workstation, task, and surrounding equipment. This figure places the bottom of the crewmember's bare feet (no restraint devices considered) at the deck level in a comfortable, best fit, operating position for design eye point and functional reach parameters with her small frame resulting in less interference from adjacent equipment, crewman contact, and associated traffic patterns from the interdeck access hatch.

This figure also represents the lower sizing limit of the design envelope imposed on the Orbiter. An elevated foot restraint could possibly improve the interface at the console for this particular crewmember. Such an improvement in positioning may accrue with the advent of the foot restraint system in the near future, which could place the wearer as much as two inches (5.08 cm) off the deck in the nominal condition.

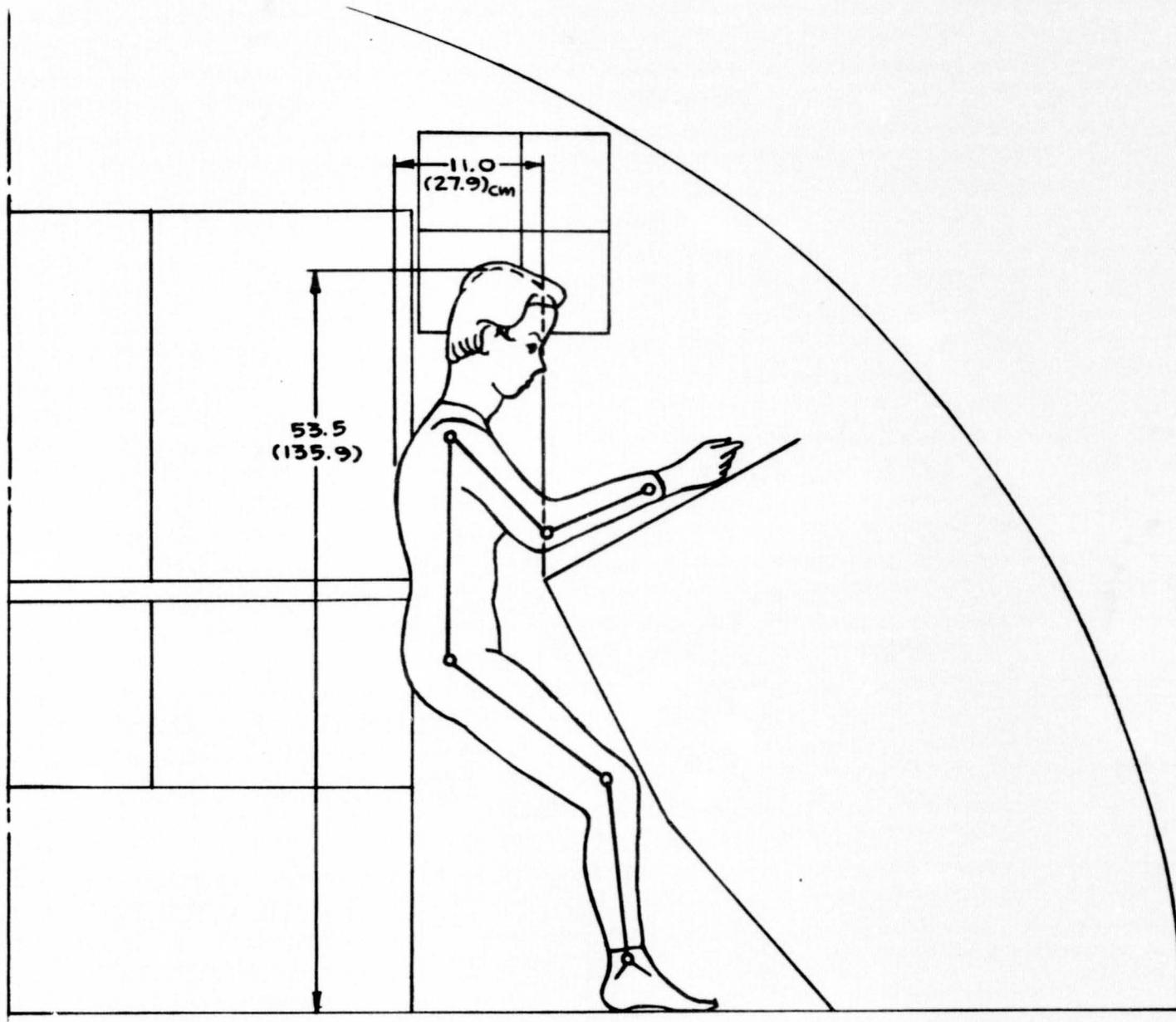
Figure 82 illustrates the PS console cramped operating position for the USAF, 1985, 95th percentile flying officer, the upper limit of the Orbiter design envelope, with his bare feet placed at the deck level. The opportunity for interference is obvious and the addition of a foot restraint system that would nominally elevate the crewmember two inches (5.08 cm) from the deck would only serve to aggravate the cramped posture necessary to operate at the console.

Figure 83 shows the theoretical 50th percentile male in the PS console operating position, again reiterating the point that an average size crewman obviously fits quite well not only for positioning the eye for monitoring and operation at this workstation but for good functional reach and less interference with adjacent equipment. The point is once again made that the "average" anthropometric male is the traditional standard design interface in man-machine interface designs for manned spacecraft.

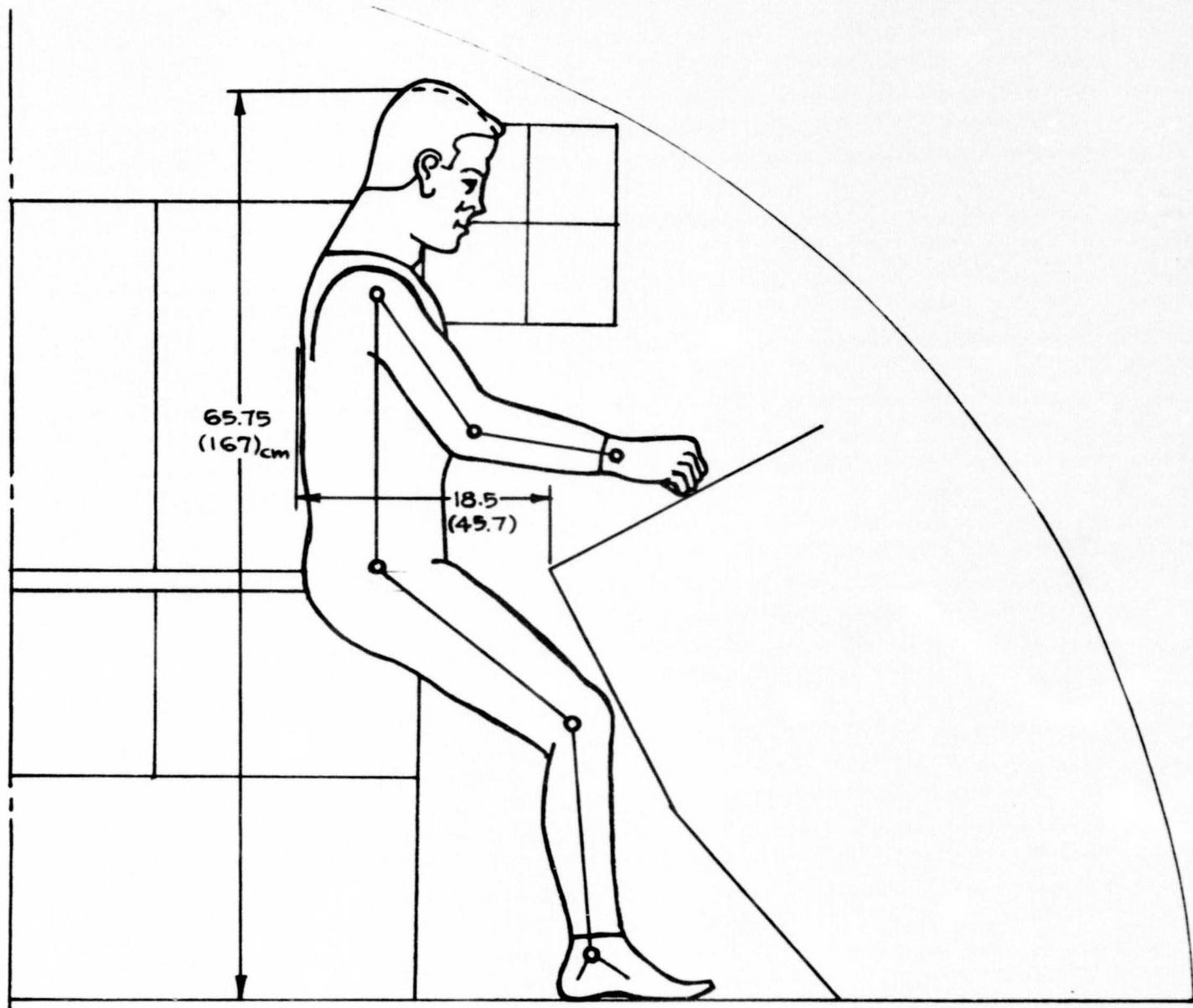
Figure 84 shows the aft and side stations in plan view, with a large and a small crewman working concurrently at the two consoles. The large man is the USAF, 1985 95th percentile flying officer, and the small man is the 14th percentile Skylab crewman, with head positions indicated to correspond with Figures 72, 73, and 74. The opportunity for interference is obvious, and with different combinations of theoretical crewmen, the interference could get better or worse. Two large crewmen would probably have trouble staying out of each other's way, and two smaller crewmen would be aware of each other's presence (see Figure 85), but probably would not present continuous contact problems for each other.



DIMENSIONED PROFILE OF PS CONSOLE
FIGURE 80

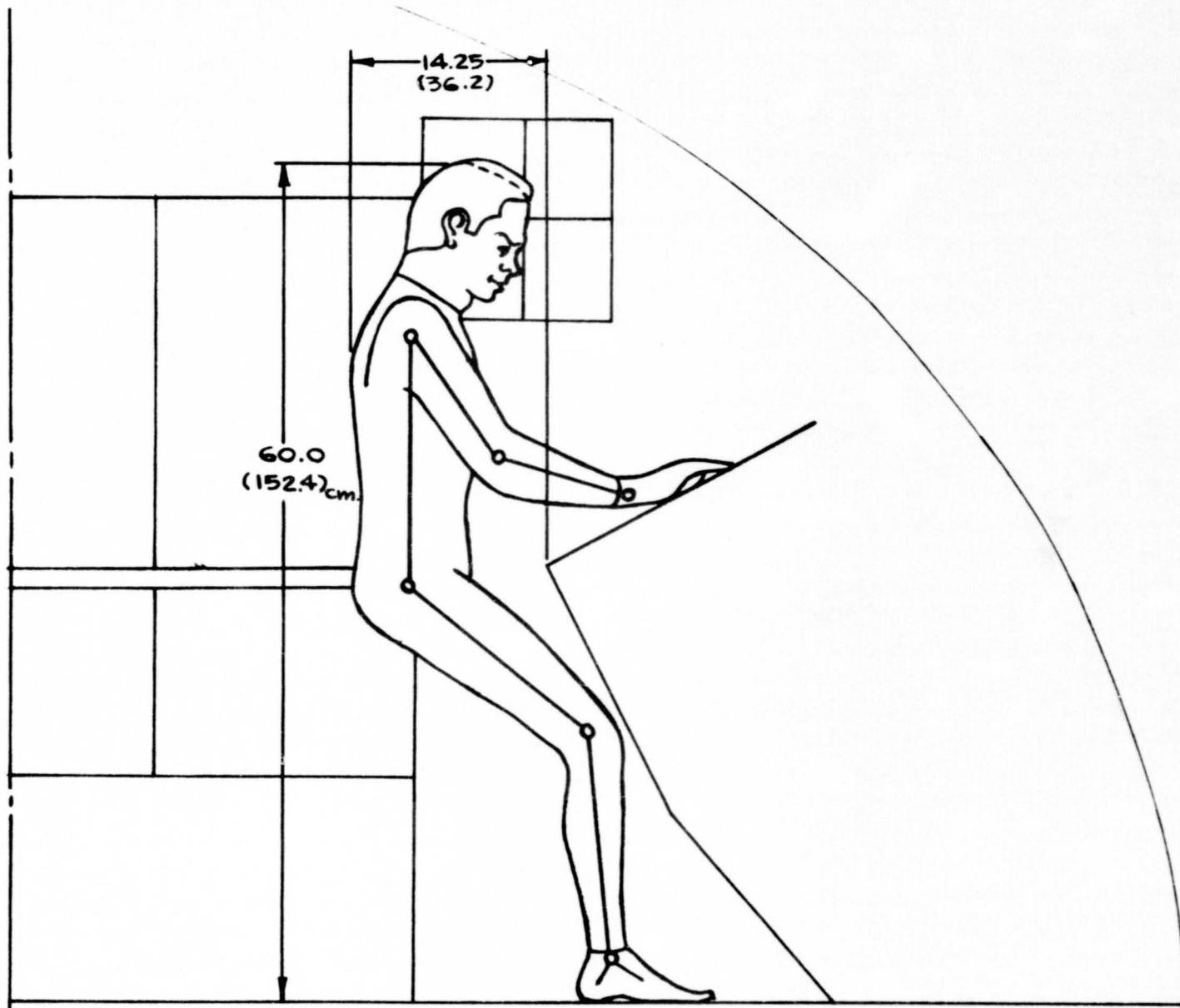


PS CONSOLE OPERATING POSITION, 5TH PERCENTILE FEMALE
FIGURE 81



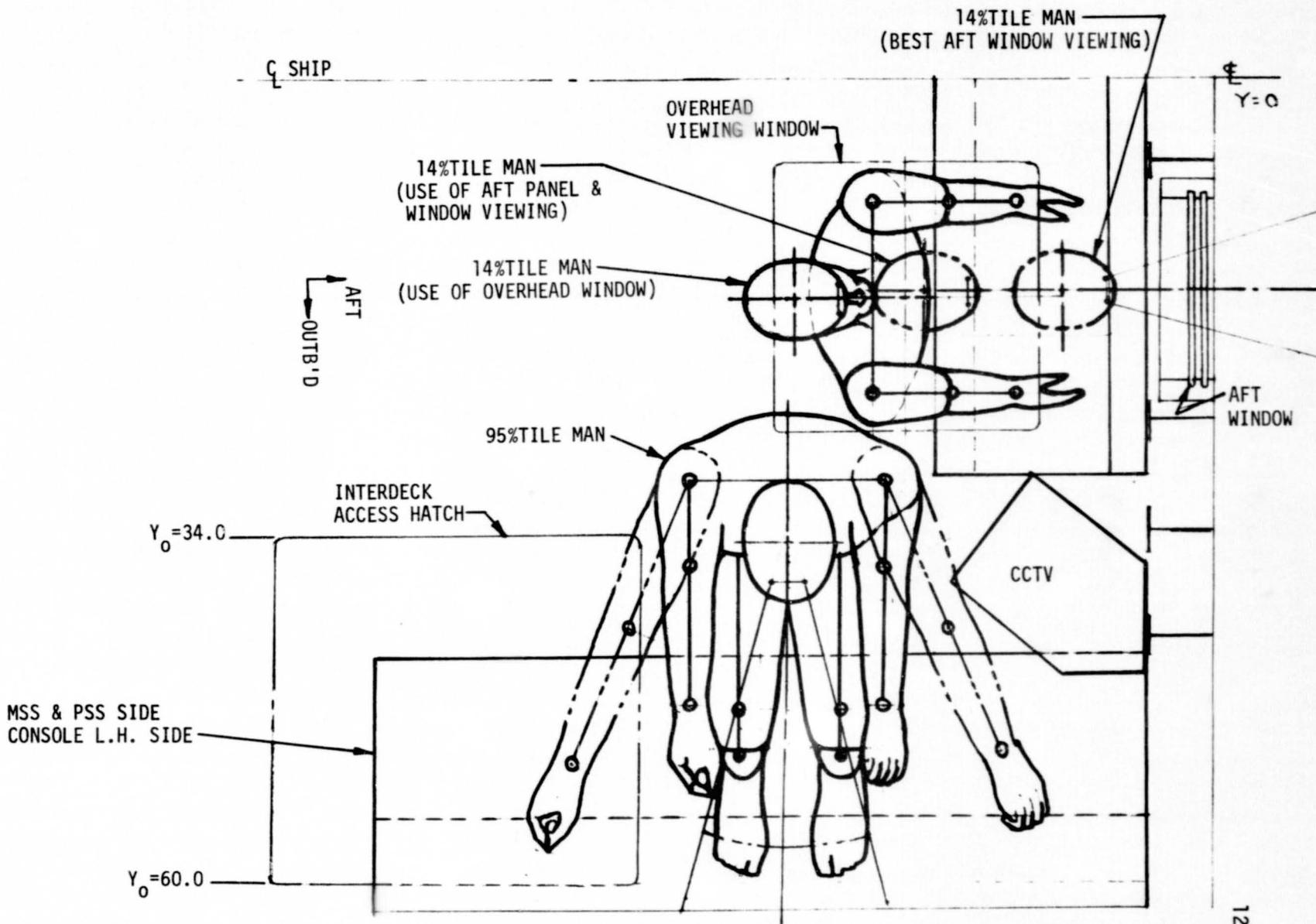
PS CONSOLE OPERATING POSITION, 95TH PERCENTILE MALE

FIGURE 82

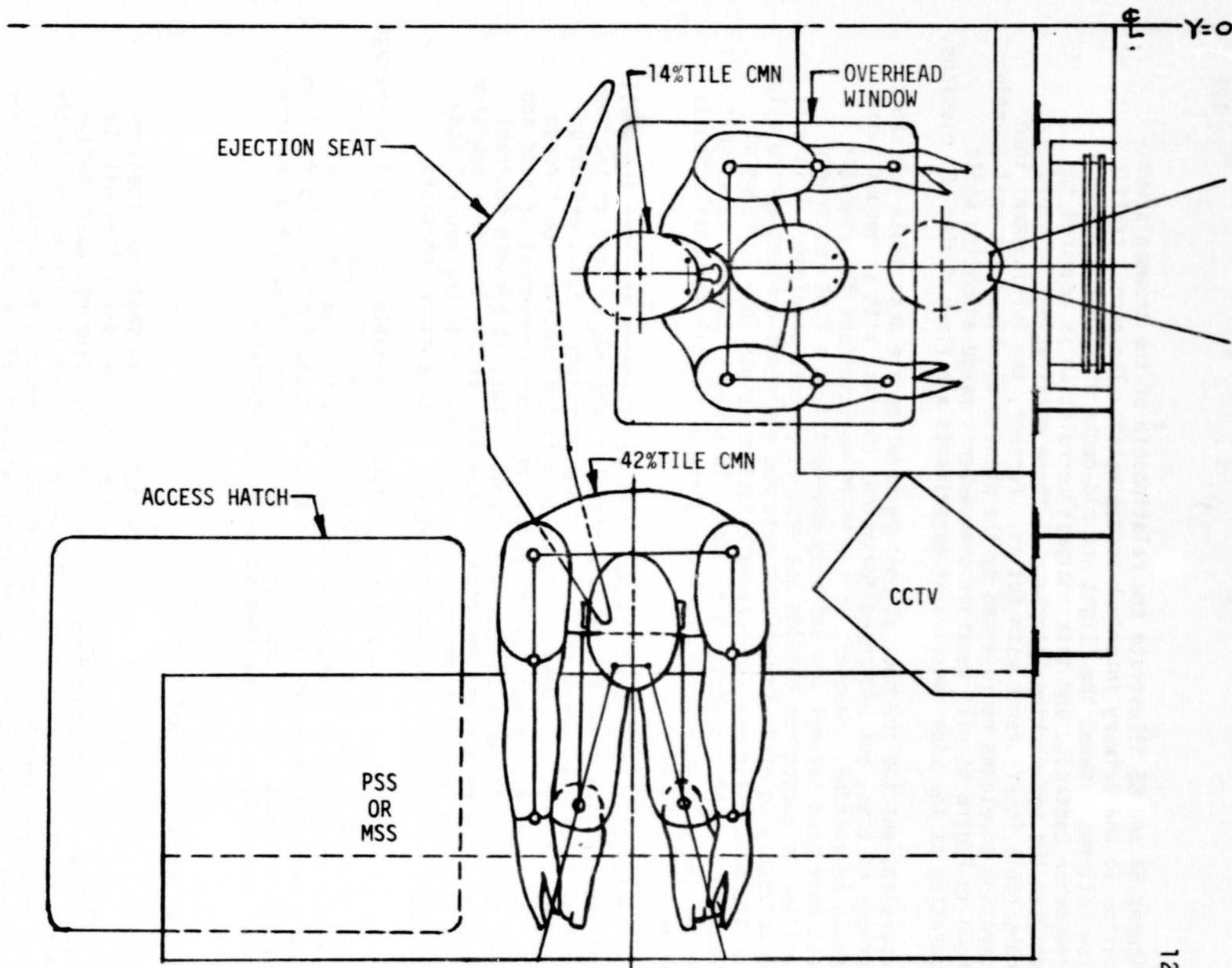


PS CONSOLE OPERATING POSITION, 50TH PERCENTILE MALE

FIGURE 83



PLAN VIEW OF AFT & SIDE STATIONS SHOWING INTERFACE OF 14TH & 95TH PERCENTILE CREWMEN
 FIGURE 84



PLAN VIEW OF AFT & SIDE STATIONS SHOWING INTERFACE OF 14 & 42 PERCENTILE SKYLAB CREWMAN
 FIGURE 85

Figures 84 and 85 illustrate the relationship of the crewman's workstation to the primary interdeck access hatch. The normal traffic flow patterns between the flight and mid-decks will create potential crewmember contacts, and task analysis correlation is required to optimize the man-machine interface at these workstations to avoid undesirable interference with duties. Further, the infringement into operating envelopes represented by the phantom ejection seat rail mounting shown in Figure 85 will restrict crewmember's range of motion while operating at the side consoles if experiments are flown during OFT missions.

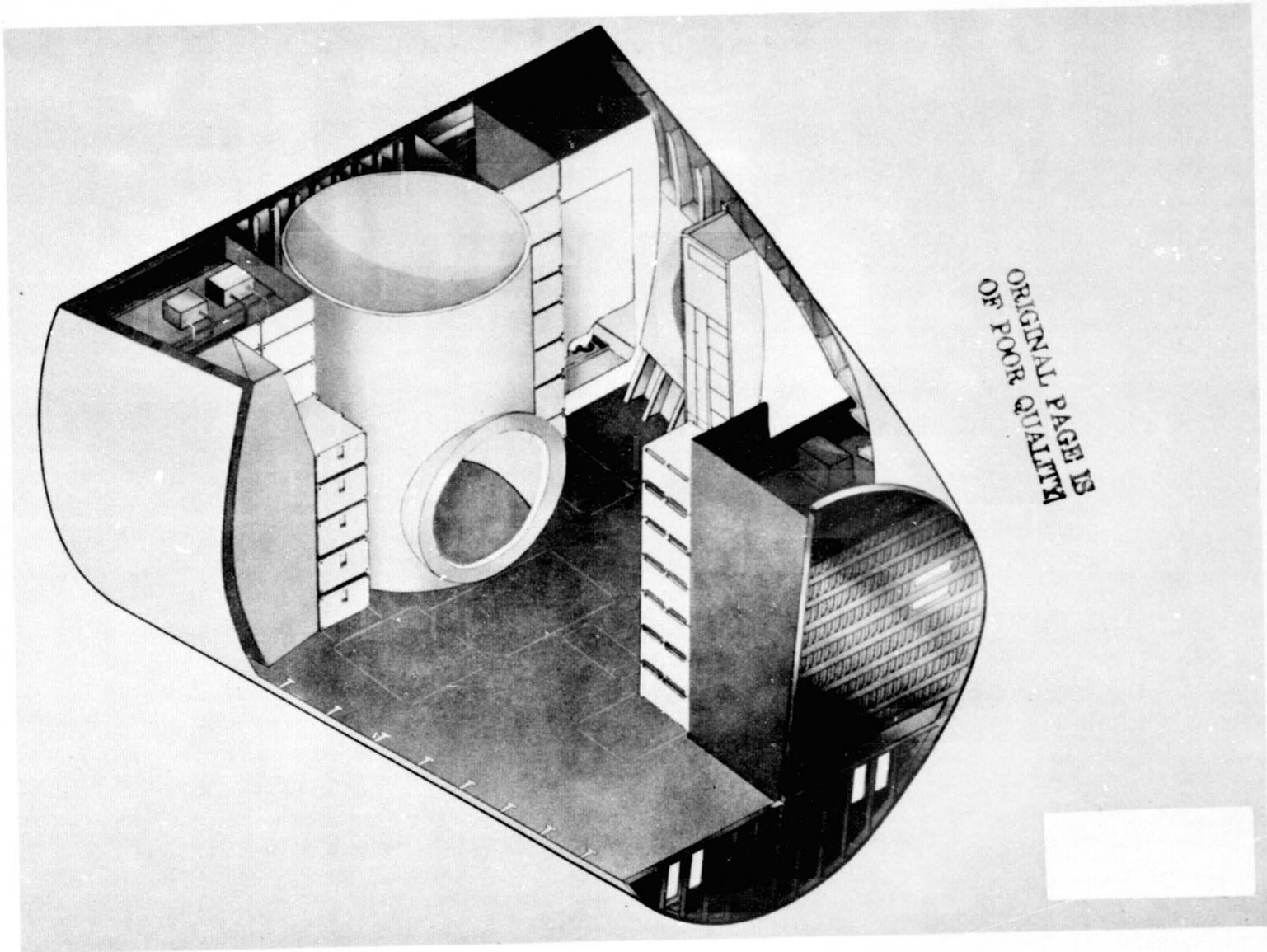
Excursions outside the neutral posture envelope are acceptable for short periods of time, but prolonged deviations combined with strenuous tasks should be avoided. However, at the MS/PS workstations the operator must have good lateral arm and body movement from a foot restrained position to excursions outside the neutral posture envelope. This will be necessary to avoid inadvertent crew and equipment contact and to allow for the most efficient man-machine relationship possible in terms of functional reach and design eye point. This means that all tasks must be located well within the reach and grasp of the 5th percentile female shown in Figure 81.

The conclusions concerning the MS and PS workstations are that the small and average size crewmen have no particular problems related to the man-machine interface except those facing any operators: i.e., avoiding inadvertent physical contact with crewmen in the traffic flow through the interdeck access hatches and requiring lateral movement of head and body to cover the complete console layout. Thus, it becomes desirable to place viewing screens and high use controls in the immediate operator area to avoid lateral movement and excursions outside the neutral body envelope for long duration monitoring and console operation tasks.

Large size operators will probably be less comfortable than small or average size crewmen at the MS and PS workstations, especially the USAF-1985 male crewman who is quite cramped in the confined work area. Nevertheless, any crewmember assigned to a mission will no doubt find ways to function at all stations, even if some tasks are not performed at a high efficiency level due to less than optimum man-machine interfaces.

6.1.3 Mid-Deck Workstations

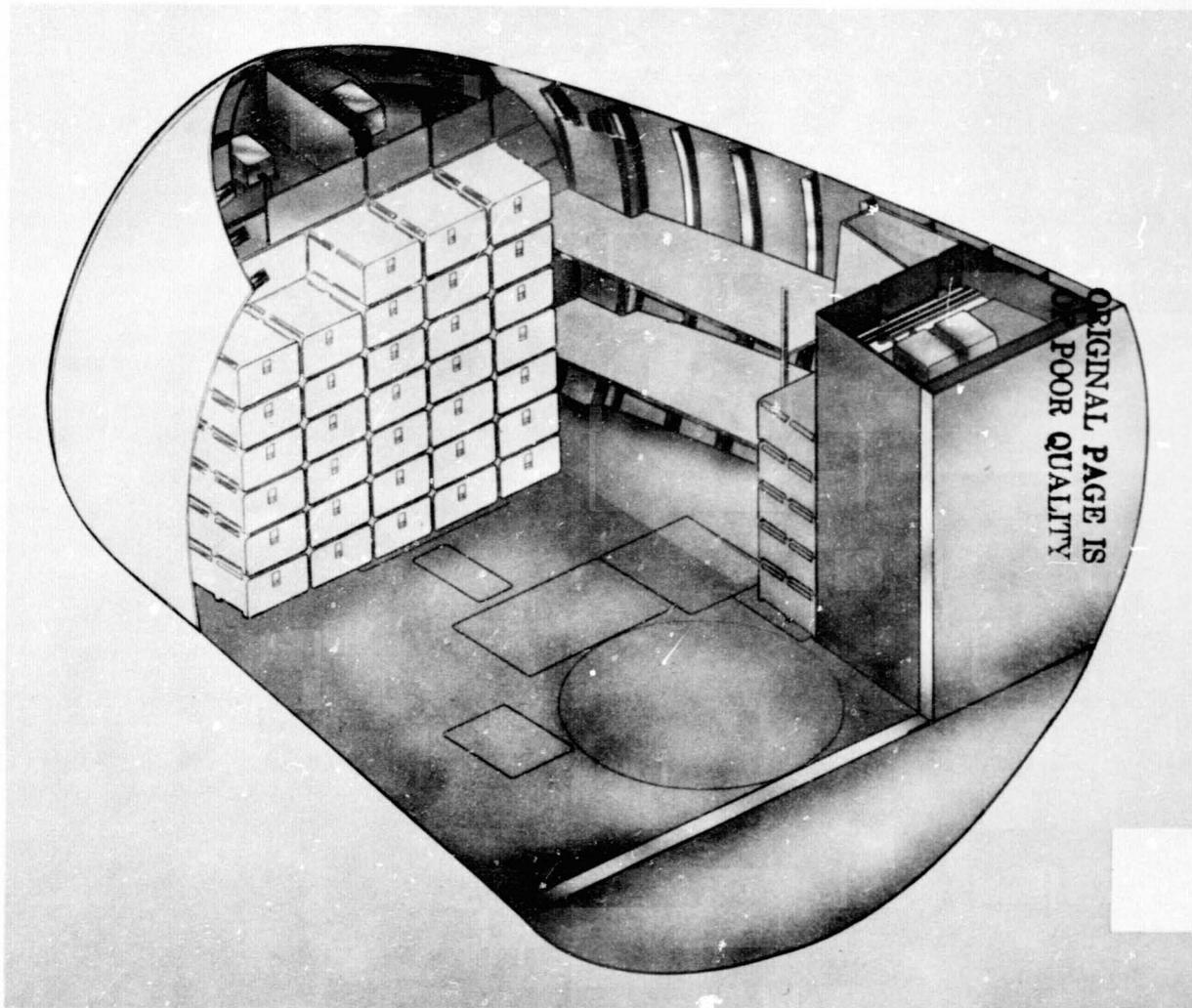
The Orbiter mid-deck will provide the habitability features necessary to sustain the crew during their mission. Support facilities will be available within the mid-deck to handle eating, sleeping, waste management, and hygiene activities. This area is shown in perspective in the two views provided by Figures 86 and 87. Somewhat like Skylab, workstations will no doubt be abundant in this area of the Orbiter, but for the sake of simplicity of presentation one workstation was chosen as a



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ORBITER MID-DECK (PORT SIDE)

FIGURE 86



ORBITER MID-DECK (STARBOARD)

FIGURE 87

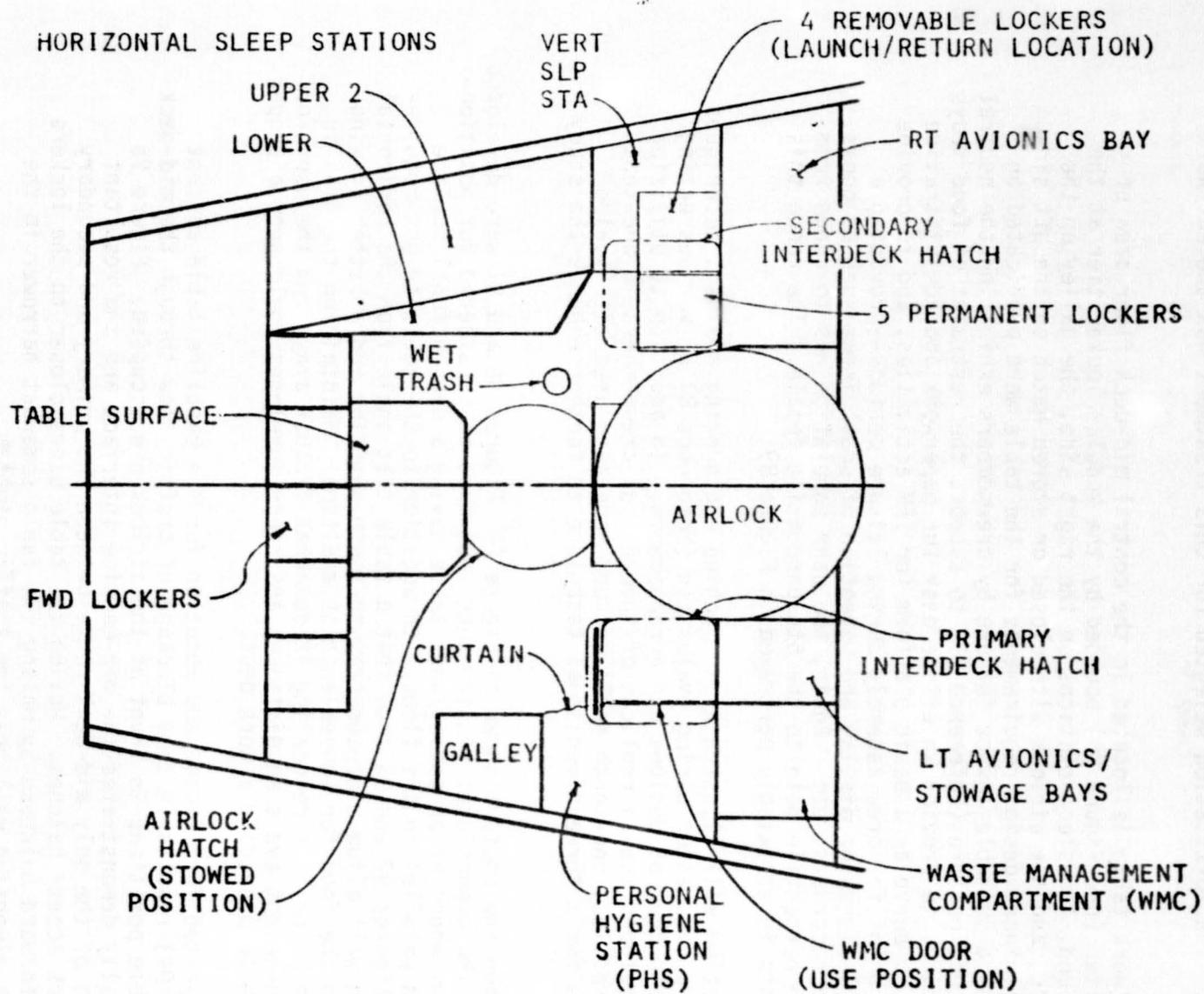
representative example to show the manner in which the data presented in earlier sections of this report can be directly applied to an on-going project. The workstation selected for this treatment was the eat/work table.

The eat/work table is located in the central mid-deck floor area of the Orbiter (see Figure 88) bounded by the modular locker tier at the forward end, the sleep stations on the right side, the galley on the left side, and the airlock with closed or stored hatch on the aft side. The preliminary design requirements for the table were predicated on providing a suitable device for use by crewmembers exhibiting the neutral zero-g body posture (Reference 1), to support the restraint of food trays at mealtime, to provide an office desk for paperwork and administrative chores, to serve as a basic platform for IFM activities, and to provide a focal point for crew assembly during leisure periods--providing a stable platform for display and retention of small items such as books, cassette recorders, etc. Again, the user population was to range from the 95th percentile male to the 5th percentile female. The range this represents is strikingly portrayed in Figure 89.

This section will illustrate man-machine engineering analysis techniques used by a contractor during evaluation (Reference 8) of various eating/work table concept designs and arrangements. In addition to utilizing NASA developed scaled replicas of theoretical crewmembers in one-tenth scale profiles, one-tenth scale mockups were also used with scaled manikins for a three-dimensional technique to further enhance the study effort.

Based upon the posture shown in Figure 27, Figures 90 and 91 were developed to show the dimensional requirements that must be considered for positioning crewmembers at an eating/work table having a conventional surface oriented parallel to the floor. In addition to the table height requirements, Figures 92 and 93 show that a table tilt angle from the horizontal position will allow a closer tray-to-mouth position and a better viewing angle to the food for convenience at mealtime. Maintaining the tray in the same plane, but relocating it somewhat farther away from the user for more convenient eye scan distances and reach envelopes would seem a proper approach to providing a work desk.

The suggested form factor and location for the baseline table concept (Figure 94) results in some blockage of traffic flow through the mid-deck when table positions in front of the airlock are occupied. Figure 95 graphically demonstrates the man-machine interface and the resultant blockage of the only mid-deck route between the primary and secondary interdeck access hatches. Moving the table users closer to the lockers on the forward bulkhead by making the table somewhat narrower in the fore-aft dimension will help the traffic problem.



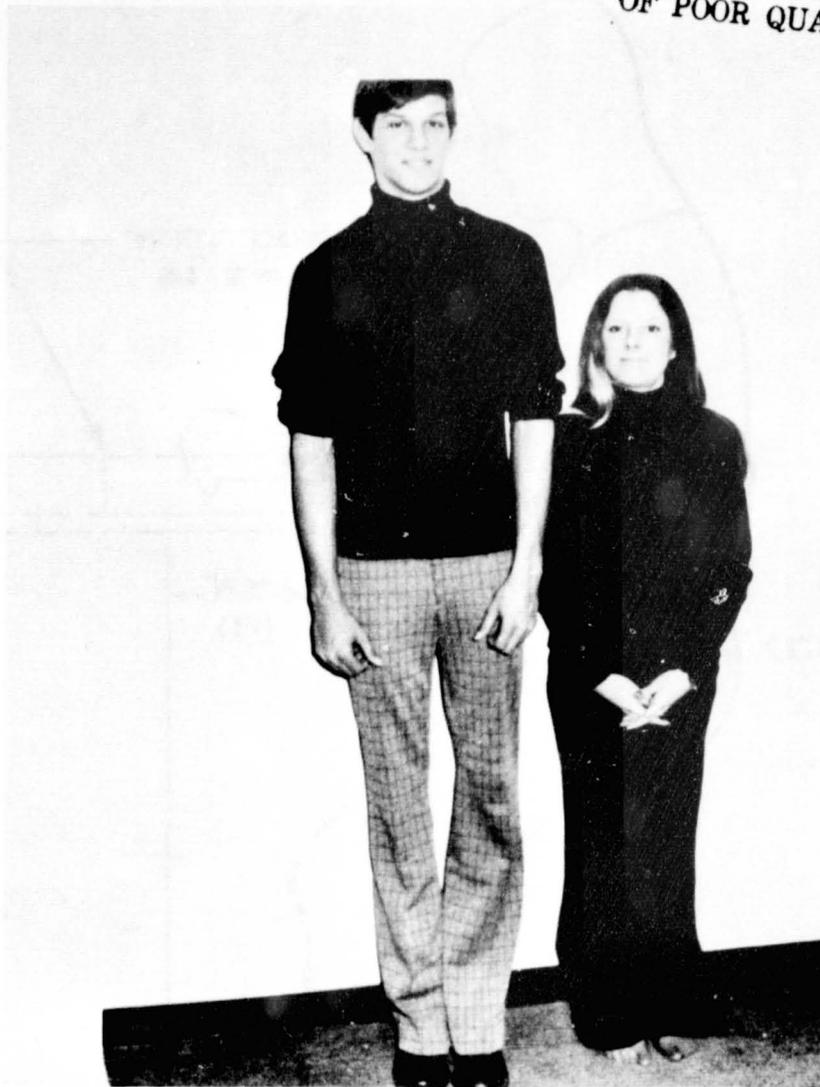
MID-DECK BASELINE ARRANGEMENT WITH AIRLOCK

FIGURE 88

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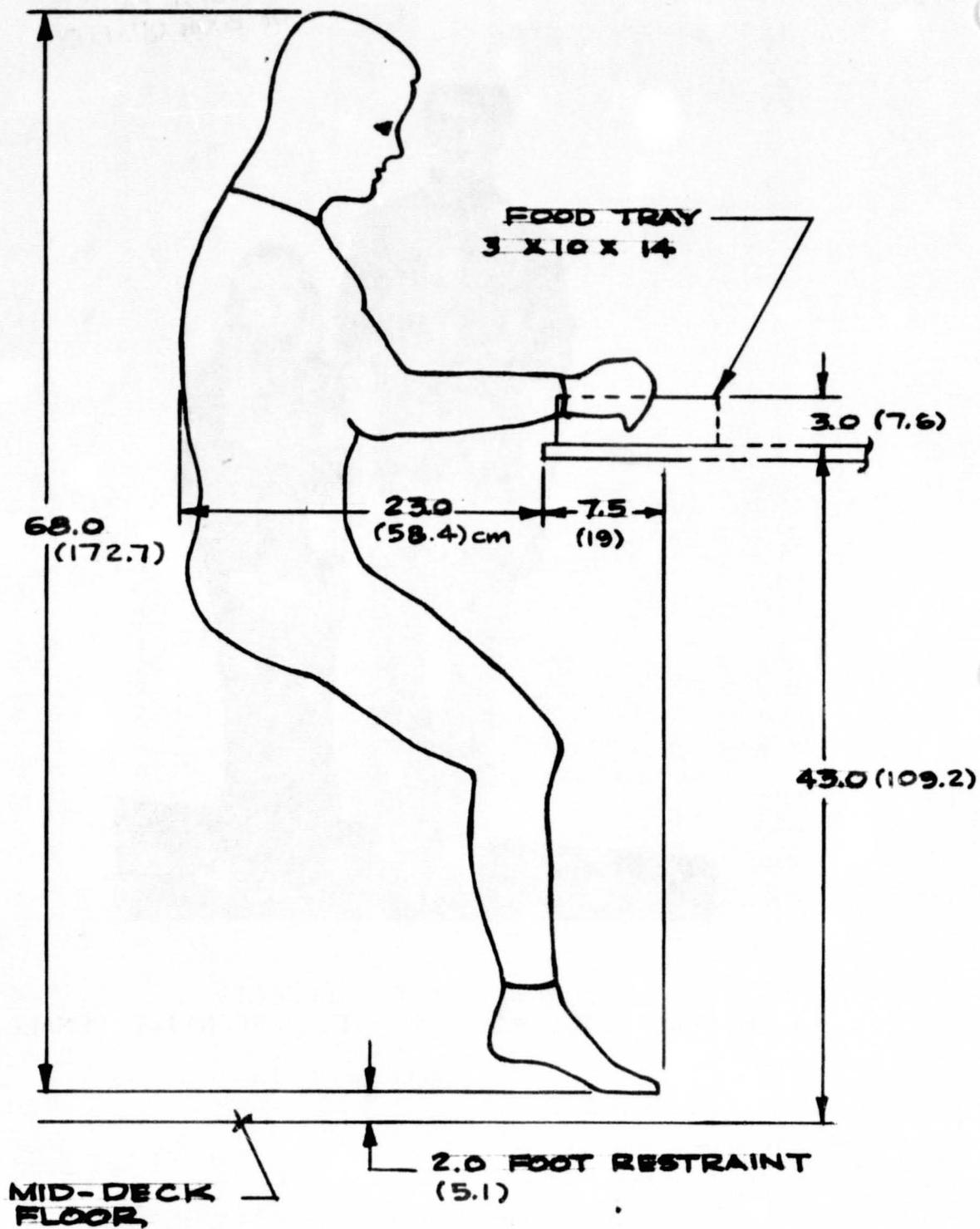
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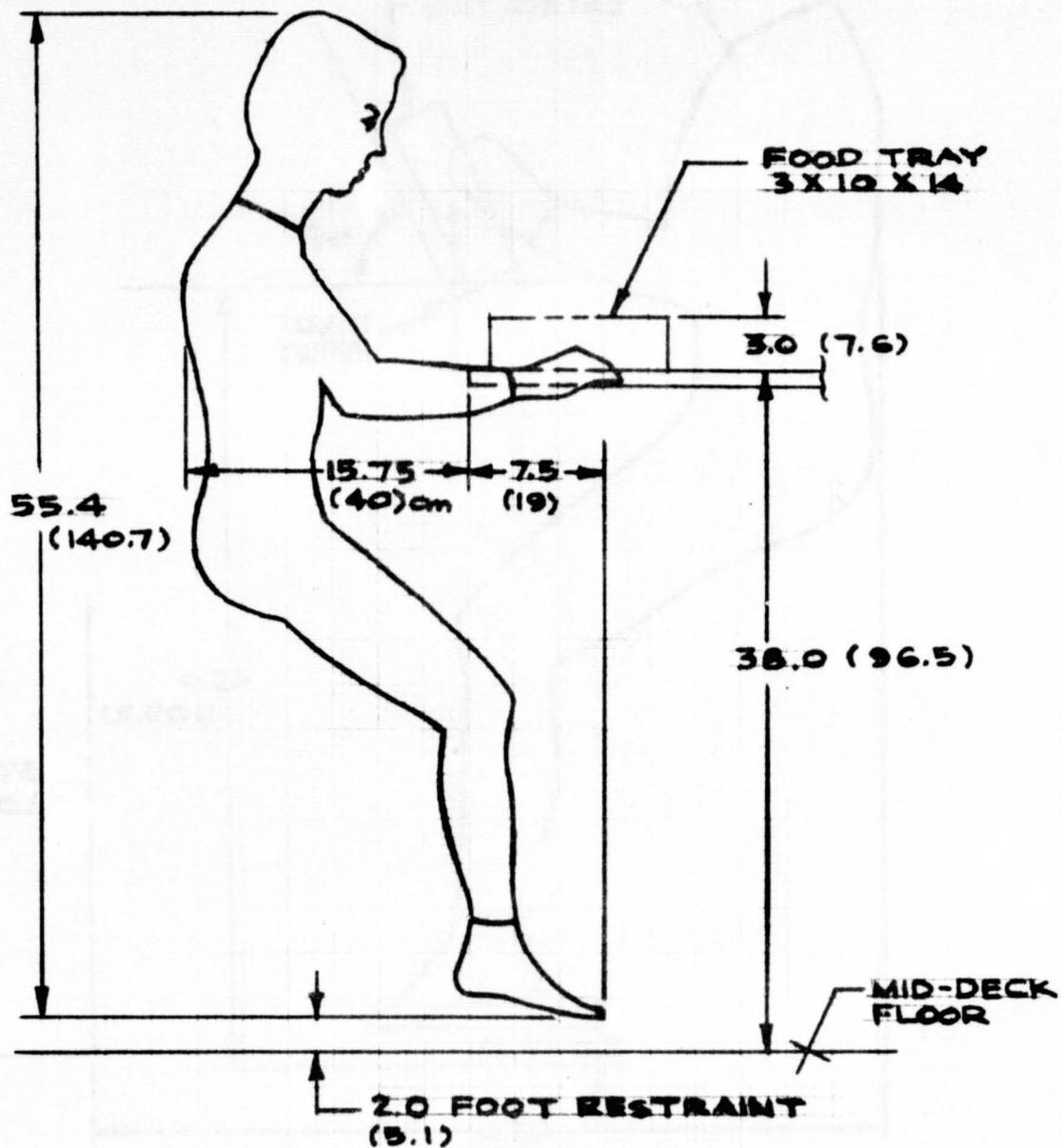
COMPARISON OF SUBJECTS
(95TH PERCENTILE MALE AND 5TH PERCENTILE FEMALE)

FIGURE 89



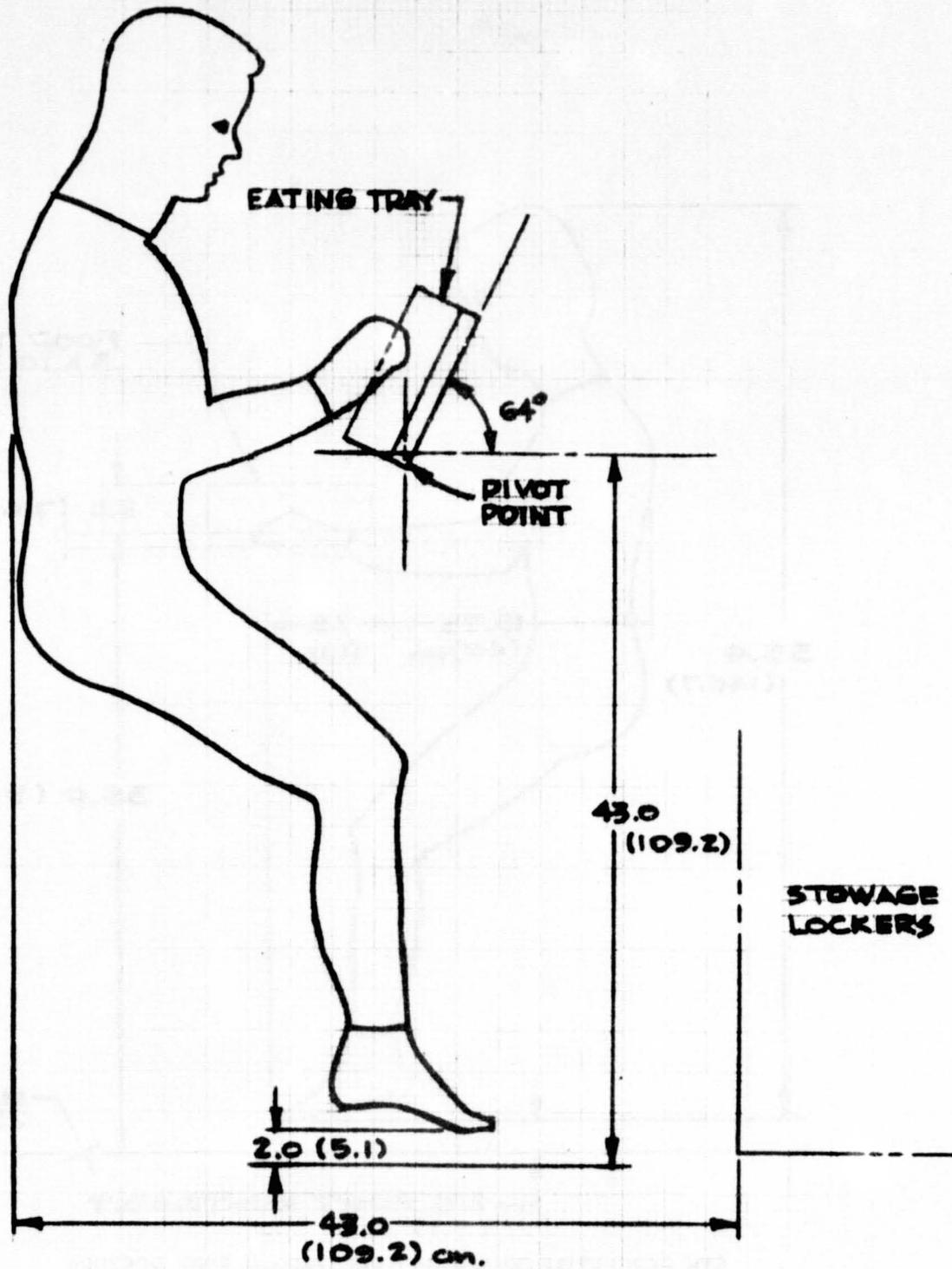
95TH PERCENTILE MALE NEUTRAL ZERO-G BODY POSTURE
AT HORIZONTAL TABLE - SIDE VIEW

FIGURE 90



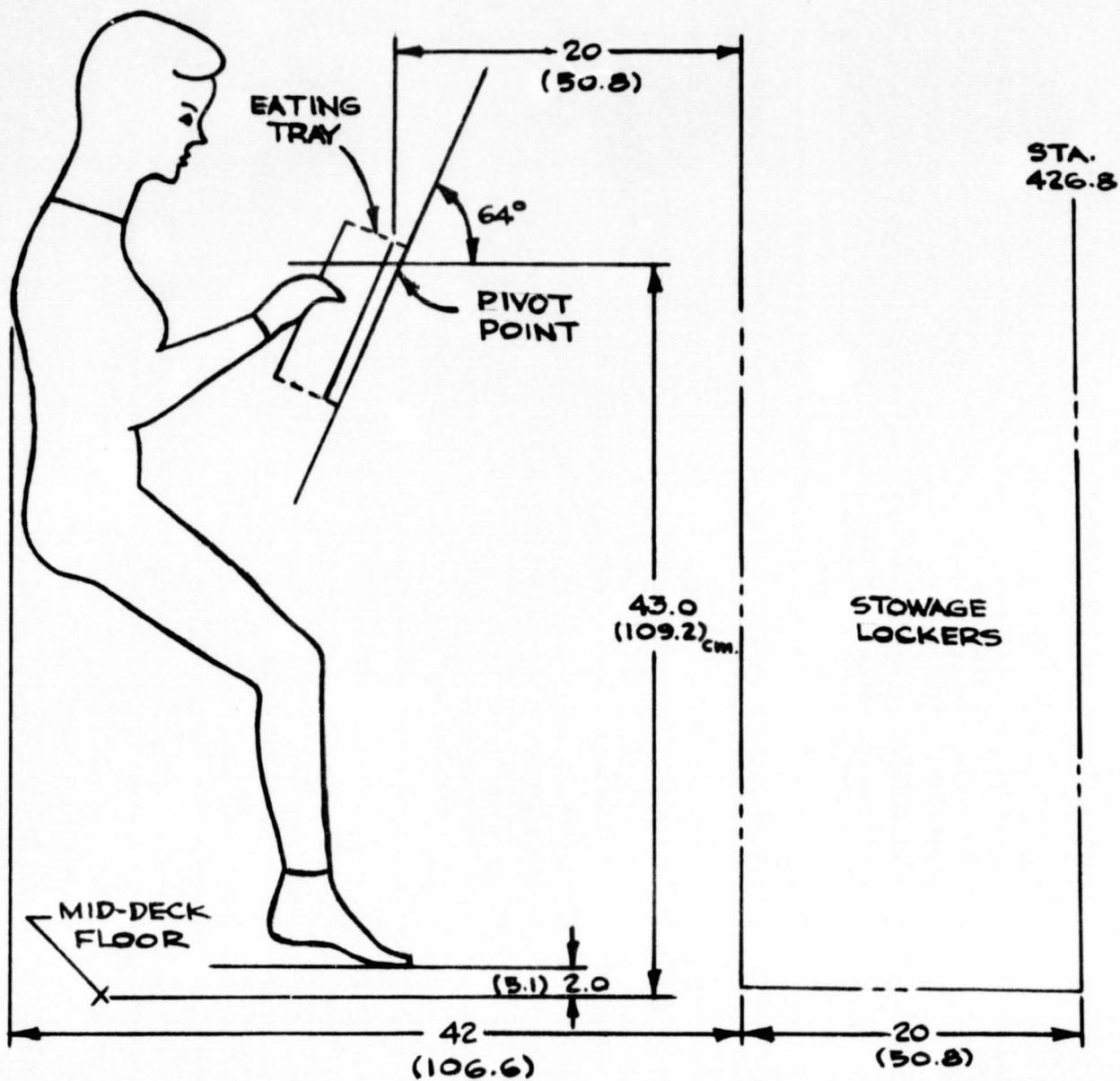
5TH PERCENTILE FEMALE NEUTRAL ZERO-G BODY POSTURE
AT HORIZONTAL TABLE - SIDE VIEW

FIGURE 91



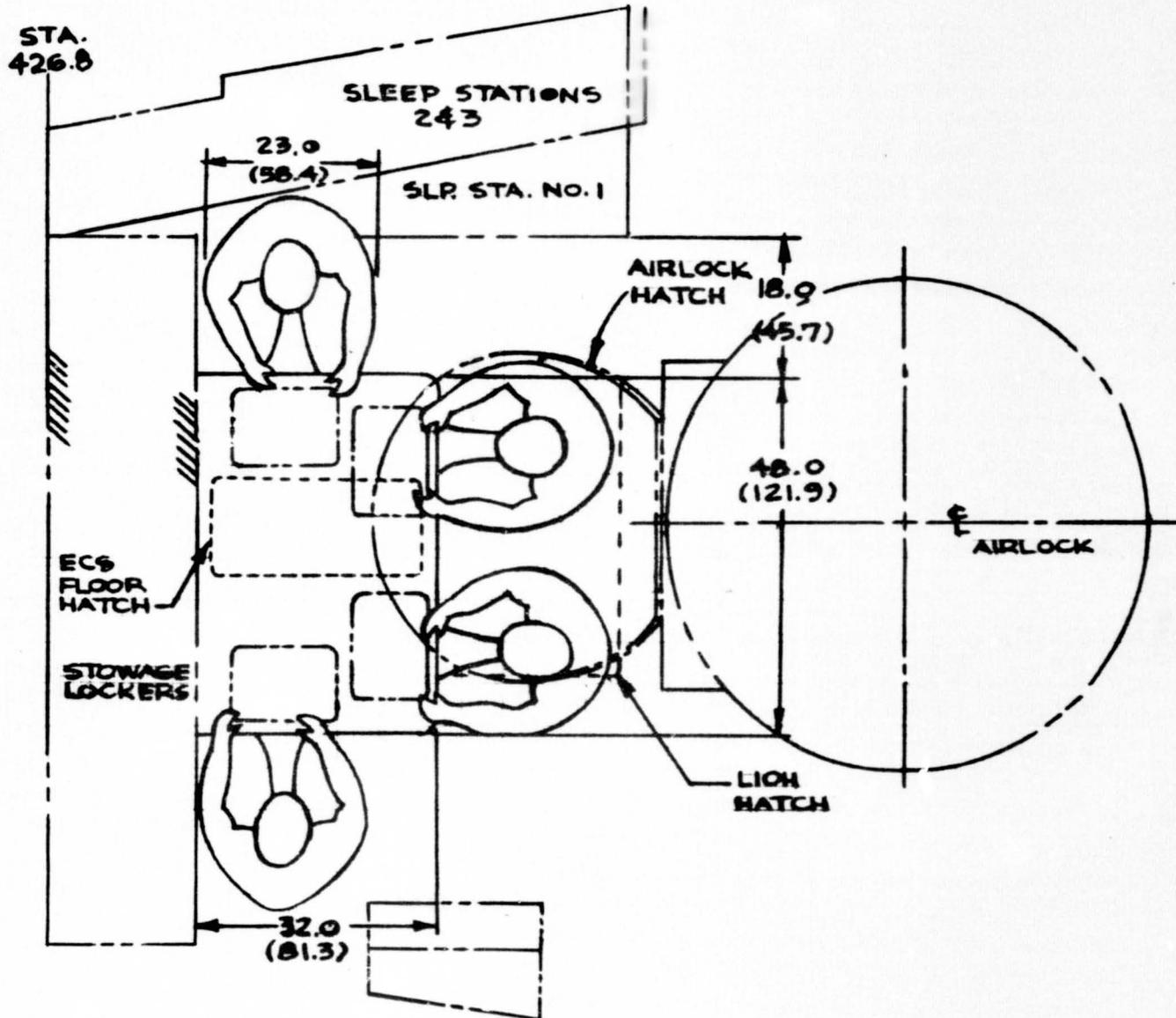
95th PERCENTILE MALE NEUTRAL ZERO-G BODY POSTURE
AT TILTED TABLE

FIGURE 92



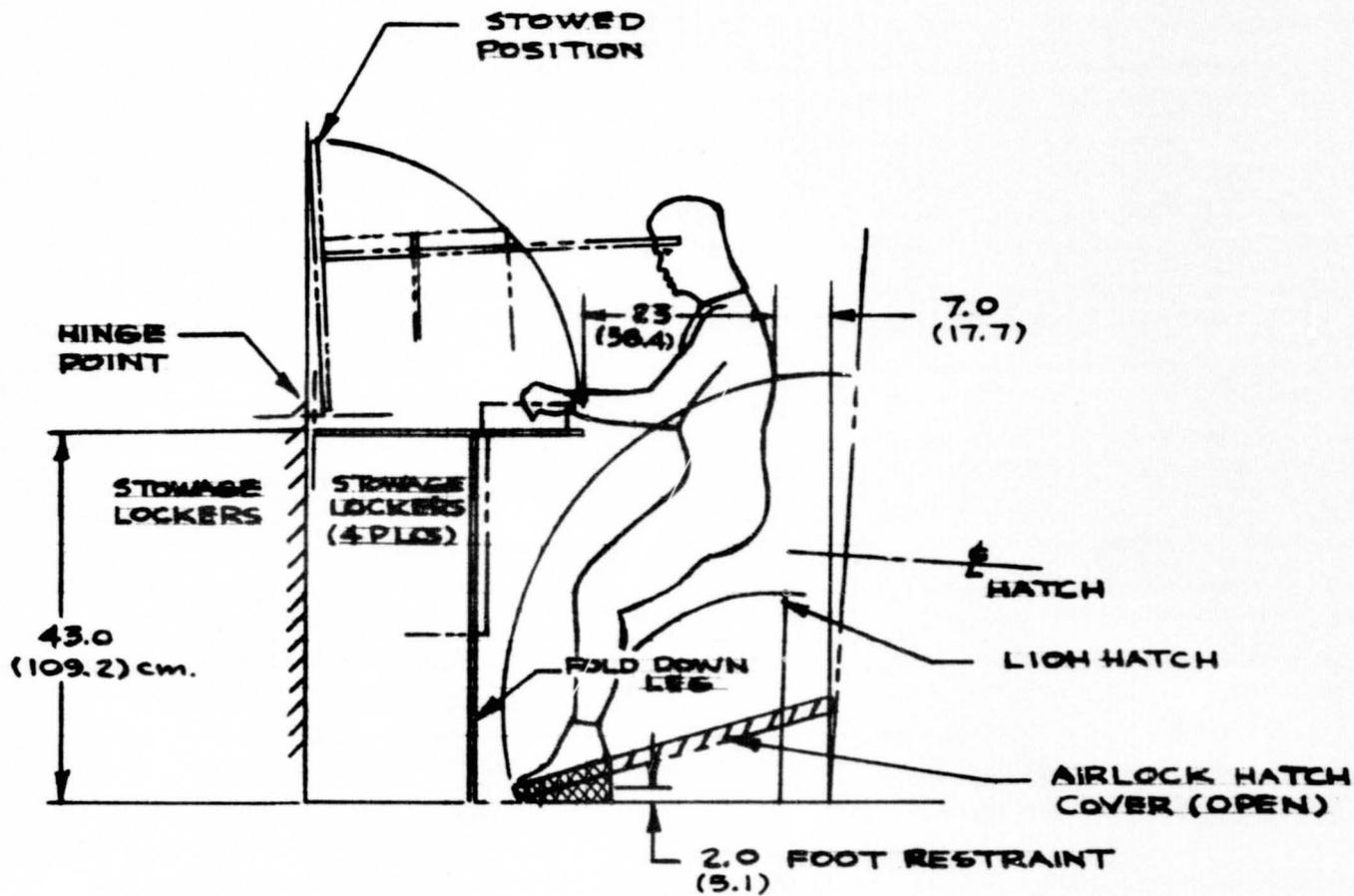
5TH PERCENTILE FEMALE NEUTRAL ZERO-G BODY POSTURE
AT TILTED TABLE

FIGURE 93



BASELINE EATING/WORK TABLE ARRANGEMENT - PLAN VIEW

FIGURE 94



EATING/WORK TABLE CONCEPT

FIGURE 95

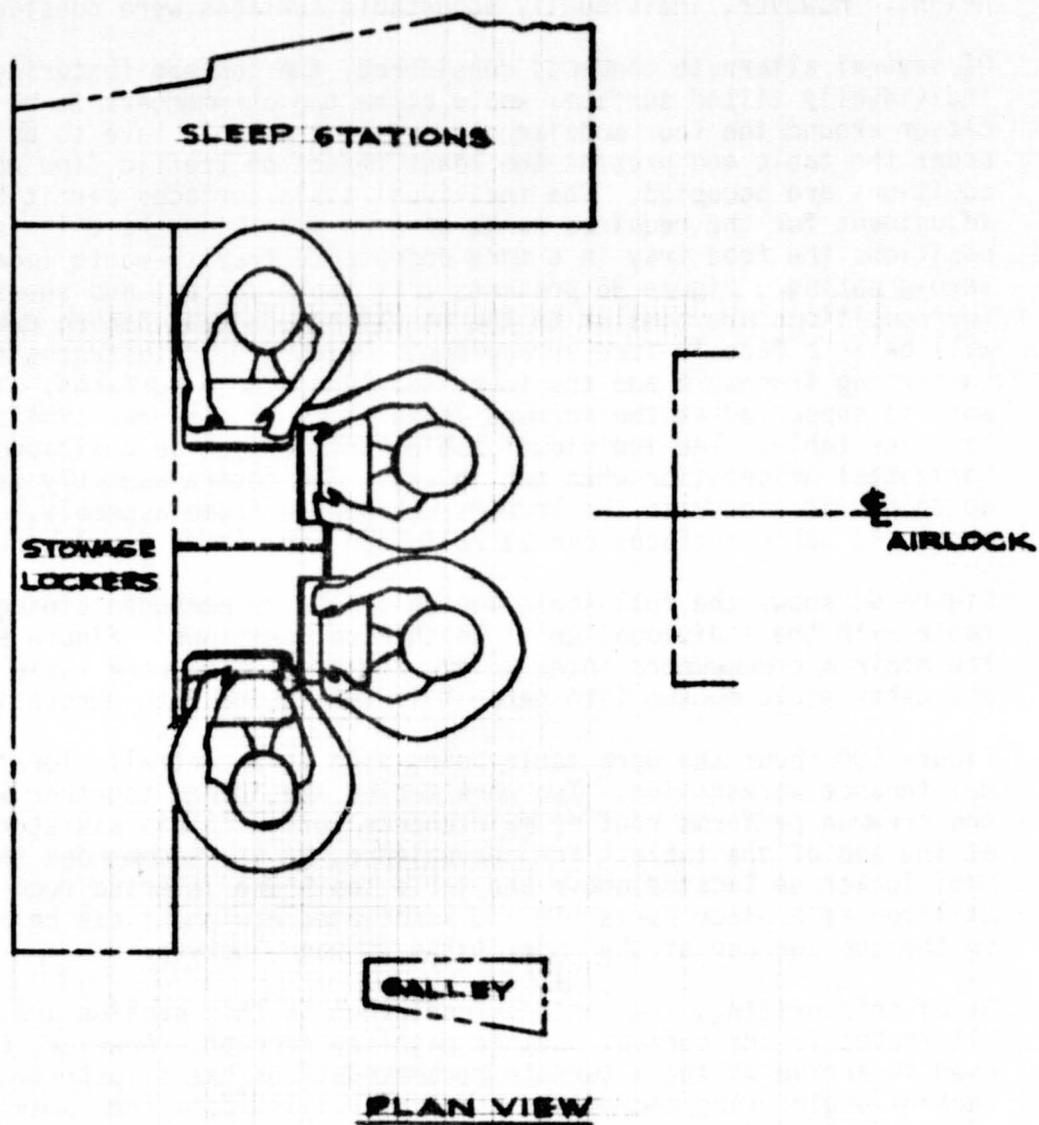
A table height difference of approximately 5 inches (13 centimeters) ranging from 38 inches (97 centimeters) for a 5th percentile female and 43 inches (109 centimeters) for a 95th percentile male was found to be required. Use of a single table surface to accommodate four crewmembers of various heights would require a mutually acceptable average table height. However, individually adjustable surfaces were considered.

Of several alternate concepts considered, the concept featuring individually tilted surfaces would allow the crewmembers to be grouped closer around the four modular stowage lockers that have to be stowed under the table and present the least impact on traffic flow when table positions are occupied. The individual table surfaces permit height adjustment for the required range of crew sizes and the tilt feature positions the food tray in a more acceptable tray-to-mouth location for zero-g eating. Figure 96 presents this table concept and shows that the four positions are similar to the baseline such that dining crewmembers will be in a face-to-face arrangement. Figure 97 illustrates the supporting framework and the four individual table surfaces. The framework is supported at the forward locker tier in a manner similar to the baseline table. The individual table surfaces can be positioned in a horizontal orientation when not in use. The entire assembly can be swung up to permit access to the lockers behind the frame assembly. The entire frame and table surfaces can be collapsed and stowed for launch/reentry.

Figure 98 shows the full-scale mockup of the recommended dining/work table with the individual units in the use positions. Figure 99 shows the manikin crewmembers interfacing with the eating/work table in the one-tenth scale mockup (5th percentile female and 95th percentile male).

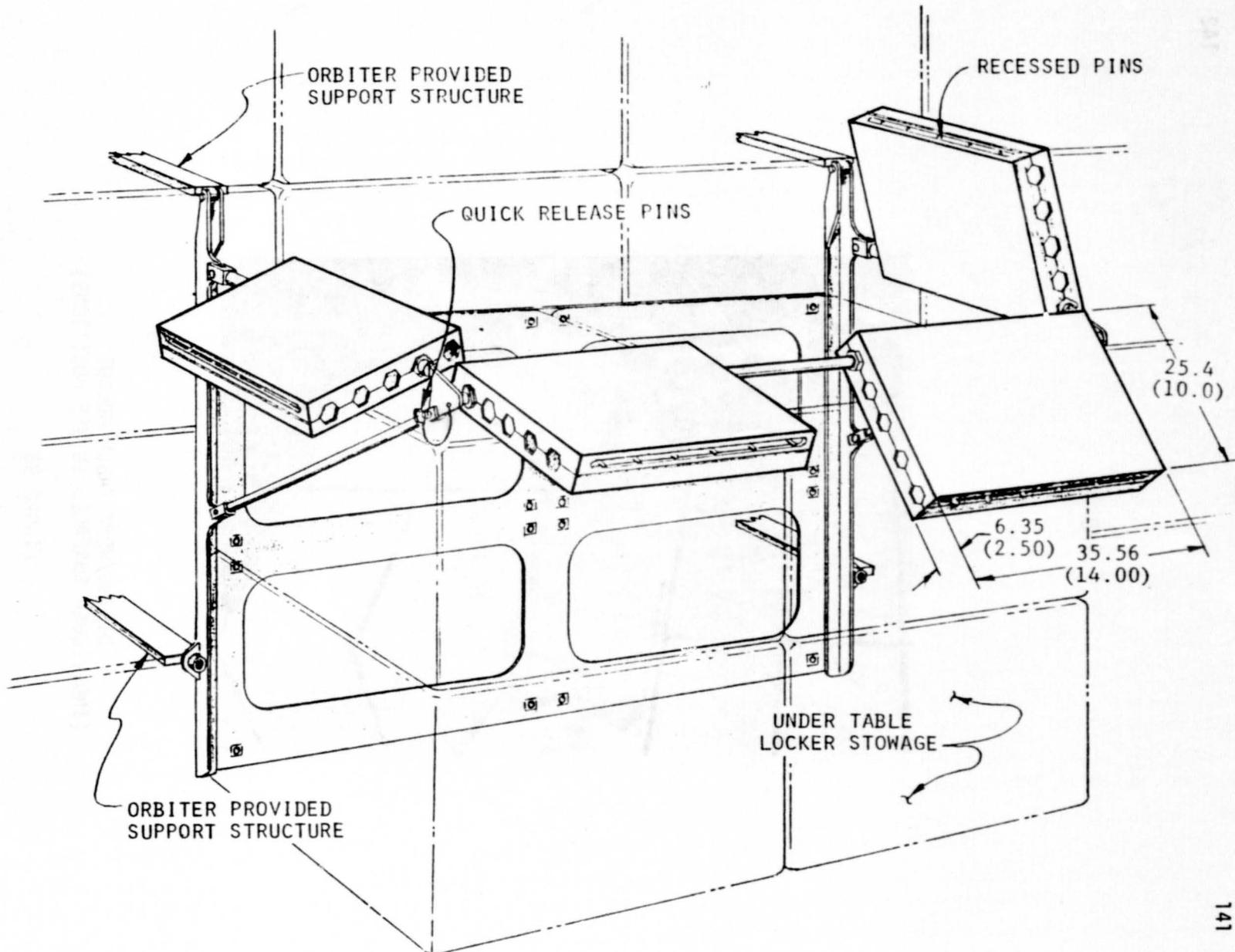
Figure 100 shows the work table being used as a centrally located maintenance workstation. Two work tables are joined together where the crewman performs routine maintenance work with his assistant located at the end of the table. For convenience, it is recommended that the tool locker be located above the table top. One inverted food tray is utilized as a piece parts bin and associated equipment can be restrained on the top surface of the under table stowage lockers.

As of this writing, the concepts contained in this section are recommended alternates to the current Shuttle baseline concept. However, the process used to arrive at the alternate recommendations has illustrated the man-machine engineering techniques used in applying data from previous programs to the design of ongoing and future projects. A continuing program is under way to evaluate the alternate configurations for the table and settle upon the most acceptable device for Orbiter operations.



EATING/WORK TABLE RECOMMENDED CONCEPT - PLAN VIEW
(USE POSITION)

FIGURE 96



UTILITY ADJUSTMENT AND MOUNTING CONCEPT FEATURES FOR EATING/WORK TABLE

FIGURE 97



DINING/WORK TABLE MOCKUP
(INDIVIDUAL SURFACES IN USE POSITIONS)

FIGURE 98

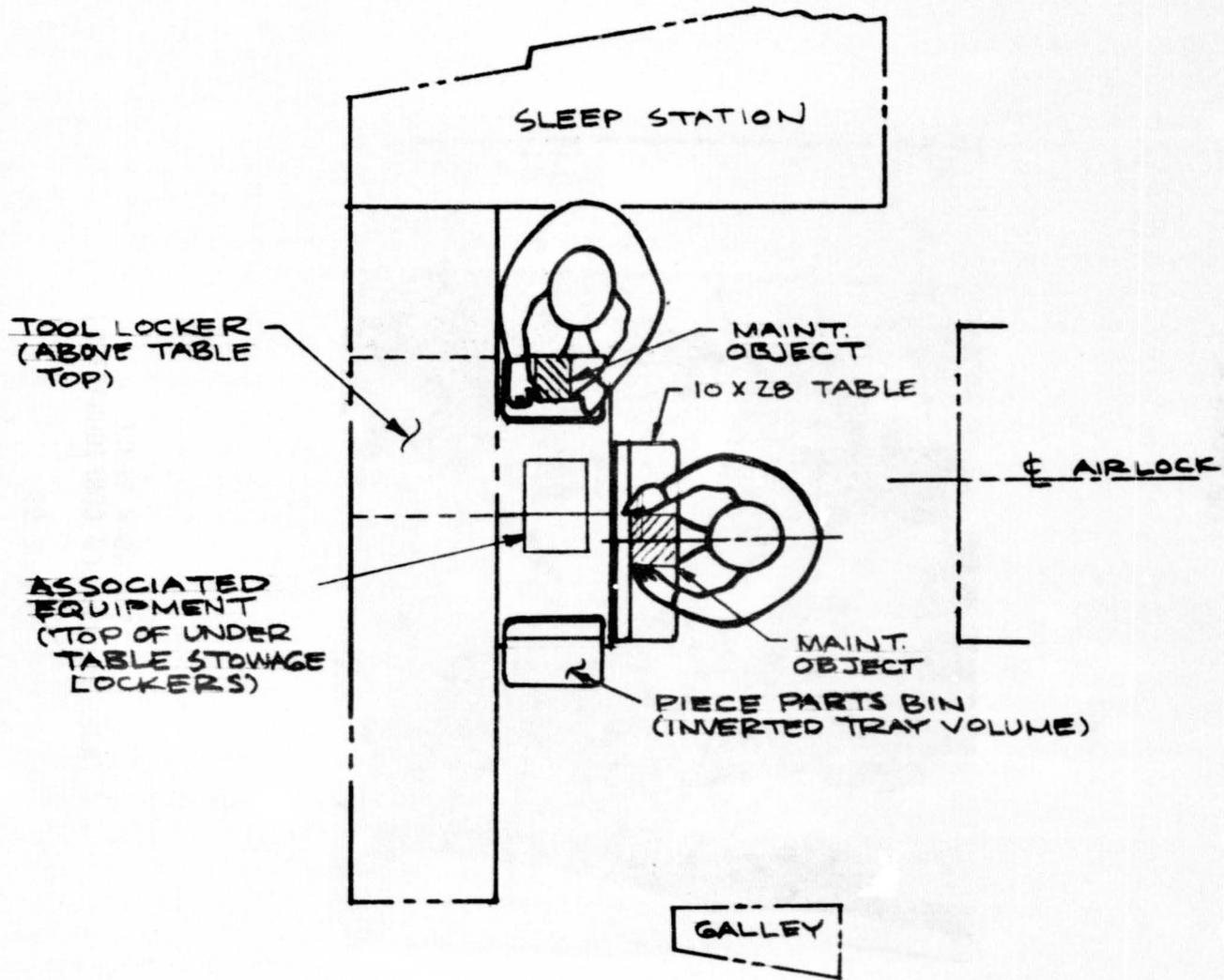
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EATING/WORK TABLE
(NJE RECOMMENDED CONFIGURATION)

FIGURE 99



WORK TABLE APPLICATION
FIGURE -100

6.1.4 Extravehicular Activities

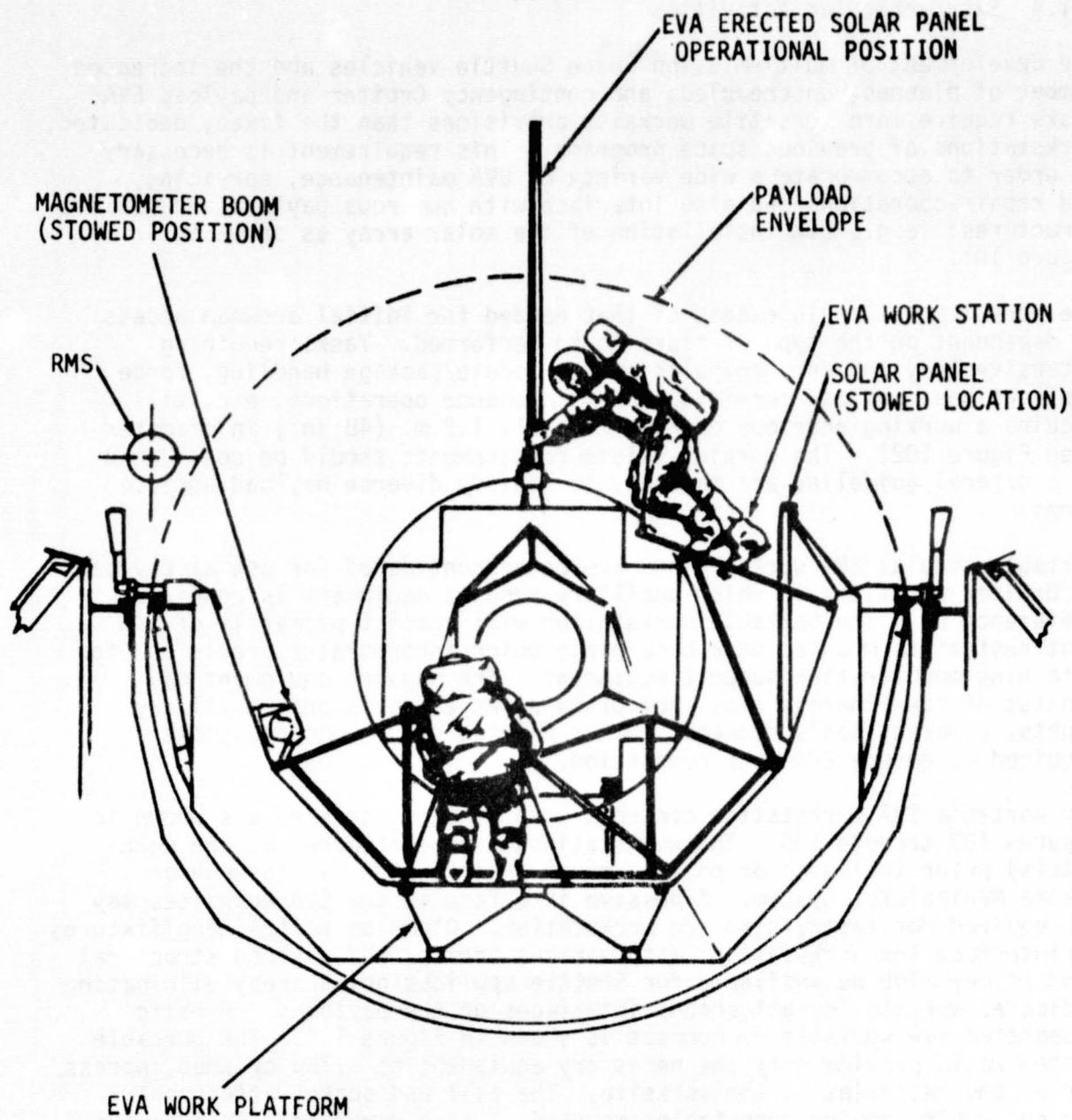
The development of multi-mission Space Shuttle vehicles and the increased number of planned, unscheduled, and contingency Orbiter and payload EVA tasks require more versatile worksite provisions than the fixed, dedicated, workstations of previous space programs. This requirement is necessary in order to accommodate a wide variety of EVA maintenance, servicing, and repair operations and also interface with numerous payload and vehicle structures: e.g., EVA installation of the solar array as shown in Figure 101.

The worksite volume in excess of that needed for initial crewman access is dependent on the type of tasks to be performed. Tasks requiring extensive body and arm manipulation for module/package handling, force applications, payload servicing and maintenance operations, etc. will require a working envelope of approximately 1.2 m. (48 in.) in diameter (see Figure 102). The working volume requirements should be considered as a general guideline and may vary to satisfy diverse payload applications.

Portable modular EVA workstations are being considered for use at payload or Orbiter worksites in which ancillary support equipment is required (Reference 9). The portable workstation will consist primarily of EVA foot restraints mounted on a base plate which incorporates provisions for attaching modular task support equipment. The support equipment may consist of crew ingress aids, temporary stowage provisions, auxiliary lights, cameras, tools stowage, tether points, or various equipment required to ensure EVA task completion.

Two portable EVA workstation concepts with modular hardware are shown in Figures 103 through 105. The workstations may be attached at the worksite(s) prior to launch or positioned on-orbit by the EVA crewman or Remote Manipulator System. A passive interface at the EVA worksites may be required for restraining the workstation. Clamp-on restraining fixtures to interface the workstations with various Orbiter and payload structural members may also be available for Shuttle application, thereby eliminating dedicated workstation attachment interfaces on the payloads. A basic integrated EVA workstation concept is shown in Figure 106. The portable system would provide only the necessary equipment to allow crewmen ingress/egress and restraint at the worksite. The ball and socket attachment concept would require receptacles mounted at each worksite. An adhesive attachment concept is shown in Figure 107.

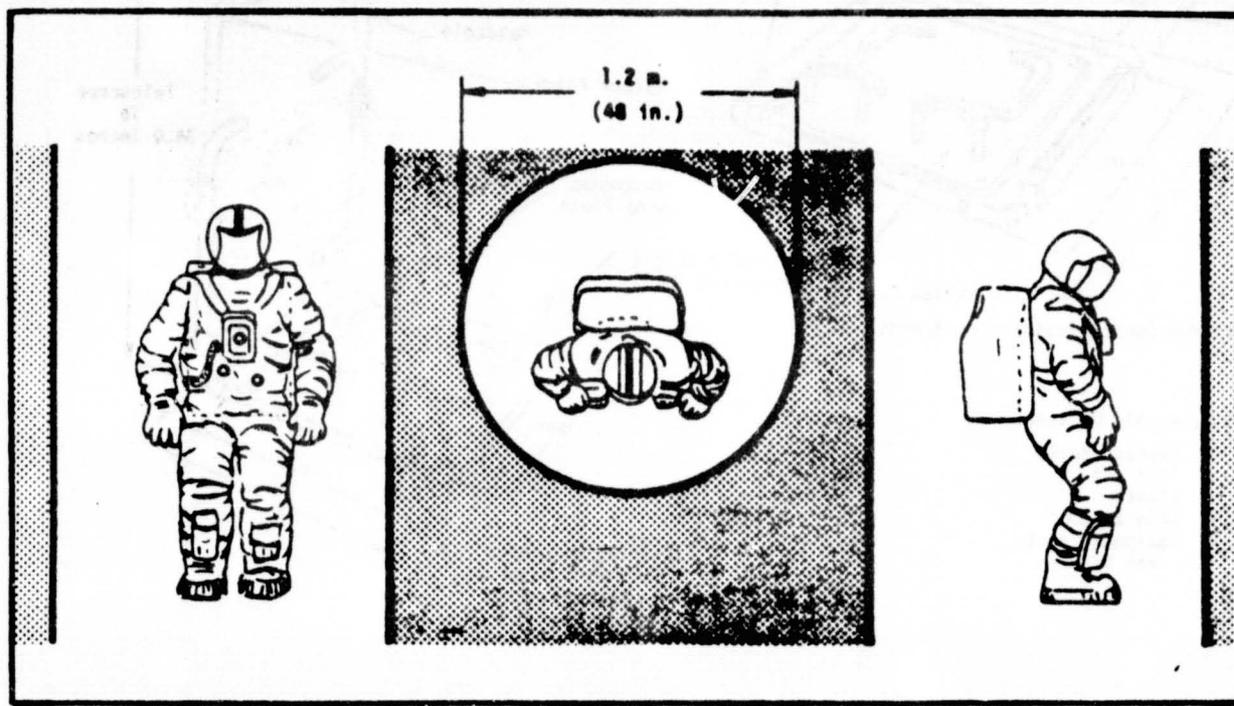
A key man-machine interface for EVA and workstation design is the functional reach of the EMU suited crewman and is defined as the distance from the palm of the hand to the nearest interference point (either the chest or EMU support gear) when reaching forward while standing erect. The crewman's



EVA INSTALLATION OF SOLAR ARRAY

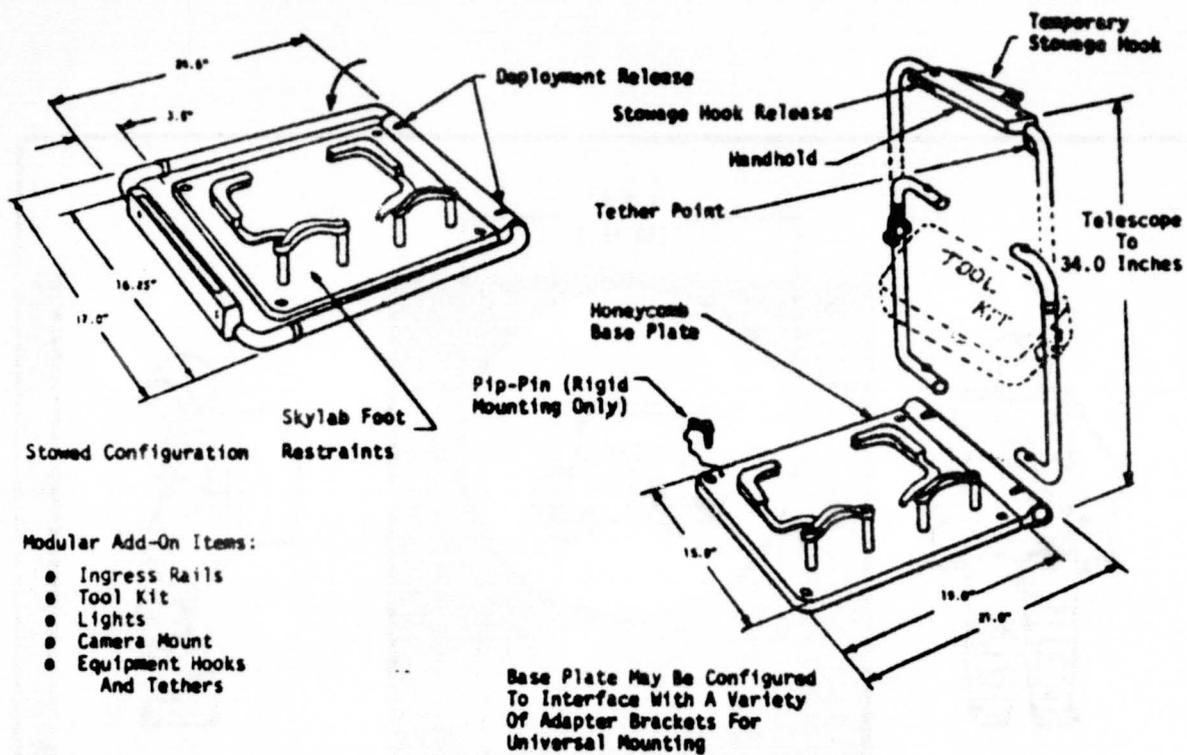
FIGURE 101

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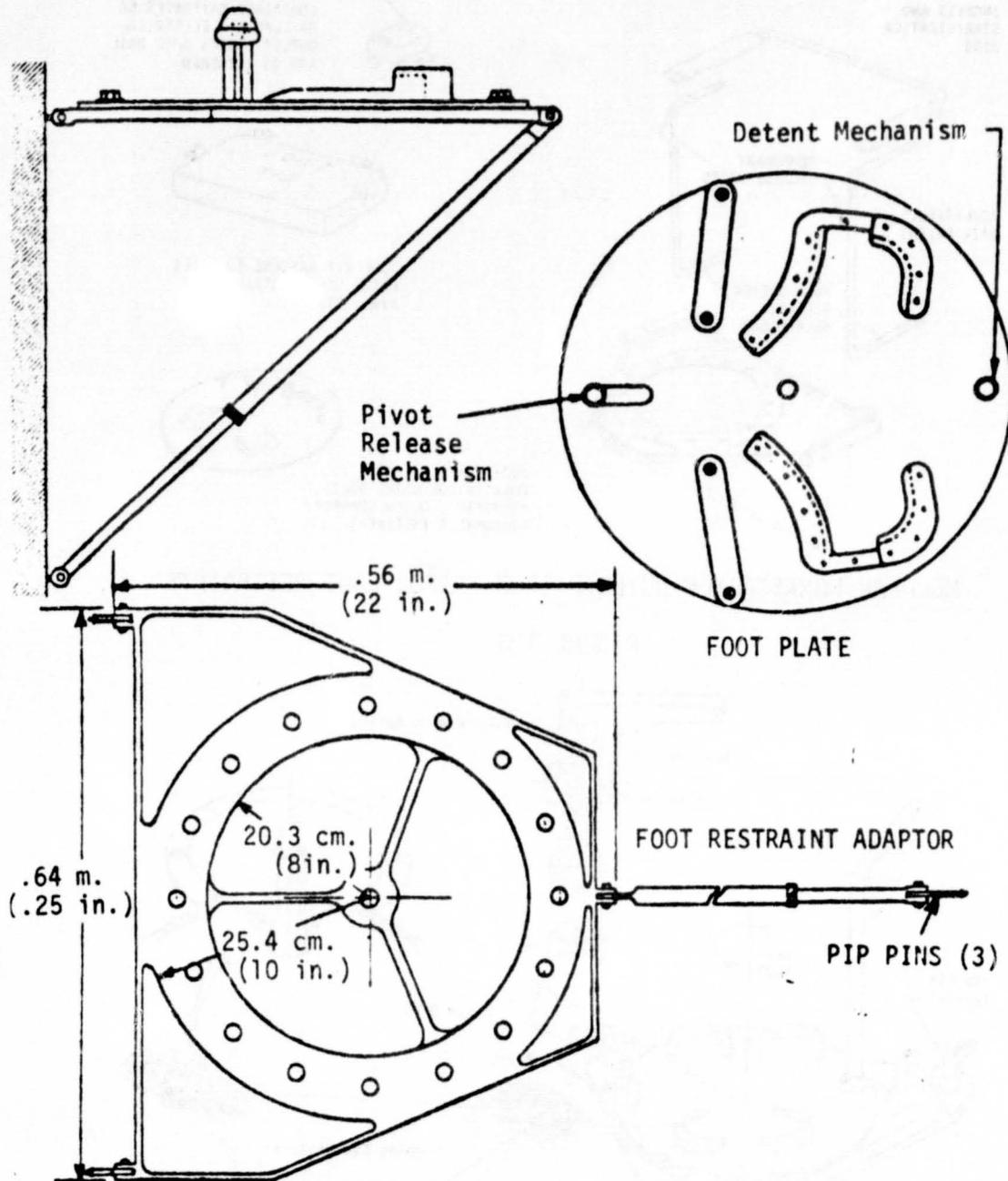
RECOMMENDED ENVELOPE FOR MANIPULATIVE EVA TASKS

FIGURE 102



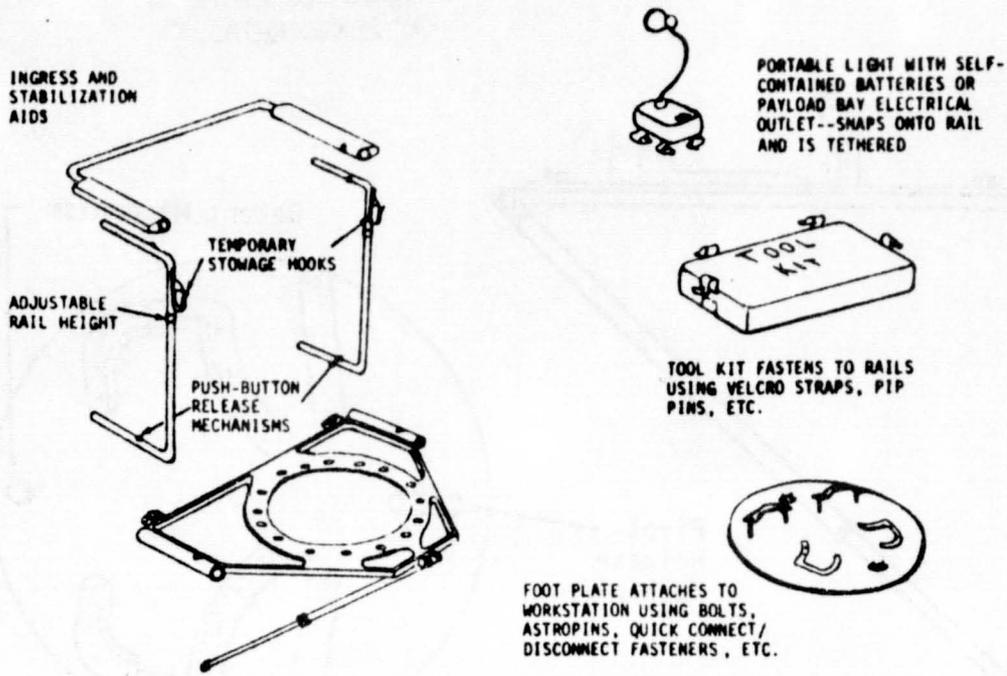
FLAT PLATE EVA WORKSTATION CONCEPT

FIGURE 103



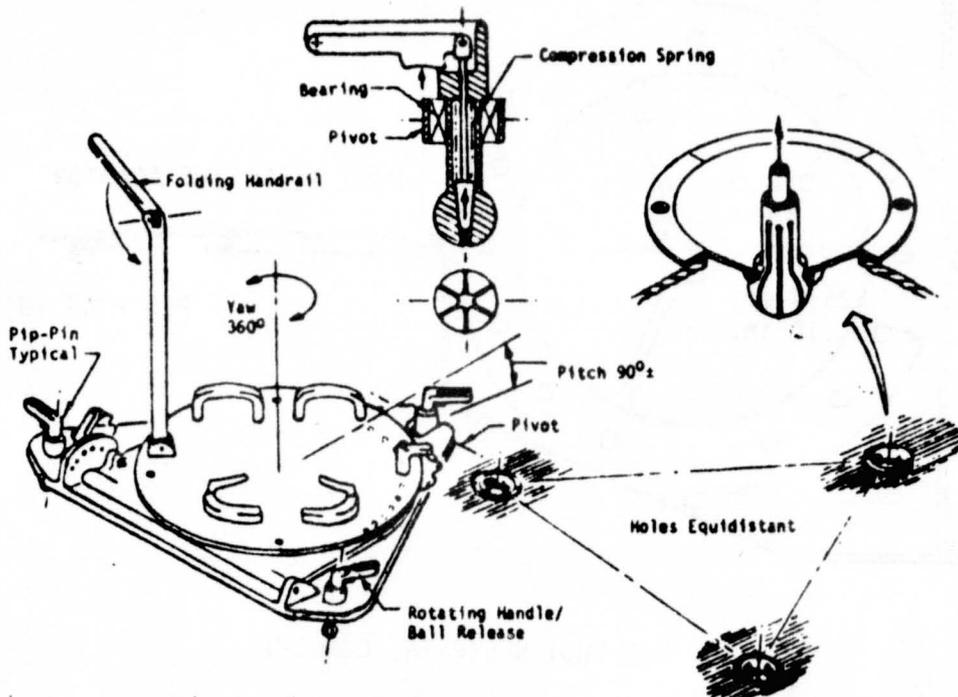
TRIPOD FOOT RESTRAINT CONCEPT

FIGURE 104



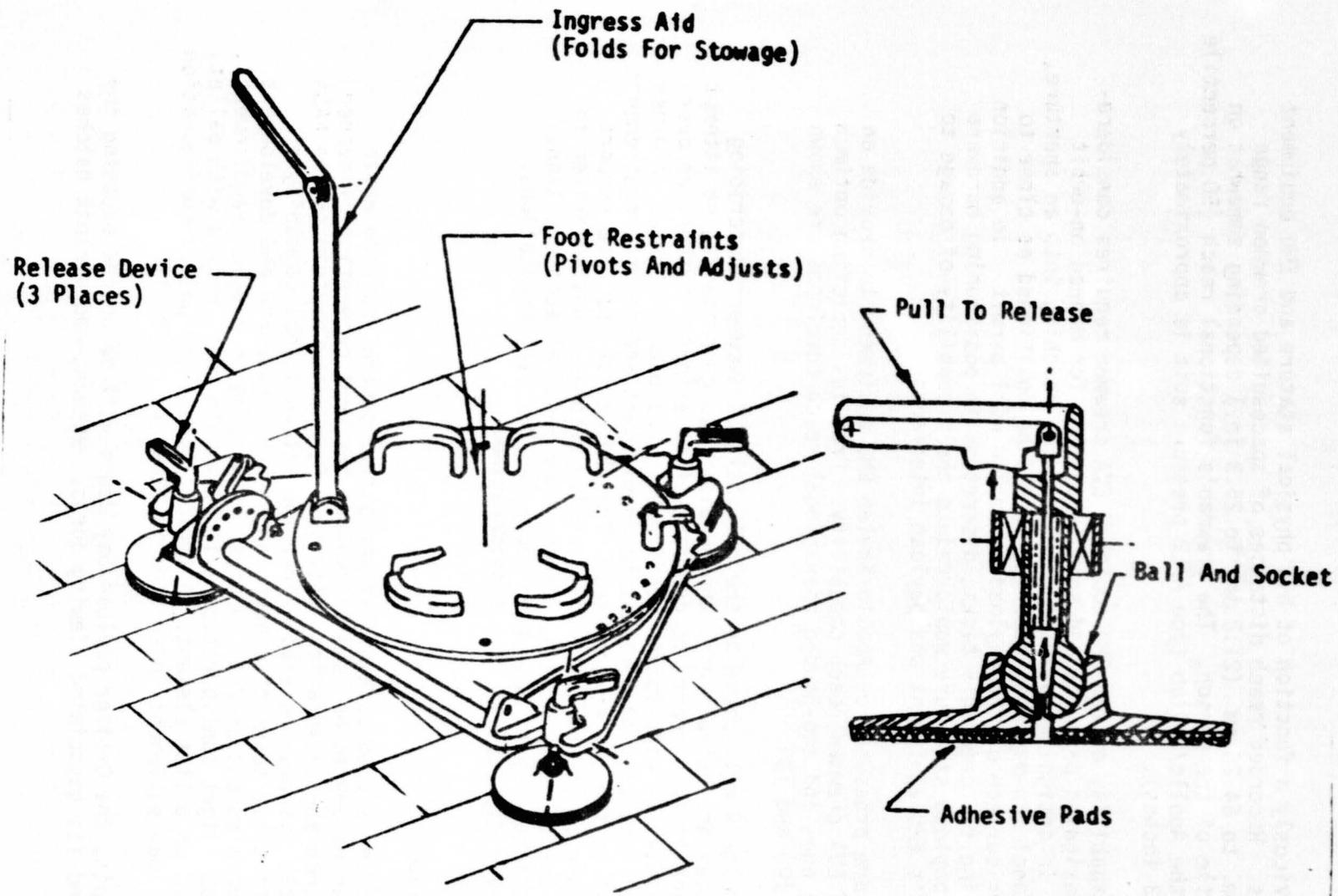
MODULAR WORKSTATION BUILDUP FROM TRIPOD FOOT RESTRAINTS

FIGURE 105



BASIC INTEGRATED EVA WORKSTATION CONCEPT

FIGURE 106



WORKSTATION ADHESIVE ATTACHMENT CONCEPT

FIGURE 107

reach is obviously a function of his physical stature and EMU equipment restrictions. Recorded reach distances of spacesuited crewmen range from 53.8 cm. to 64.26 cm. (21.2 in. to 25.3 in.) depending somewhat on the percentile of the person. The crewman's functional reach (50 percentile male) with the Apollo/Skylab type A7LB pressure suit is approximately 58.4 cm. (23 inches).

The reach capability of the EMU-equipped EVA crewman requires consideration when designing payloads and vehicle systems for manned on-orbit servicing. In designing payloads which require reaching into an aperture, the operational man-machine interface should be positioned as close to the exterior surface of the payload as design will permit. In addition to simplifying the crewman's tasks, discretion in positioning hardware within the payload structure would reduce the probability of damage to the crewman's EMU equipment and payload interfaces.

Reach data are presented on Apollo-Skylab EMU equipment to provide an overview of EVA crewman reach capability. Profiles depicting optimum and maximum one- and two-handed operational reach envelopes are shown in Figures 108 and 109.

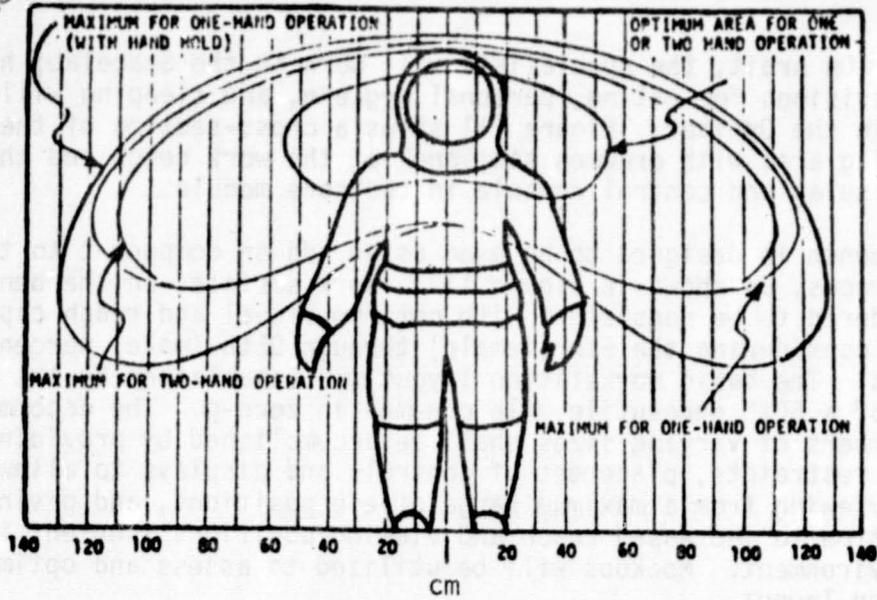
Since Reference 9 will serve as the official JSC document describing EVA interfaces and establishing the required design criteria, no attempt has been made in this report to duplicate that effort. Rather, an overview of Shuttle EVA workstation requirements has been presented in order to show the continuity of workstation development and design requirements from the IVA to the EVA environment. The protective and life support equipment worn by the EVA astronaut usually becomes a design driver in developing the EVA workstation, but the same postural accommodations are brought into play as have been addressed for IVA workstations. Figure 102 vividly depicts this consideration.

6.2 Spacelab

Spacelab is envisioned as a highly versatile, general-purpose earth orbiting laboratory to be used to support the next generation of manned space research and exploration activity. As a major payload of the NASA Space Shuttle system, Spacelab offers the international community of users an effective means of conducting in-orbit research and development projects for missions of 7 to 30 days. Depending on mission requirements, the Spacelab flight configuration will be module only, module with pallet, pallet only, or pallet element. A typical module and pallet configuration without payload equipment integrated is shown in Figure 110.

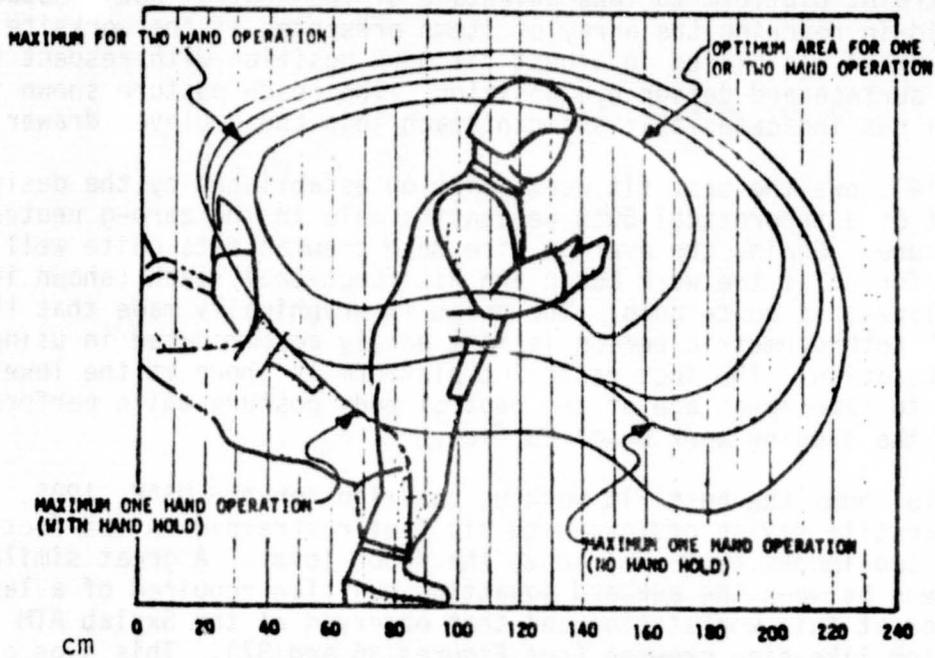
Once on orbit, the Orbiter payload bay doors will be opened exposing the Spacelab and its associated viewing ports, sensors, and airlock hatches

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EVA CREWMAN SIDE REACH ENVELOPE (APOLLO-SKYLAB)

FIGURE 108



EVA CREWMAN FORE-AFT REACH ENVELOPE (APOLLO-SKYLAB EMU)

FIGURE 109

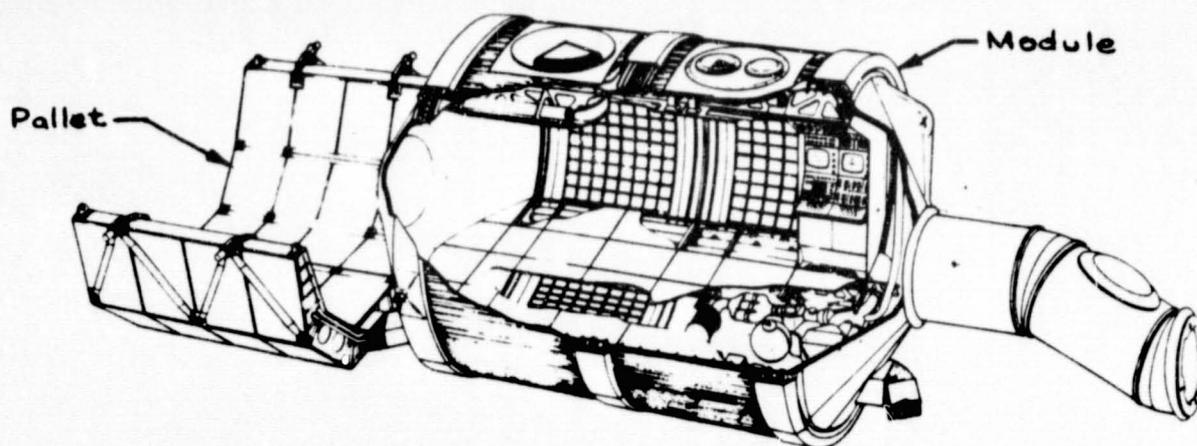
to space. On orbit, the specialists will work in the Spacelab; habitability provisions for eating, personal hygiene, and sleeping will be provided in the Orbiter. Figure 111 shows a cross-section of the primary crew working area with crewmen stationed at the work bench and the primary display and control console in the core module.

The work bench is designed to be used as an add-on component to the standard racks, as shown in Figure 112. Work surfaces on the bench are considered to be consistent with optimum visual and reach capabilities, considering the 5th (female) through 95th (male) percentile crew sizes. The basic workstation layout was established by the eye position of a 50th percentile male crewman in zero-g. The accommodation of crewmembers of varying sizes shall be accomplished by providing adjustable foot restraints, placement of controls and displays to allow operation and viewing from a maximum range of eye positions, and giving design consideration to increased reach and viewing positions inherent in the zero-g environment. Mockups will be utilized to assess and optimize workstation layout.

A Spacelab worksite was laid up in Figure 113 to show the interface with the smallest eligible crewmember (5th percentile female). Also illustrated is the application of a rotatable (adjustable in pitch) foot restraint platform to take advantage of the neutral body posture and to aid in reaching the array of items presented at the worksite. The crewmember was placed in a best fit work position with respect to the work surface and design eye position. The reach posture shown in phantom lines indicates that she can reach into the deployed drawer.

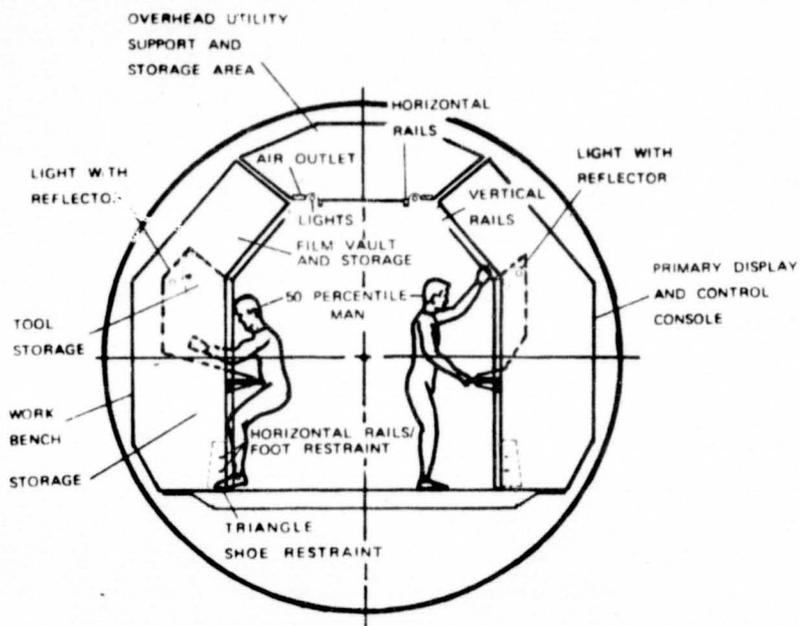
Figure 114 shows the best fit work position established by the design eye point of a theoretical 50th percentile male in the zero-g neutral body posture. Again, the average size male crewman fits quite well for tasks performed at the work bench and his functional reach (shown in phantom lines) is quite good. The point is graphically made that the "average" anthropometric person is most easily accommodated in using this workstation. The foot restraint platform is shown at the lowest position to take advantage of the neutral body posture while performing tasks on the sloping work bench surface.

Figure 115 shows the best fit working position for the USAF, 1985, 95th percentile flying officer with his feet restrained on the foot platform two inches (5.08 cm) above the floor level. A great similarity can be seen between the awkward squatting position required of a large crewmember at this workstation and that observed at the Skylab ATM console for like-size crewmen (see Figures 36 and 37). This type of forced work posture may impose difficulty on the extremes of the population envelope at the large end of the scale. Consequently, work performance may be affected if a comfortable posture can not be attained or if an unrestrained position becomes necessary for comfort.



TYPICAL SPACELAB

FIGURE 110



PRIMARY CREW WORKING AREA

FIGURE 111

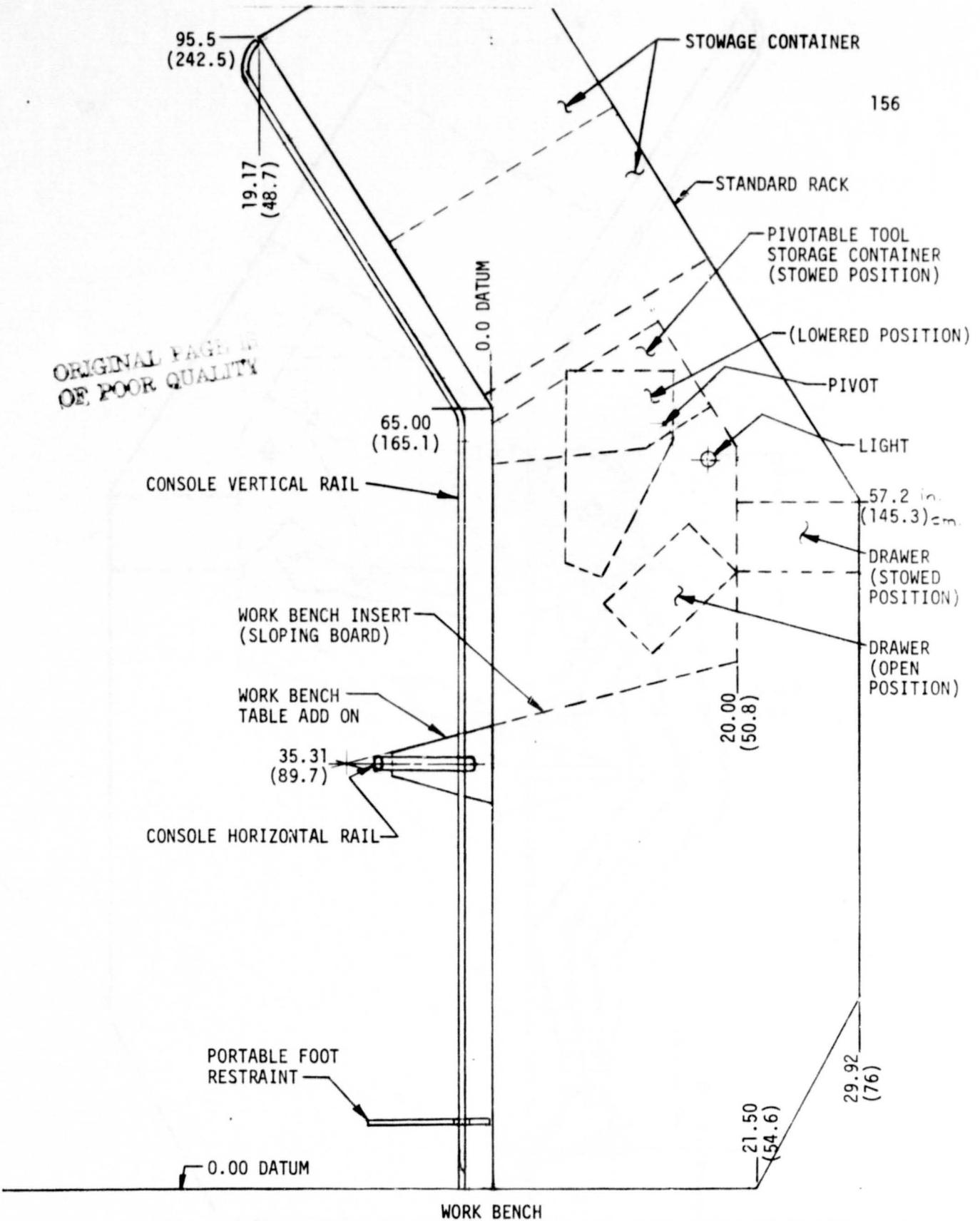
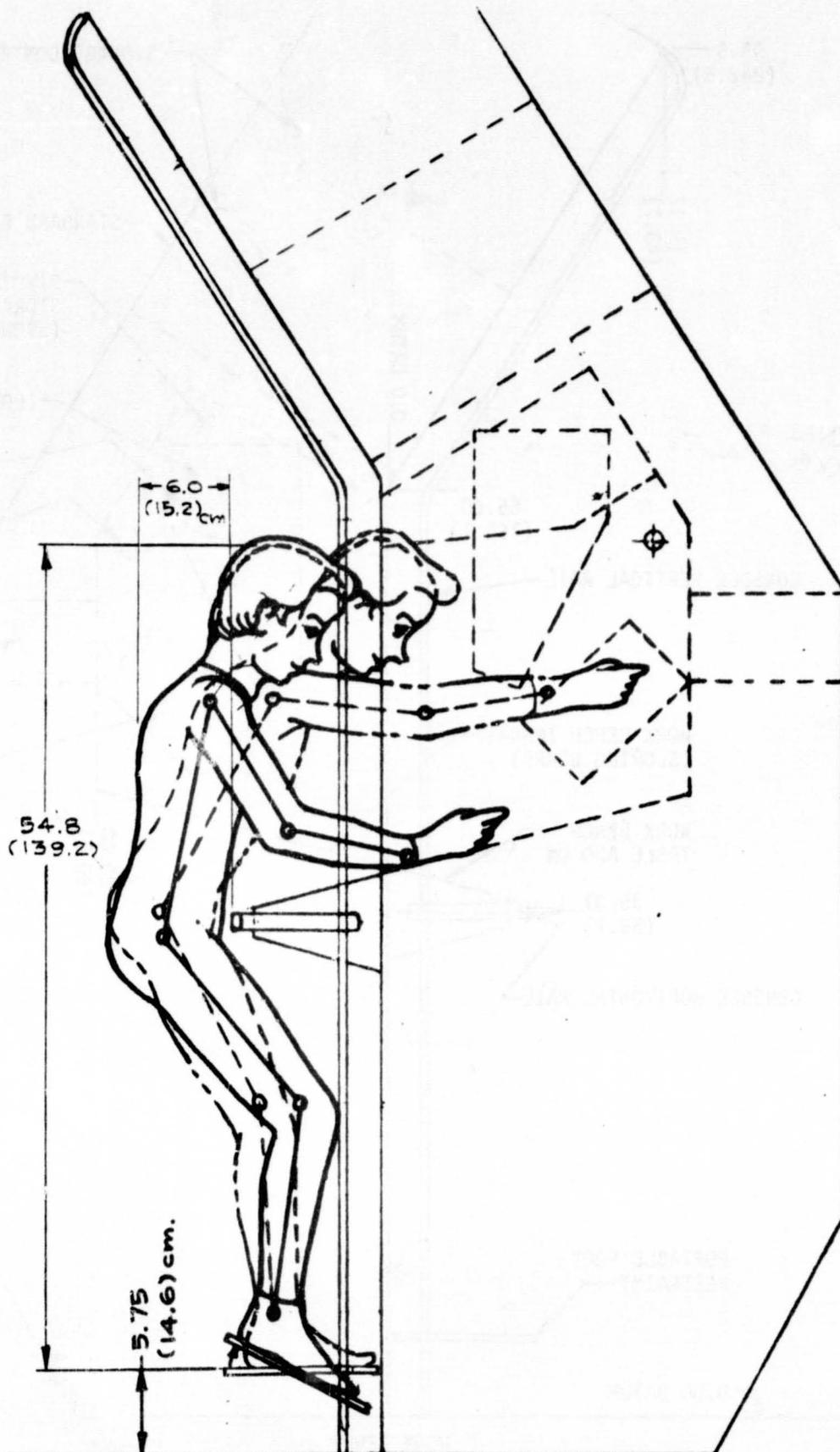
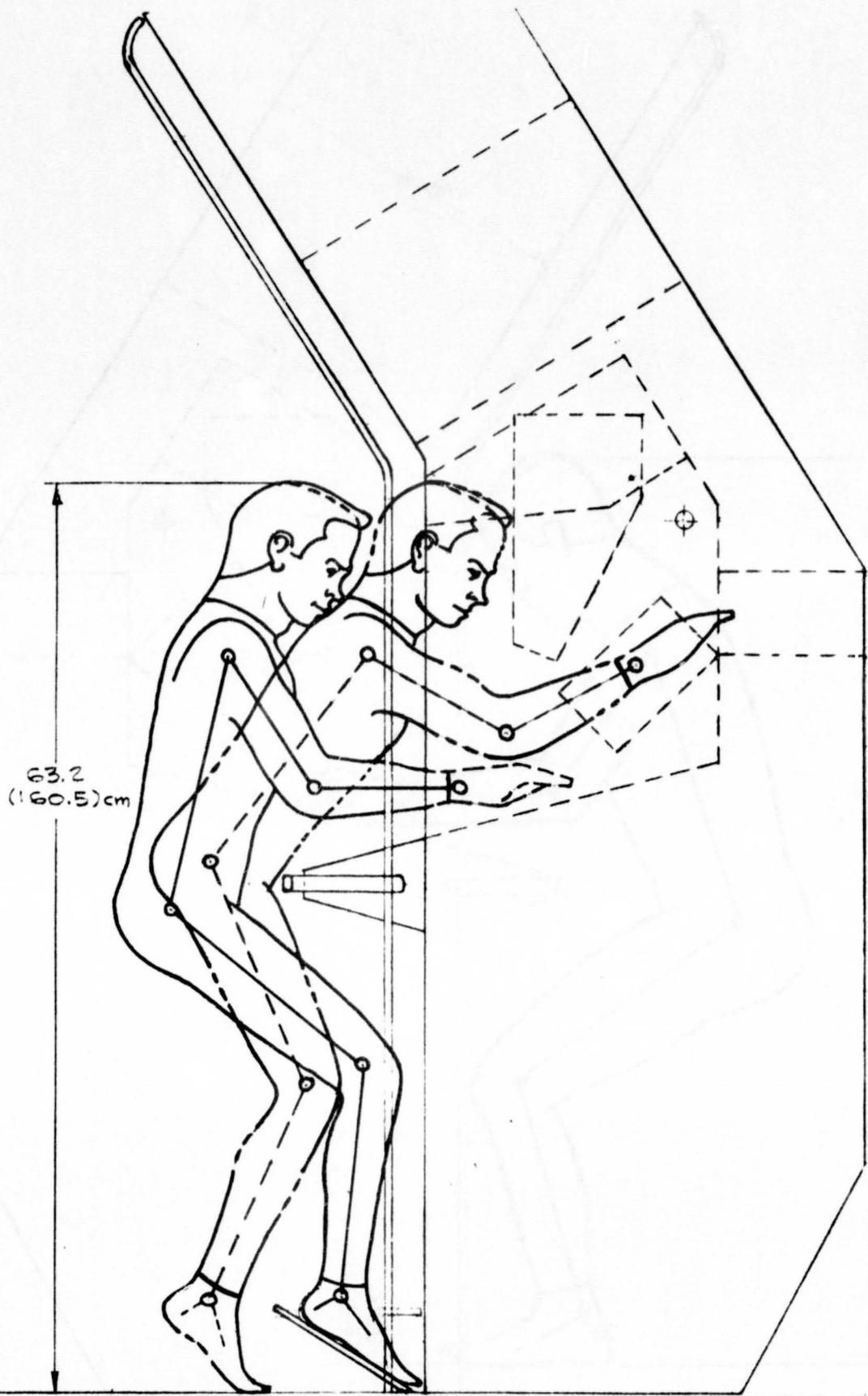


FIGURE 112



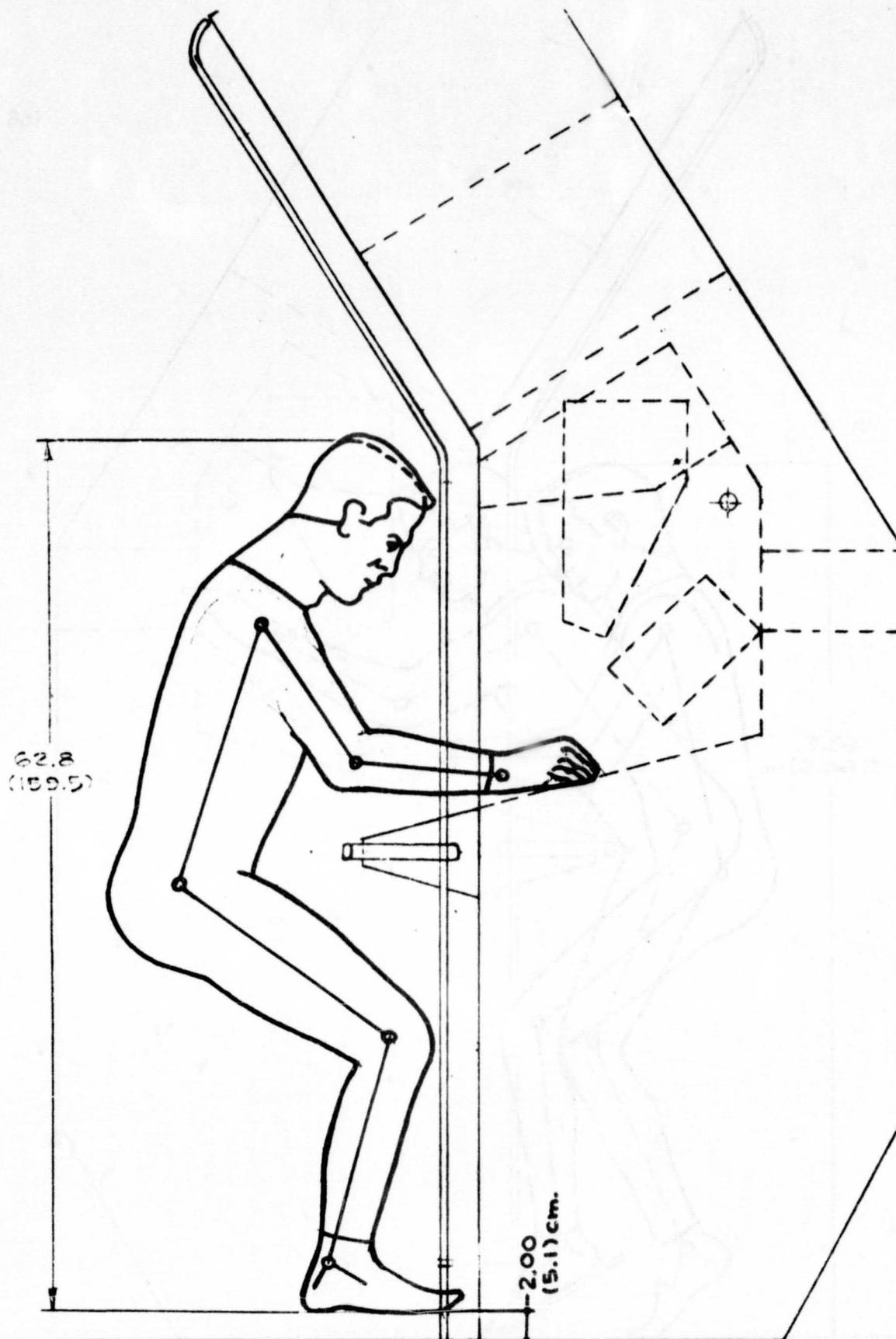
5th PERCENTILE FEMALE AT SPACELAB WORK BENCH

FIGURE 113



50th PERCENTILE MALE AT SPACELAB WORK BENCH

FIGURE 114



95TH PERCENTILE MALE AT SPACELAB WORK BENCH

FIGURE 115

The conclusions concerning the Spacelab work bench station are that small and average size crewmembers have no particular problems related to the man-machine interface; however, the large size crewmembers will be less comfortable because of the awkward positions they will have to assume at this worksite.

7.0 OPEN PROBLEM AREAS

This report has been intended as an information document, designed to show the evolution of the zero-g workstation across the manned space-flight programs. The inflight experiences presented have been directed toward establishing the need for a more thorough "look" at the zero-g workstation as an integral element in the man-machine system and an element which can drastically influence performance if not properly designed. In some instances, issues have been raised and resolutions offered; in other cases the issue remains open and the need for additional investigation, analysis, and implementation is evident. In these latter cases, the unresolved issues have been summarized in this section as "open problem areas."

1. Deviations from the neutral body posture are considered normal and necessary, however, the question remains open concerning how much deviation toward the extremes or excursions outside of the defined neutral body posture envelope can be tolerated without seeing a reciprocal influence in terms of reduced efficiency and performance. No firm quantitative case has been built concerning the performance decrement that might be associated with forcing an operator's posture outside the neutral body envelope. Further inflight data on muscle activity and fatigue must be acquired and correlated with appropriate task analyses if this question is to be answered.

2. Even though much of the data presented in this report is quantitative, it is flavored in many instances by correlation with crew comments. Subjective data is not to be considered bad or not useful, for in many circumstances the subjective evaluation of an item focuses attention on some aspect that might not have surfaced on the strength of numbers alone. Nevertheless, a move toward more quantitative data in the man-machine engineering discipline seems necessary. Developing unintrusive instrumentation techniques is a challenge to be met in future manned missions.

8.0 CONCLUSIONS AND RECOMMENDATIONS

1. The human body seeks a relaxed posture in zero-g that is identifiable within a reasonable envelope.
2. Zero-g workstation design must be given considerable attention in future manned spacecraft to avoid the creation of inefficient man-machine interfaces.
3. Seated-type operations in zero-g are very undesirable and workstations should be designed to accommodate an operator exhibiting the neutral body position and restrained at the feet for the following reasons:
 - a. Sitting is unnatural in zero-g where the body tends to seek a neutral, relaxed position, and trying to force a seated posture needlessly works against the natural postural tendencies.
 - b. The "tied down" crewman in a seated restraint suffers an unnecessary restriction of motion and reach.
 - c. Uncomfortable pressure points can be brought to bear on the user's body.
4. Operational interfaces that are always addressed by either seated or standing crewmembers in one-g will probably always exhibit significantly different perspectives for those crewmembers in zero-g.
5. For any workstation requiring a combination of equipment installation and subsequent long-term operation or monitoring, the need for different man-machine interfaces for these two functions must be recognized and accommodated in the design of that station.
6. Operator or user performance at workstations would be better served in zero-g by allowing height and tilt adjustments of the supporting surface to be made at crew option to best suit individual postural differences. These adjustments may be designed either into the surface itself or the crew restraint system which positions crewmembers with respect to the surface. Such adjustments would, of course, be subject to programmatic implementation based on weight, cost, and other tradeoffs.
7. Any workstation (e.g., Skylab STS) supporting tasks that require full attention to be performed should be located outside areas of potential interference by other crewmen or surrounding equipment and should have adequate body positioning devices included as an integral element of design.

8. Simply placing a body positioning device in the general area of a workstation, i.e., Skylab MPF, is not adequate; the device must be designed as an integral part of the overall layout to produce desirable results.

9. Not all work needs can be anticipated prior to flight; thus, a versatile system of crew positioning and retention devices must be developed to allow the most efficient possible conduct of chores that arise unannounced.

10. Shuttle Orbiter and payload EVA tasks require more versatile worksite provisions than the fixed, dedicated, EVA workstations of previous space programs.

11. The "average man" is an anthropometric generalization. However, the designer must be aware of the most "critical" anthropometric parameters for a given design, and these drivers must size a design for a given application. The use of the small and large percentile extremes is more meaningful than the middle percentiles because together they represent a design criteria range.

12. Using the anthropometric dimensions of the Skylab crewmen was a distinct advantage in conducting the data analysis related to this report. Their percentile rankings represented known quantities taken from real people rather than theoretical generic models. As a result, confidence was high in resultant man-machine layouts. Also, having the actual person available to participate in 3-D dynamic exercises was an added bonus. The theoretical percentiles were brought into play in discussing Shuttle and Spacelab designs since they represented design criteria limits for those programs.

13. After progressing through the 2-D layout phase of early design option evaluations, all zero-g workstation designs should be evaluated in full-scale 3-D situations with a representative range of users before committing to hardware.

14. Any future zero-g workstation calling for an operator to use hands and feet to accomplish assigned tasks will require a development outside of the scope of this report.

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