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Neutral Buoyancy Testing of a Shuttle Orbiter Crew Compartment

Approved by NASA

Prepared for
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Johnson Spacecraft Center
Houston, Texas

MARTIN MARIETTA

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FINAL REPORT
FOR

NEUTRAL BUOYANCY TESTING A SHUTTLE ORBITER CREW COMPARTMENT

MAY, 1973

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FOREWORD

This report was prepared by the Martin Marietta Corporation under Contract NAS9-11947 (IS), DRL T-784, Line Item 4, "Neutral Buoyancy Testing a Shuttle Orbiter Crew Compartment, for the Johnson Spacecraft Center of the National Areonautics and Space Administration. The effort was administered under the technical direction of the Spacecraft Design Office with Mr. Gordon Rysavy acting as the technical manager. This report documents and summarizes the results of the entire contract work, including recommendations and conclusions based on the experience and results obtained.

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I. INTRODUCTION

This contractual effort was initiated to study and analyze the architectural and man-machine aspects of a Shuttle Orbiter Crew Compartment as a total system. Previous studies of various habitability enities have been conducted and have established a beginning for Shuttle design criteria. Two recently conducted efforts, NAS9-10761, "Engineering and Architectural Study for Extraterrestrial Architectural Design" and NAS9-11947, "Neutral Buoyancy Testing of Architectural and Environmental Concepts of Space Vehicle Design" have added to the data base significantly. This effort examined all phases of the Orbiter's flight mode from launch through zero-gravity, re-entry and ferry flight. This data, integrated with previous efforts, provides an initial design criteria that considers the crew compartment as a total system and provides data that has a direct contribution to the development of flight hardware.

The scope of this effort was to analyze, develop, fabricate and test by simulation the various flight modes of the NASA-JSC concept 040A version of the Shuttle Orbiter Crew Compartment. Primary interest was placed on the architectural aspects of the galley, hygiene facility, passenger couches, airlock, system station and flight deck access. The man-machine interface emphasis was placed on identifying and developing solutions for problems in mobility/restraint, ingress/egress, accessibility, volume utilization, and crew equipment design. Design criteria concerning man-machine interfaces and architectural aspects was developed from analyzing the test data. This data was obtained from testing a mockup of the crew compartment in both one-g and simulated zero-g neutral buoyancy environments. The one-g tests included testing with the Orbiter Mockup X-axis vertical to simulate the launch, and horizontal for the re-entry/landing/ferry flight modes. The neutral buoyancy tests simulated the zero-g mode with the Orbiter mockup x-axis on the horizontal in the neutral buoyancy tank.

The design criteria generated by these efforts are presented in an A/E Handbook, Supplement 2, specifically for the Shuttle Orbiter Crew Compartment. The rationale to substantiate the criteria in the A/E Handbook, Supplement 2, is presented in a rationale Supplement 2. Both of these supplements are submitted as individual books but are to be considered as part of this final report.

A. DEFINITIONS

The following definitions and references axes will be used in this document when the terms or reference to an axis are specified.

1. Gross Volume - Gross volume is that volume which would be available if all furniture items, storage modules, controls and control panels, and equipment were removed from the room leaving the room walls only.

2. Net Volume - New volume is the usable room volume that remains when all furniture items are deployed as they are to be used and when all storage modules, controls, and equipment are in place.

3. Access Volume - Access volume is that volume required for man to interface with a specific item of furniture, control, storage module, or equipment as they are deployed and in the position in which they are to be used.

4. Man's Reference Axis - In zero gravity, the human body can be considered to be a free, inflexible body with six-degree freedom of motion. For this reason a reference system for the body is required to define the movements of the body in a zero-gravity environment. The axes and relative motions are illustrated by Figure I-1 and all references to man's axis in this document will use these axes.

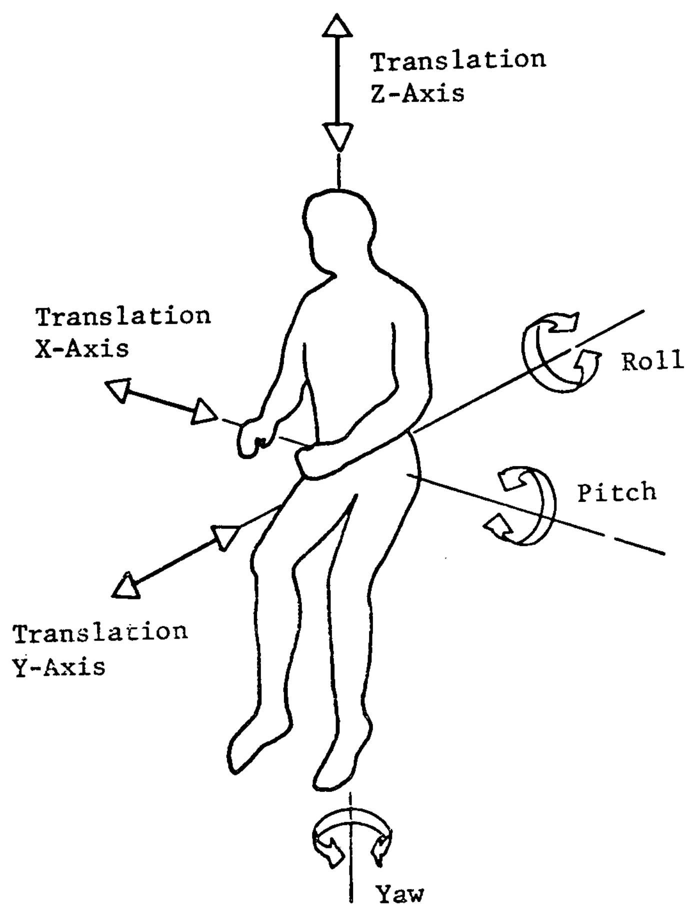


Figure I-1 Axes and Six Degrees of Body Motion in Zero Gravity

5. Couch Reference Axis - When reference is made to the axes of a couch within this document the axes as defined by Figure I-2 will be used.

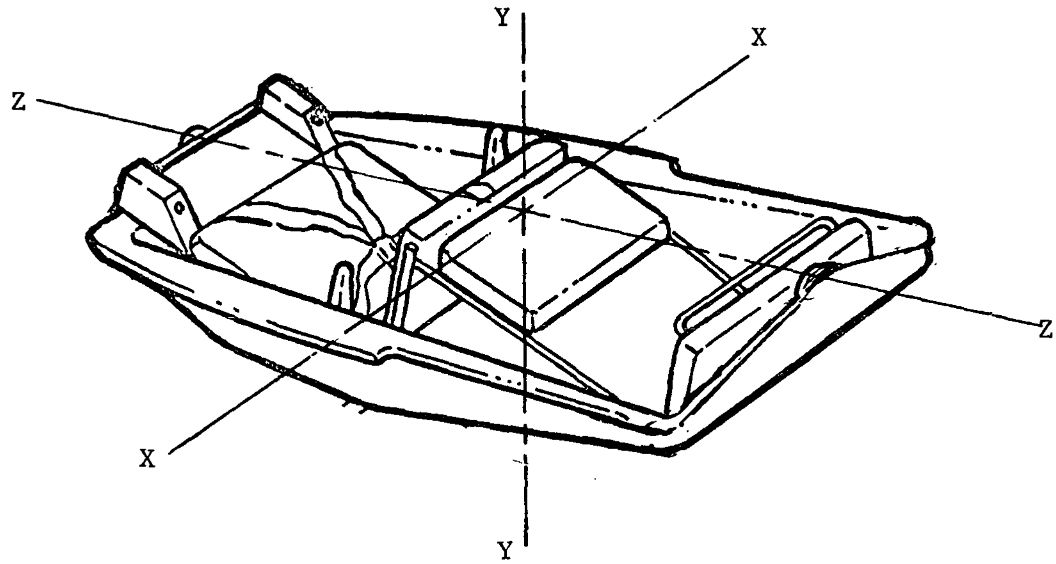


Figure I-2 Couch Reference Axes

6. Vehicle Reference Axis - When reference is made to the axes of the vehicle within this document the axes as defined by Figure I-3 will be used.

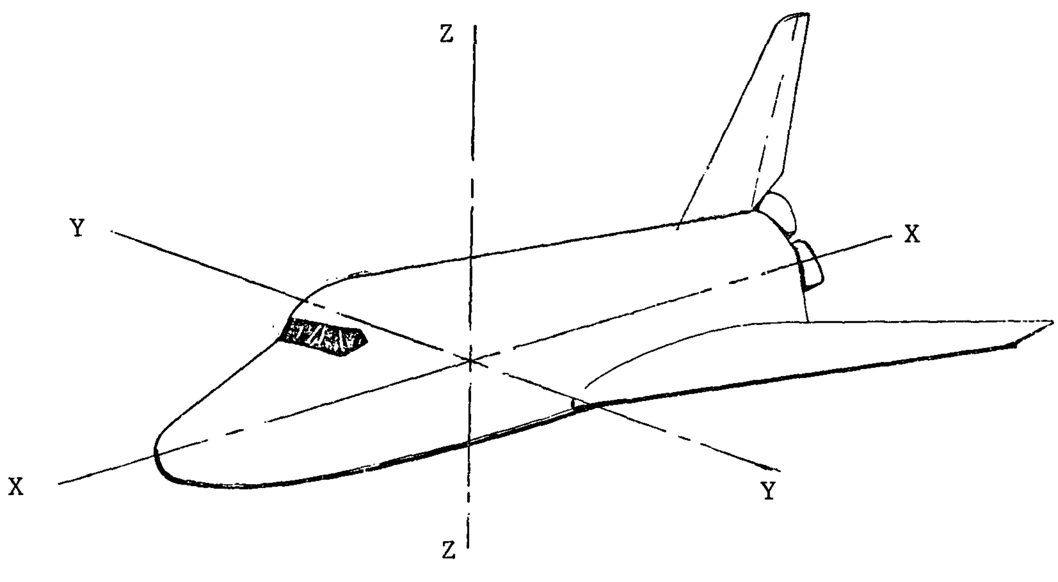


Figure I-3 Vehicle Reference Axes

II. DESIGN ANALYSIS STUDIES

This section will define and discuss the analyses performed during the contract. The areas that were investigated were the Shuttle nose configurations, crew area habitability analysis which includes crew/passenger requirements and task description, and amplification of the man model for zero gravity. The following paragraphs give a summary of the data collected during the contract.

A. SHUTTLE NOSE CONFIGURATIONS

It became quite evident during the analysis of the various nose configurations that the major factor influencing the arrangement of the crew compartment is the location of the docking mechanism and airlock. The size and positioning requirements of these volumes in a large part determine the degree of flexibility possible for crew compartment arrangements. Before a realistic analysis could be performed some specific groundrules, which apply to each analysis regardless of docking arrangement, were established and are presented in Table II-1.

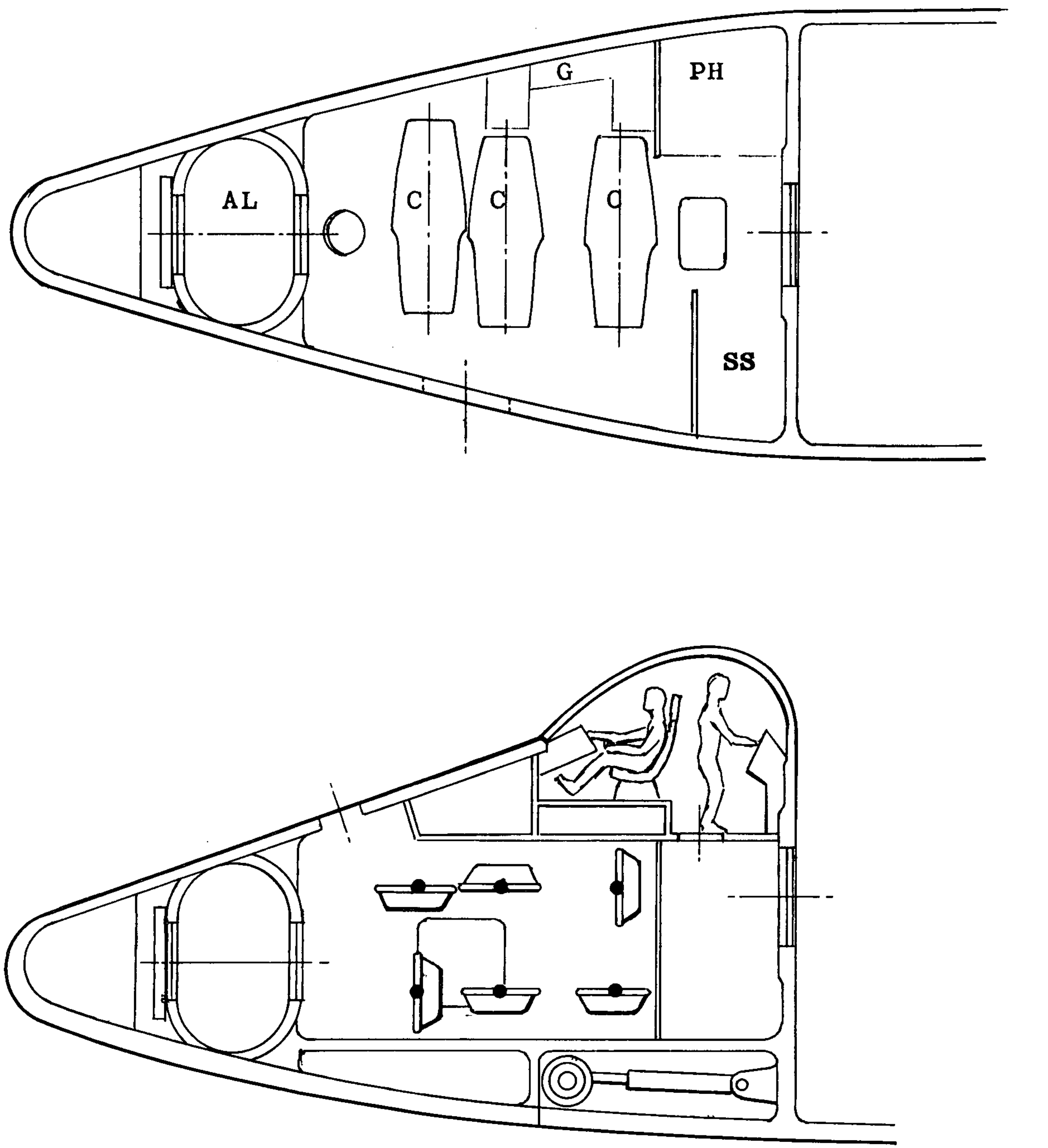
Four different types of docking arrangements were investigated during the contract and are defined as follows:

1. X-Axis Docking - The shuttle nose incorporating this docking arrangement had the docking mechanism and airlock located in the vehicle nose as shown in Figure II-1. A separate airlock may be provided in the payload bay which would require a hatch into the crew compartment if the requirement for inflight acces is stipulated by the mission.

2. Dual Hood Docking - In this arrangement the docking mechanism is located immediately in front of the flight deck with a continuous airlock under the flight deck to the payload bay. A hatch is provided in the airlock side to permit access between the crew compartment and the airlock. This concept is depicted in Figure II-2.

3. Hood Docking - This arrangement is similar to the dual hood docking. The exceptions are the docking mechanism is located immediately behind the RCS in the vehicle nose and the airlock would open directly into the crew compartment. This would require a separate airlock for the payload bay similar to the x-axis docking arrangement.

4. Z-Axis Docking - The Z-or skewed-Z-axis docking has the docking mechanism through the top of the flight deck with



LEGEND:

AL - AIRLOCK

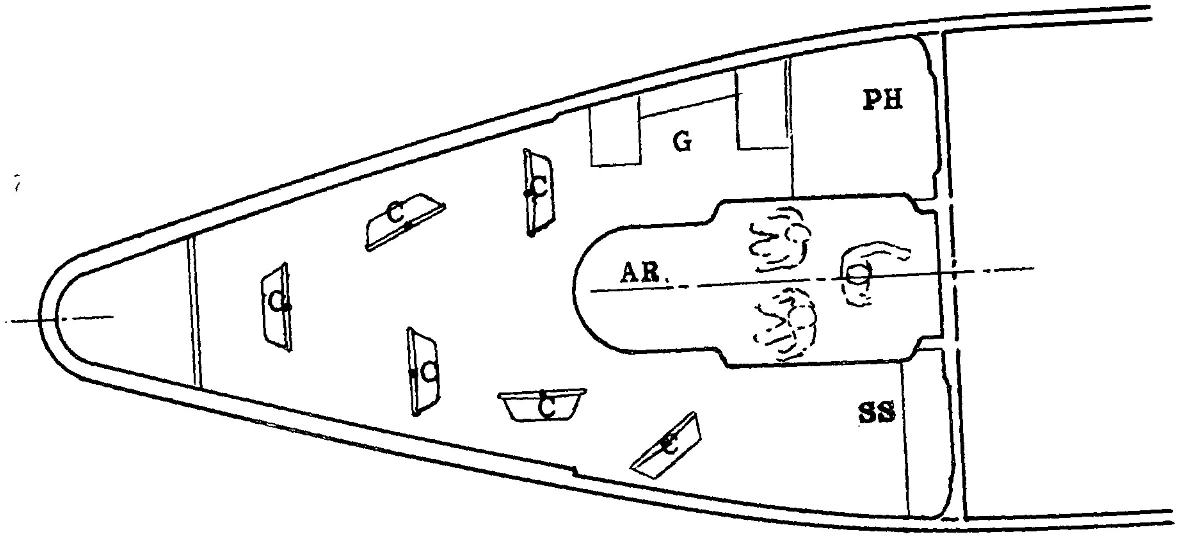
PH - PERSONAL HYGIENE

G - GALLEY

C - COUCHES

SS - SYSTEM STATION

Figure II-1 Shuttle Nose - X-Axis Docking



LEGEND:

AL - AIRLOCK

PH - PERSONAL HYGIENE

G - GALLEY

C - COUCHES

SS - SYSTEM STATION

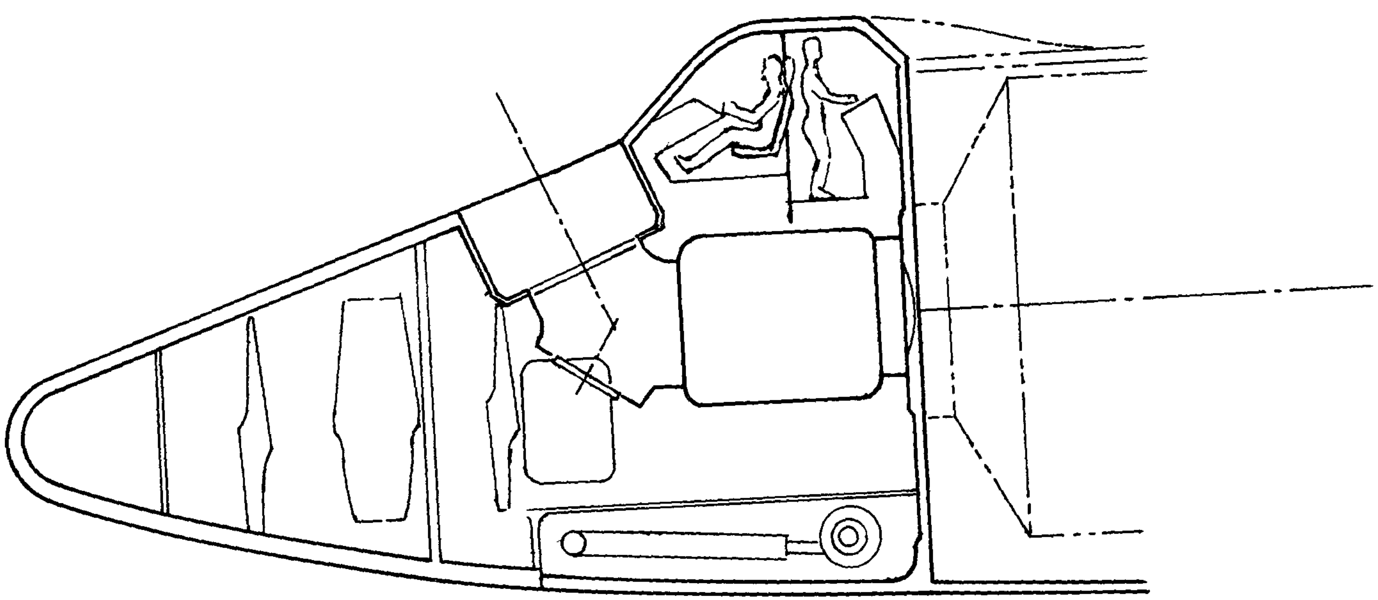


Figure II-2 Shuttle Nose - Dual Hood Docking

TABLE II-1 SHUTTLE ORBITER CREW COMPARTMENT ANALYSIS GROUNDRULES

1. RCS must be located in or around nose of spacecraft.
2. Airlock must be sized to accommodate two suited crewmen plus equipment.
3. Wheel well located below crew compartment.
4. Galley and personal hygiene units are discrete, defined packages which can be located as required in the crew compartment volume.
5. Flight deck will seat four, have 5 stations.
6. Exterior hatches are located -- in the flight deck roof (emergency), in the passenger compartment on the port side, and in the docking mechanism.
7. Galley and personal hygiene unit will contain consumables for 7 days within the units themselves; no additional supplies will be onboard.
8. Personal items of the crew and passengers (clothes, sleep restraint, shaving gear, etc.) will be stored in the seats/couches. A small volume (2-3 ft^3) will be provided the flight crew for community property (binoculars, cameras, games, etc.)
9. Six couches will be located in the passenger compartment; with the four crewmen in the flight deck; the maximum total is 10 people.
10. Personal hygiene unit must be usable in one mode of one gravity and in zero-gravity.
11. All airlock hatch inside diameters are one meter.
12. Crew compartment sizes for analysis purposes are 370 inches long by 176 inches high at rear by 180 inches wide at the rear. Contained within these dimensions are the following fixed volumes: RCS 450 ft^3, Airlock/Docking Mech. 385 ft^3, Equipment Bays 710 ft^3, Storage 35 ft^3 (wheel well 135 ft^3). For other than x-axis docking, the test structure will be 240 inches long, since the RCS would occupy the entire nose volume.
13. Galley used for snacks in 1-g; full use in 0-g.
14. A maximum of six people can be accommodated in the passenger compartment during sleep period.
15. Passengers will not remain onboard the Shuttle Orbiter for more than 24 hours except in emergency modes as necessary.
16. Couch height is 78 inches, width is 36 inches, depth is 12 inches. The center of rotation of the couch about the z-axis is located three and a half inches above the top surface of the couch.

a continuous airlock to the payload bay hatch and another hatch into the crew compartment. This concept is shown by Figure II-3.

Each of the above arrangements were investigated with respect to the impact on the habitability requirements. Each specific area was analyzed as an end item and then combined into a complete vehicle crew compartment.

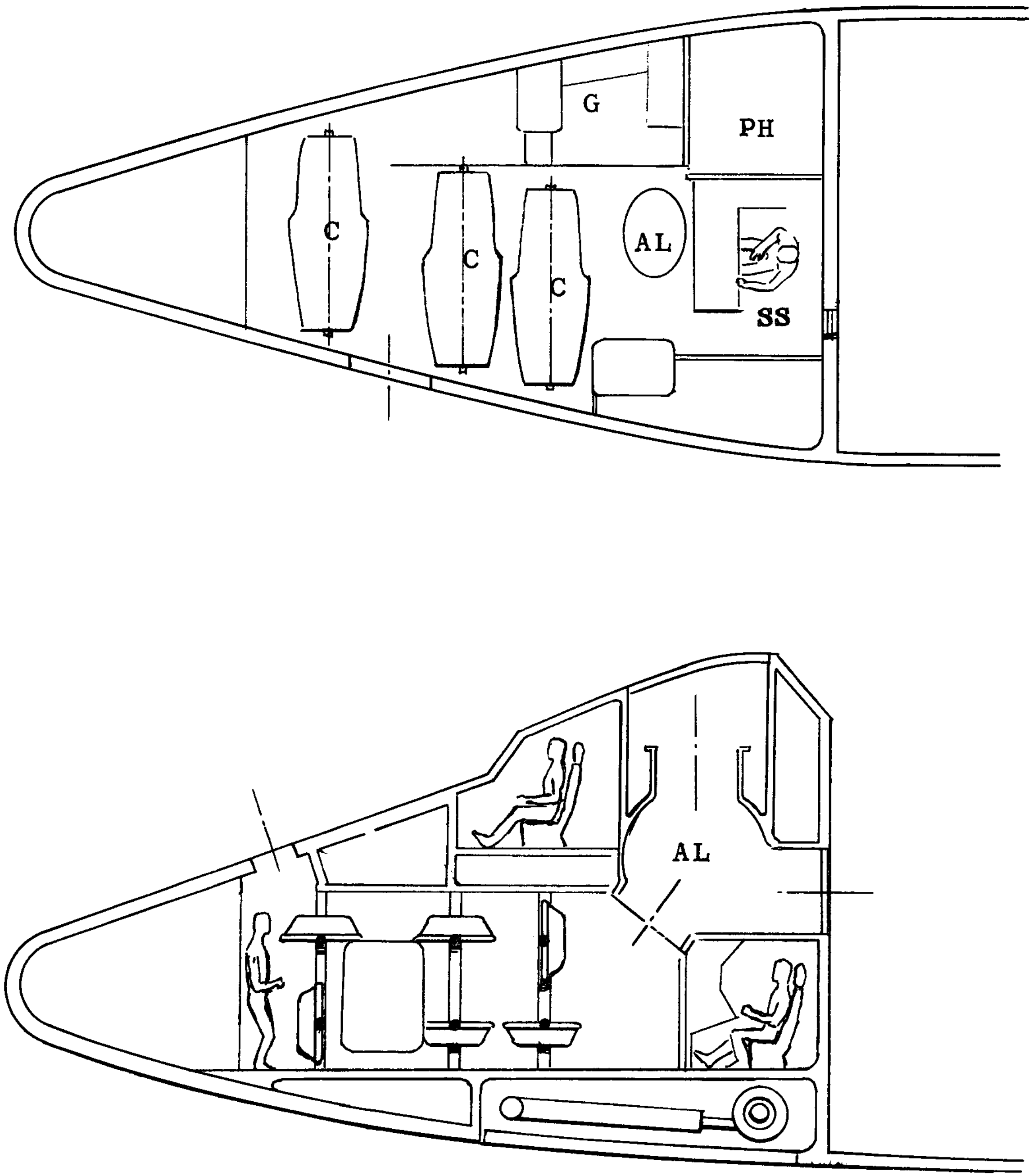
B. CREW AREA HABITABILITY ANALYSIS

To determine the volumes and equipment required to support the habitability requirements of a multi-purpose vehicle such as the Shuttle, it becomes necessary to define the guidelines of the mission requirements and the associated tasks. The mission model used for this contract is defined in Table II-2. From this baseline, the task that would be performed during the mission must be defined along with the ancillary equipment.

TABLE II-2 MISSION MODEL

Launch Vehicle - Orbital Shuttlecraft (basic NASA Concept 040A)
Crew Size - 2 to 4 men, 6 passengers, 10 maximum
Pressurized Volume - 2000 to 3500 cu. ft.
Duration - 7 days
Atmosphere - N_2O_2 mixture at 5 to 14.7 psia
Gravity - zero to one-g
Altitude - 200 to 280 n. mi.
Orbital Inclination - 20^o to polar
Time Period - 1978-1985

1. Task Description - One of the most important criterion for determining the volumes needed in a given vehicle or for measuring the adequacy of a given volume is to analyze the task requirements in each area and identify the access dimensions and orientation requirements. The individual areas of the Shuttle Orbiter crew compartment are broken down as follows for the purposes of this analysis: 1) flight deck, 2) passenger compartment (couches only), 3) galley, 4) personal hygiene unit, 5) airlock, 6) avionics/equipment, and



LEGEND:

AL - AIRLOCK

PH - PERSONAL HYGIENE

G - GALLEY

C - COUCHES

SS - SYSTEM STATION

Figure II-3 Shuttle Nose - Z-Axis Docking

7) miscellaneous storage areas. Due to the different modes under which the Shuttle Orbiter must operate, the orientation of the individual areas was controlled by an assumed most used and servicing mode, horizontal and one-g operation. In this mode all volumes are oriented in one direction, "heads-up", so that required tasks can be adequately performed in both one-g and zero-g modes.

Since the specific tasks to be performed in a given area are very strictly defined (e.g., galley, flight deck, personal hygiene unit), task definition and orientation requirements are very easily accomplished in most cases. For example, no reorientation is required for any tasks performed at the various stations, the equipment and storage areas and in the airlock. In the galley and personal hygiene unit, reorientation is limited to simple rotation and very minimal horizontal translation. Rotation or translation requirements in the flight deck are dependent upon the exact arrangement within the flight deck and upon the location of and the technique employed for docking.

The major impact on task and orientation requirements exists in the determination of traffic patterns between specific areas (e.g., passenger couch to galley) and ingress/egress procedures under normal and emergency conditions in all modes. Passage into or out of the passenger compartment from other internal orbiter areas is also greatly impacted by the exact location of the docking mechanism, since the total arrangement largely determines the routes used for transfer. Another parameter which helps establish the minimum passage dimensions and equipment positioning is the access requirement in each situation. These analyses are based on data contained in Supplement 1 to MSC-03909, Habitability Data Handbook, Volume 2 and on known Orbiter requirements.

For the passenger couch, access requirements which must be defined are those for ingress/egress, removing items from the storage compartments within the couch, sleeping in the couch, and eating or relaxing in the couch. The degree to which two or more couches can share access is very important in order that total volumes be minimized.

The principal modes which were investigated to ensure that all activities can be properly performed are launch, re-entry, the crash mode, and zero-g flight.

III. CONCEPT DESIGNS

In this section specific recommendations and rationale are presented for the modules within a Shuttle Orbiter crew compartment. These will include six couches, galley, personal hygiene, system station, airlock and flight deck. It should be noted, however, that the low fidelity of the flight deck, airlock and system station mockups prevented the collection of enough significant data to make specific recommendations as to actual volumes and configurations. The most significant data obtained in these areas were the transfer procedures, hatch openings, and problems associated with a vehicle that must operate in two one-gravity attitudes that are 90 degrees apart and also zero-gravity. The overall Shuttle nose mockup size was as dictated by NASA-MSC and modified to fit the neutral buoyancy tank required for simulated zero-gravity testing. The area reduced for neutral buoyancy tank installation was the extreme rear corners, but with moveable interior modules the habitability area was simulated.

A. SHUTTLE NOSE DESIGN CONCEPT

The Shuttle nose mockup design followed the data supplied by NASA-MSC and defined as Shuttle Orbiter 040A Baseline Interior and shown in Figure II-1. Since the mockup was to be used for neutral buoyancy test as well as one-gravity test, the mockup had to be constructed, such that it would minimize water feed back from solid walls, equipment, etc. For this reason, in addition to the need for data collection by way of photography and video tape, solid opaque walls were eliminated where possible. Solid walls/floor were utilized to retain structural integrity and to provide a safe test structure. The overall mockup is shown in Figure III-1 which is a photograph of the mockup in the horizontal one-gravity test made. Figure III-2 depicts a plan view of the lower deck and shows the basic configuration, however, since the couches, galley, and personal hygiene unit were individual modules, they could be moved about within the lower deck areas. The major restrictions on the placement of the individual modules are mounting provisions, consideration of transfer routes for each operational mode, and emergency egress procedures.

B. GALLEY MODULE DESIGN CONCEPT

The galley design is based on the premise that all food preparation and cleanup activities are done by one man. The galley contains the equipment to prepare and store food, trash disposal, housekeeping, trays and utensils. The preparation equipment consists of oven, tray restraints, and a work counter. The storage area consists of refrigerator, water tanks, and dry storage areas. Because of these hardware

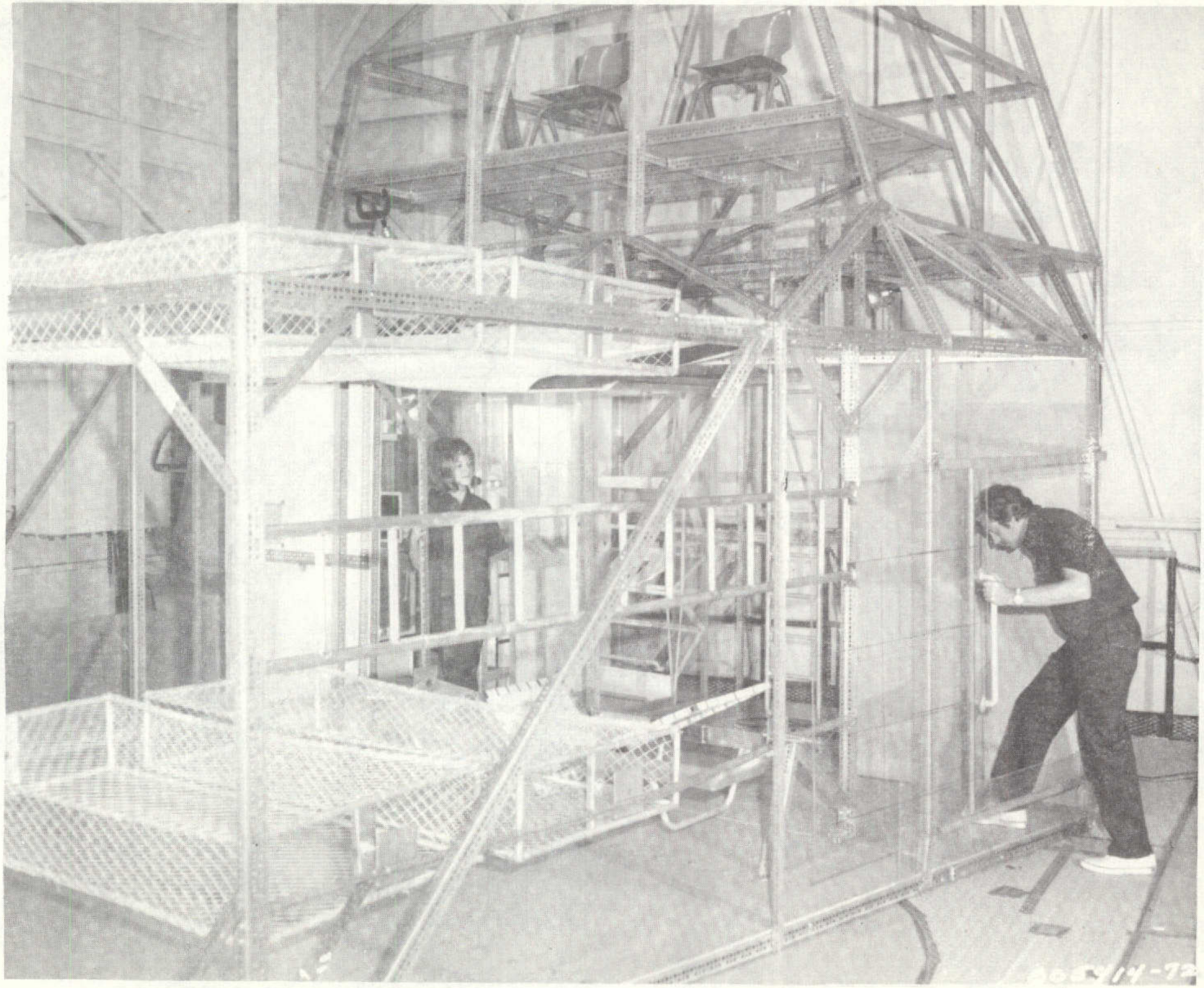


Figure III-1 Shuttle Orbital Nose Mockup

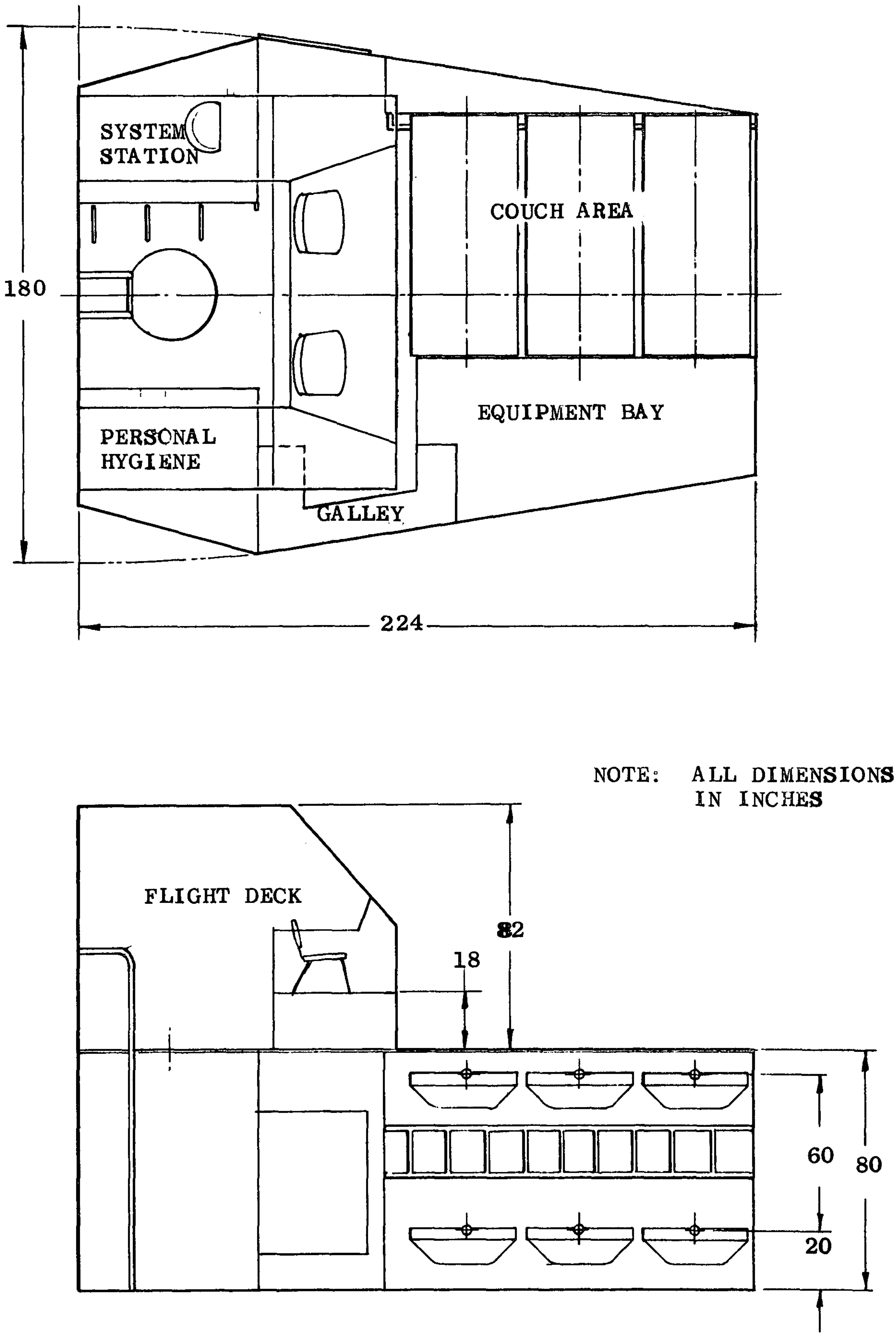


Figure III-2 Shuttle Orbiter Crew Compartment requirements and the need to store man-days plus one day of reserve of food and water in the galley. The galley is devoted largely to storage space. The galley gross volume is approximately 107 cubic feet with a net volume of approximately 39 cubic feet, meaning that 68 cubic feet are occupied by storage space and hardware. The 39 cubic feet of volume available for the galley attendant to perform his duties is entirely adequate for one mode of one-gravity and in zero-gravity with all storage and work areas readily accessible. The restraints required for zero-gravity operation did not interfere with one-gravity operation and in fact the hand rail in front of the work counter was used by test subjects as an aid or reference point.

Since the tasks performed were very specific and limited, the galley design and equipment placement was vastly simplified. This included locating and selecting the restraints required for zero-gravity due to the knowledge that very little force is required to do habitability tasks. Food items can be taken from the storage lockers, oven, or refrigerator and placed in the food tray which sits on the work counter in one-gravity and is restrained at the rear of the work counter for zero-gravity. The design dictates that only one crewman/passenger need perform the tasks in a normal meal preparation. A typical meal preparation sequence would be for the attendant to enter the galley area and remove a serving tray from storage and place it on the counter top in one-gravity or place it in the tray restraint during zero-gravity operations. The next step is to remove food as desired and place it in the oven for heating prior to placing in tray or directly in the tray and then take the tray and leave the galley area. During tray cleanup, the attendant would return with the tray and remove left-over food and containers and place them in the waste disposal, the tray would then be wiped clean and returned to the tray storage before area cleanup is accomplished with the housekeeping equipment. Figure III-3 depicts the galley design by drawing and Figure III-4 is a photograph of the galley used during the testing phase of the contract.

C. PERSONAL HYGIENE MODULE DESIGN CONCEPT

The personal hygiene module selected for testing was a modified NASA-MSC design. NASA's design is referenced by Figure III-5. The modifications included making the fecal seat adjustable to four positions, a single sliding door, and reducing the overall dimensions in width and depth to delete the support equipment area. This was done because the primary interest was with the internal or useable volume by crewmen/passengers. The overall dimensions, however, were considered when the unit was placed within the crew compartment of the Orbiter. The room was designed to accommodate eight activities: 1) donning/doffing clothes; 2) sponge

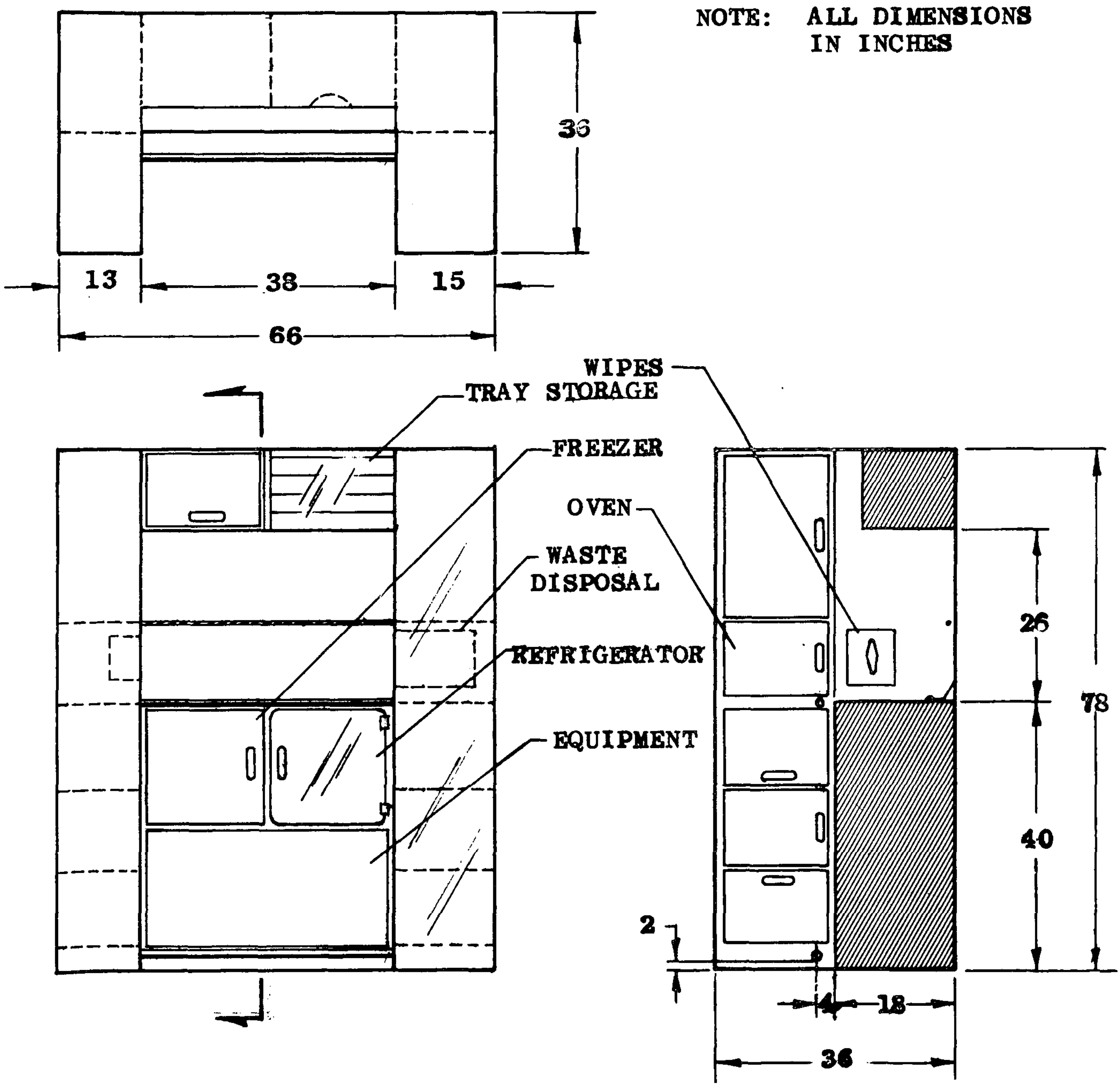


Figure III-3 Shuttle Galley Layout

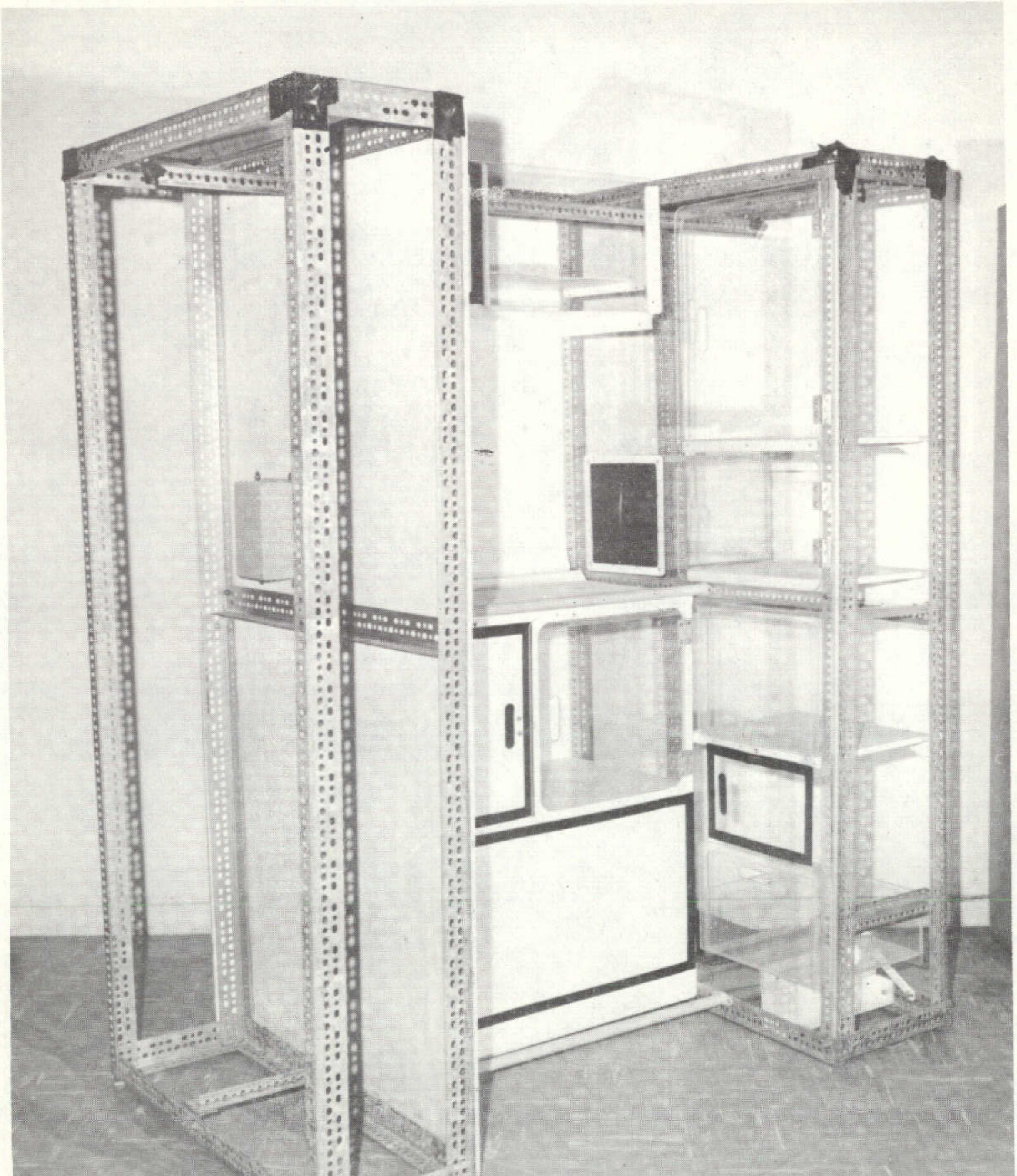
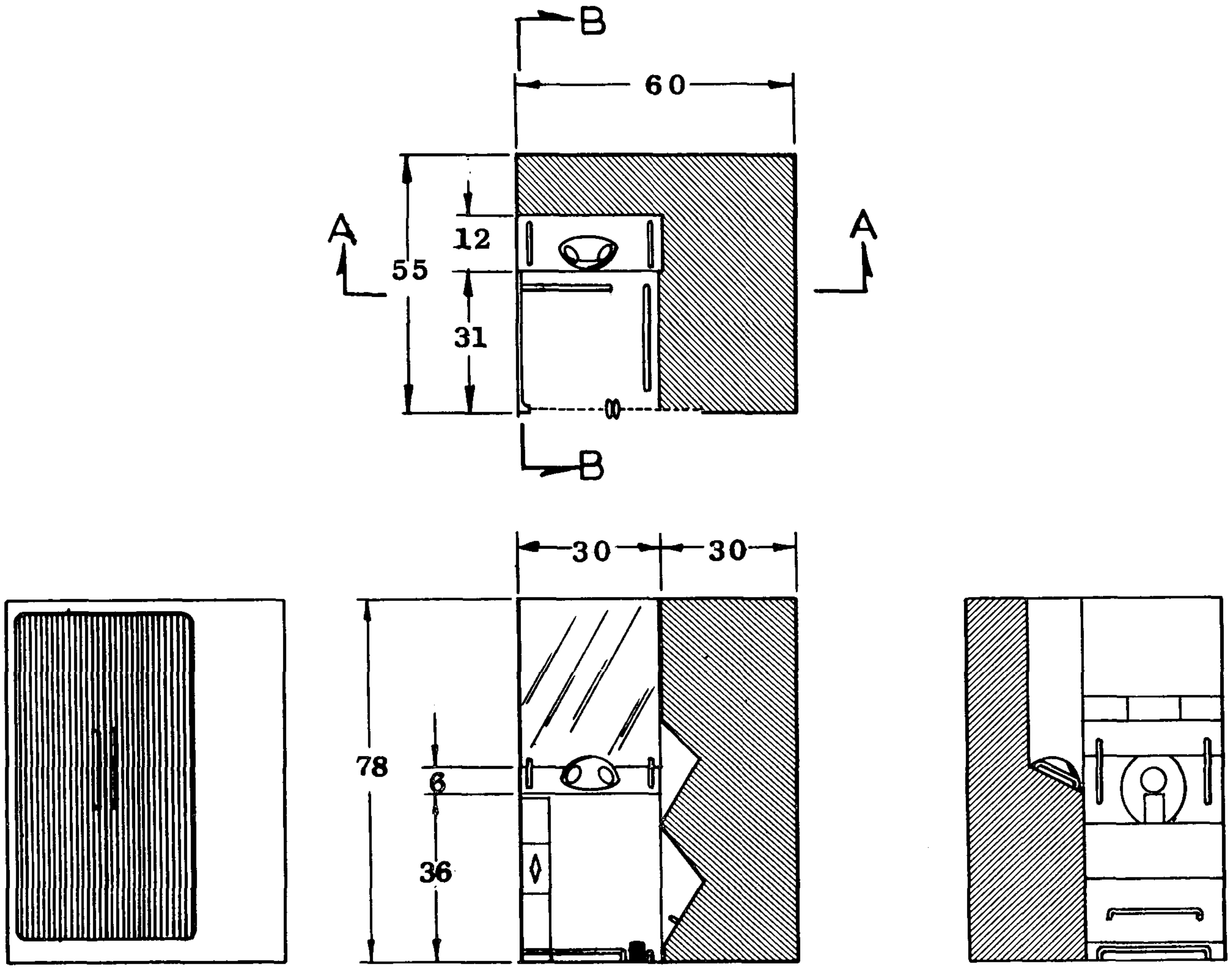


Figure III-4 Shuttle Galley Mockup



FRONT VIEW SECTION AA SECTION BB

NOTE: ALL DIMENSIONS IN INCHES

NASA-JSC
PERSONAL HYGIENE FACILITY
SAY 44 101682

Figure III-5 NASA Personal Hygiene Facility bath, 3) drying, 4) personal grooming, 5) regurgitation, 6) urination, 7) defecation, 8) housekeeping. The gross volume of the unit tested was 81.5 cubic feet, however, the volume utilized within the crew compartment was approximately 150 cubic feet which is representative of the NASA-MSC design. Of this gross volume 54.7 cubic feet was usable or net volume. This design allowed adequate volume to perform the specified tasks within the module with the door closed. All equipment and restraints were located for their functional capabilities with the man interface and consideration for having a hygienically clean area with minimum effort. The relationship of activities to equipment was established during the design phase and verified during the testing phase. Some of the more critical areas were the angle of the fecal collector seat, location of restraints, location and operation of controls, temporary storage devices, and how the interfaces were accomplished during the two modes, one/zero-gravity, of operation. It was determined early in the design phase that the personal hygiene equipment could operate in only one orientation in one-gravity without very complicated equipment whereas orientation is not a controlling factor in zero-gravity. It was also determined that since all activities involve a single individual and the tasks are unrelated, the access volume required for the urine/fecal collector can be the same area that is required for the handwash unit. This sharing of volume provides optimum volume utilization of the usable area. The tested unit is depicted by Figure III-6 which is the engineering drawing giving critical dimensions and Figure III-7 a photograph of the assembled module.

D. CREW/PASSENGER COUCH AREA

The crew/passenger couch area was determined from a volumetric analysis (reference Section IV) of the shuttle crew compartment the individual couch size determined by NASA-MSC Contract NAS9-13010. The couch size has an envelope of 36 inches wide by 80 inches long and 14 inches deep but the volume required for each couch is a 36 inch cylinder by 80 inches long or approximately 47 cubic feet. An additional volume of approximately 18 cubic feet is required for access to each couch, however, this volume can be shared by two couches if the same activities for each couch are not done simultaneously. The area was designed to allow the couches be mounted along the shuttle y-axis and also in the z-axis to test the two orientations for access and spatial economy. Figure III-8 depicts the couch area with six couches mounted in the y-axis. The relationship of this area within the Shuttle orbiter is shown in Figure III-2. This volume represents approximately 482 cubic feet which includes the six couches and the required access volume. The design as tested included two couches that the test subjects could interface with and perform the normal

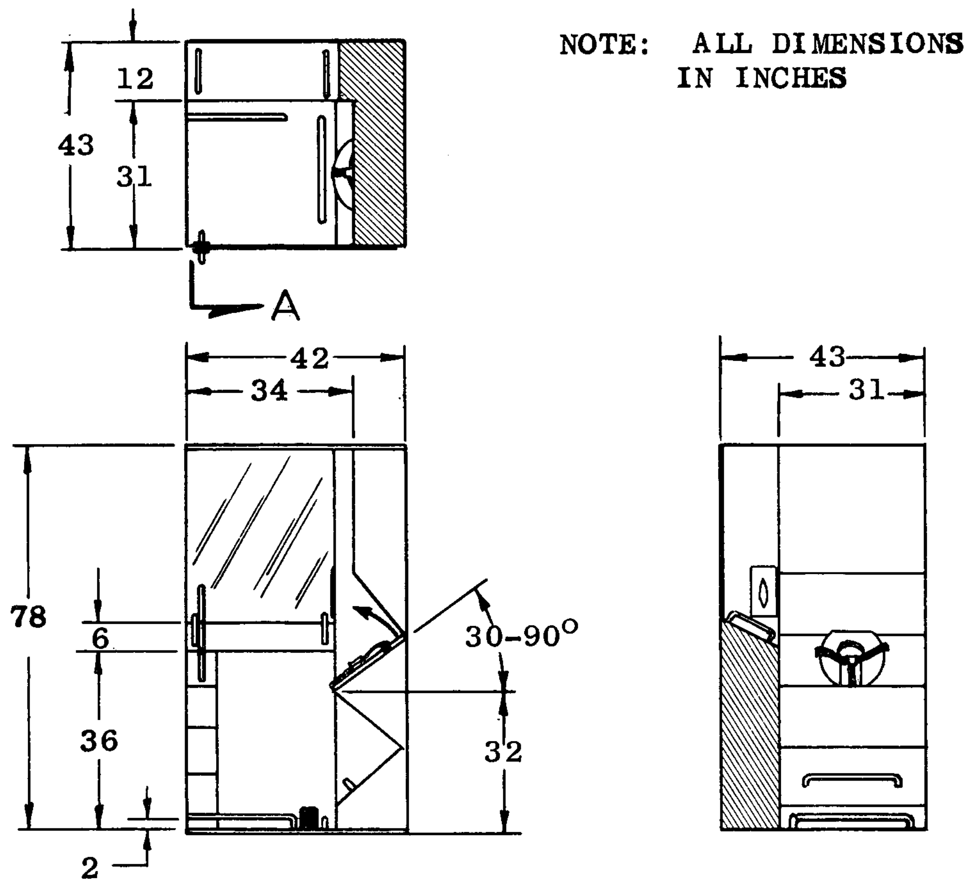


Figure III-6 Personal Hygiene Facility Layout

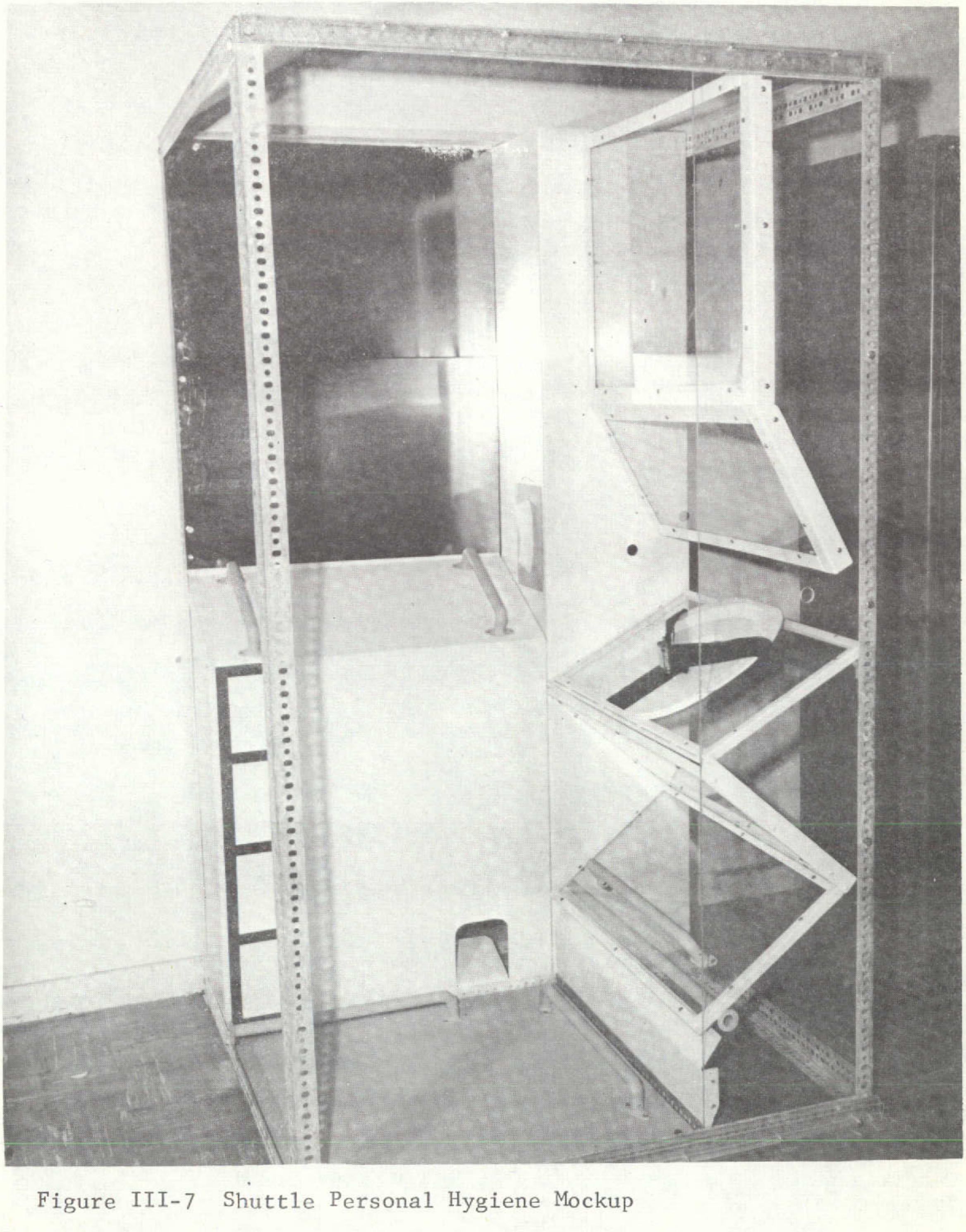


Figure III-7 Shuttle Personal Hygiene Mockup

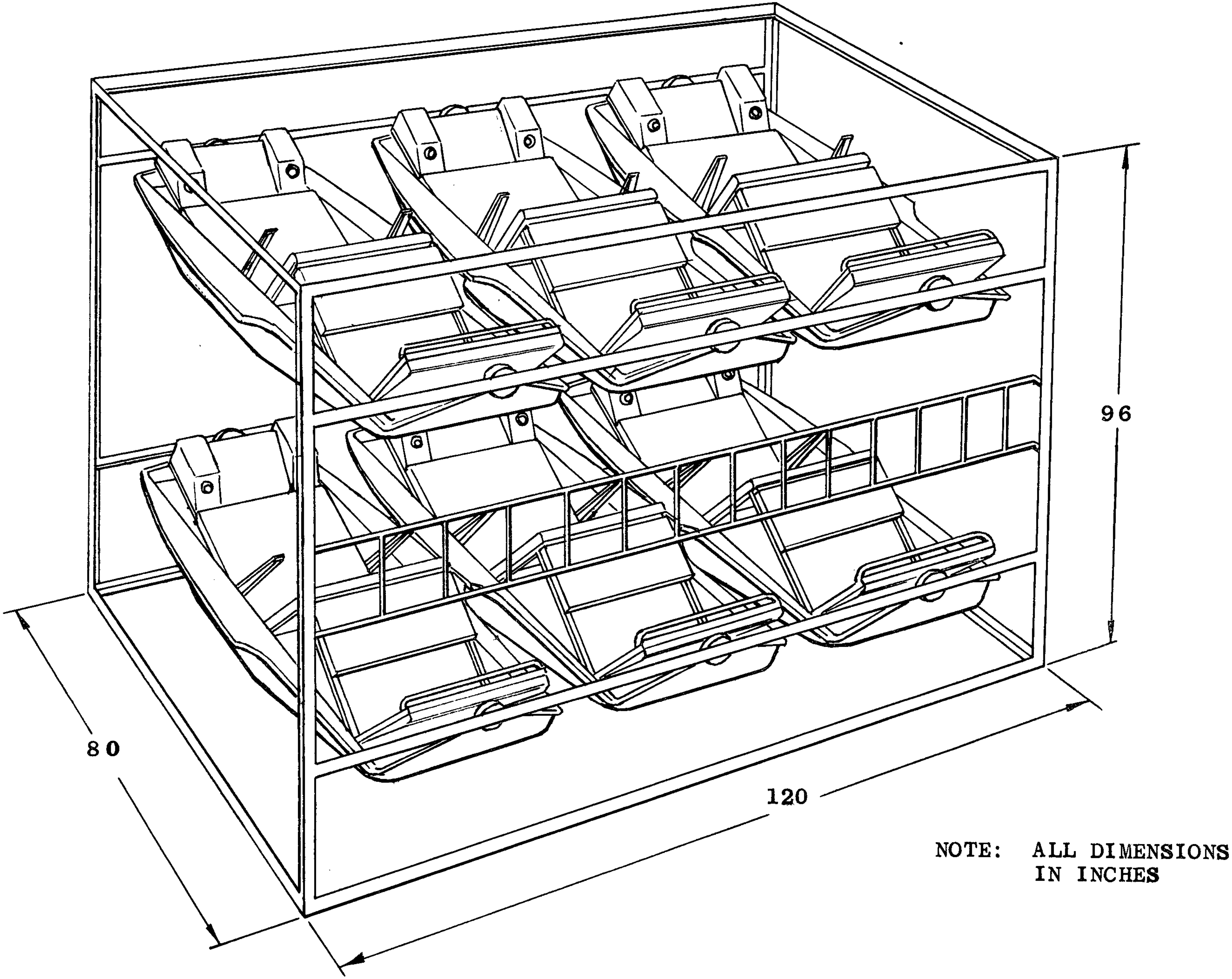


Figure III-8 Crew/Passenger Couch Area

activities and four simulated couches of the maximum couch envelope dimensions.

E. SYSTEM STATION DESIGN

The system station design was of low fidelity since the equipment that would be required for this station was not defined. Therefore, the station consisted of zero-gravity chair with belt restraint and a simulated console within a floor area of approximately four feet by five feet which gives a gross volume of 150 cubic feet. The design of this area was further simplified due to the limited activities performed in the system station. The only tasks considered were that of ingress/egress into or out of the station, sitting in the chair at a console, and general housekeeping. The chair was located to permit the station attendant to reach all parts of a console from the sitting position. This station is depicted by Figure III-9.

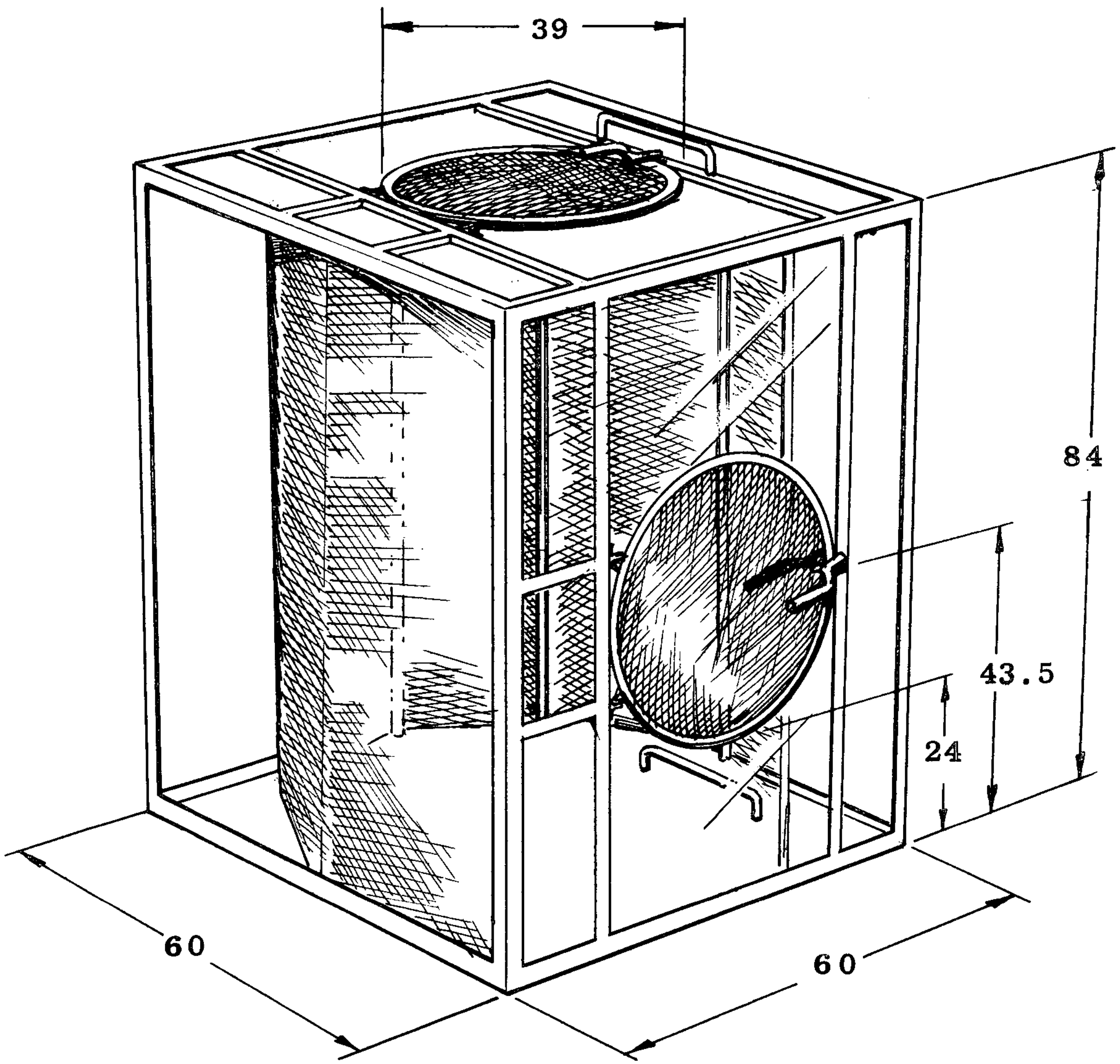
F. AIRLOCK DESIGN CONCEPT

The airlock design for overall dimensions were dictated by known parameters and NASA-MSC directed sizes for hatches. Also since airlock equipment definition was undecided the fidelity of the airlock mockup was very low. However, the size and volume were representative of a typical airlock and therefore, the data generated during the test can be considered valid. The actual usable volume in the five feet in diameter by seven feet long airlock was approximately 138 cubic feet which was adequate for the tasks performed in the airlock. The airlock activities consisted mainly of two men entering the airlock, one man after the other from the crew compartment, one man donning pressure suit, egressing through the external hatch, ingress through external hatch, doff the pressure suit, and egressing to the crew compartment through the internal hatch. The two hatches were made one meter in diameter which were more than adequate, reference Section IV Neutral Buoyancy testing. It was determined that a hatch size of 30 inches in diameter would be sufficient. The external or end hatch was designed to open in and the crew compartment hatch was designed to open out as required for pressurized compartments such as an airlock. The airlock design is depicted by Figure III-10 and Figure III-11 is a photograph of the assembled module.

G. FLIGHT DECK DESIGN

The flight deck design was to represent the overall dimensions as shown in the supplied NASA-MSC data with very little detail within the area. A pilot and copilot seat were simulated with simple chairs to provide the equipment required to demonstrate access routes and volumes. In addition the flight deck floor contained the entry hatch with a ladder leading up from the crew compartment. The gross volume of the flight deck is approximately 450 cubic feet of which a great amount will be filled with equipment and controls. However, this is

Figure III-9 Shuttle System Station Mockup



NOTE: ALL DIMENSIONS IN INCHES

Figure III-10 Shuttle Orbiter Airlock Mockup

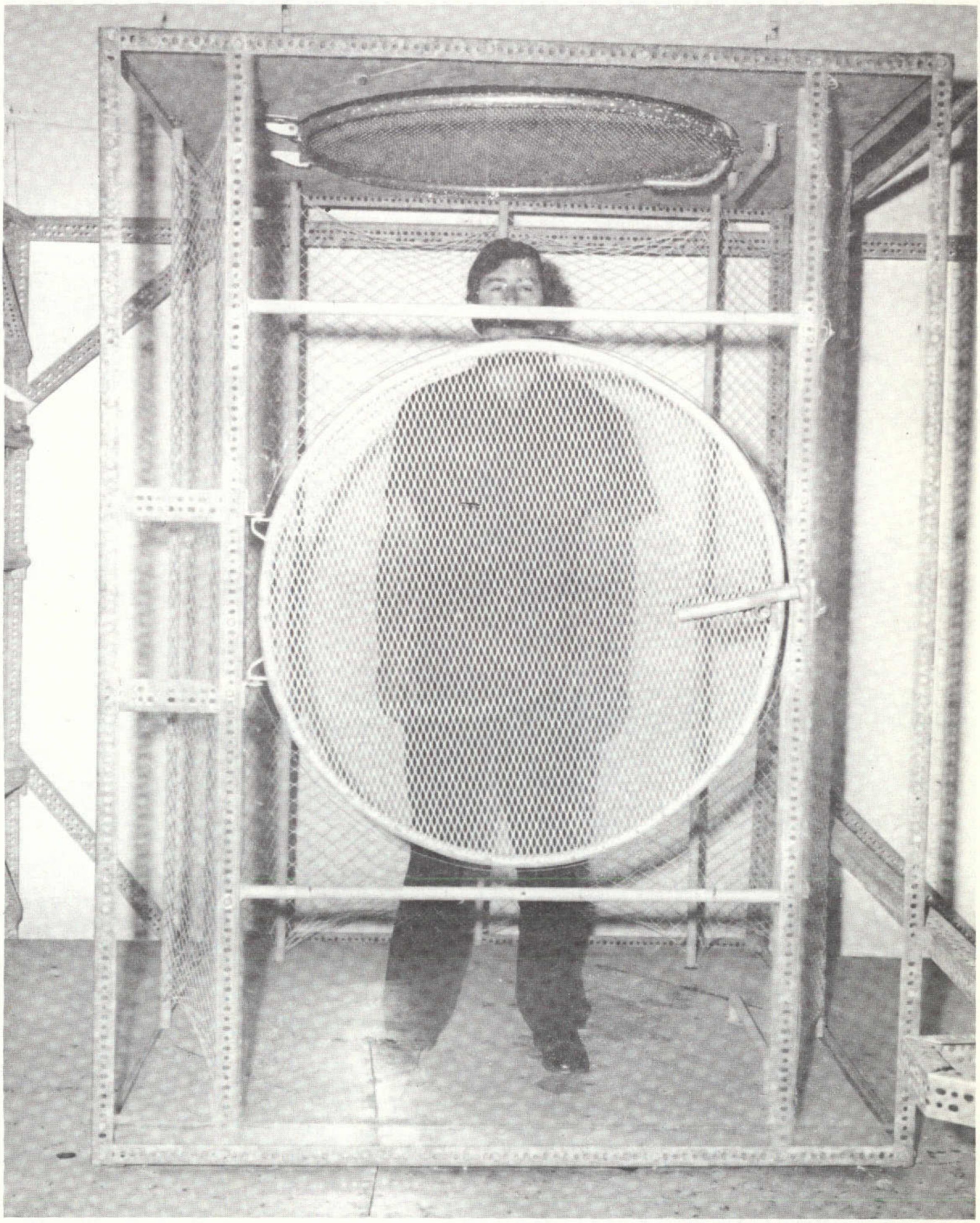


Figure III-11 Shuttle Airlock Mockup

strictly a work area and free volume is secondary to efficient operation of controls and equipment by the flight crew. Figure III-12 depicts the flight deck area with test subjects occupying the pilot and copilot seats. The relationship between the flight deck and the crew compartment is shown in Figure III-1.

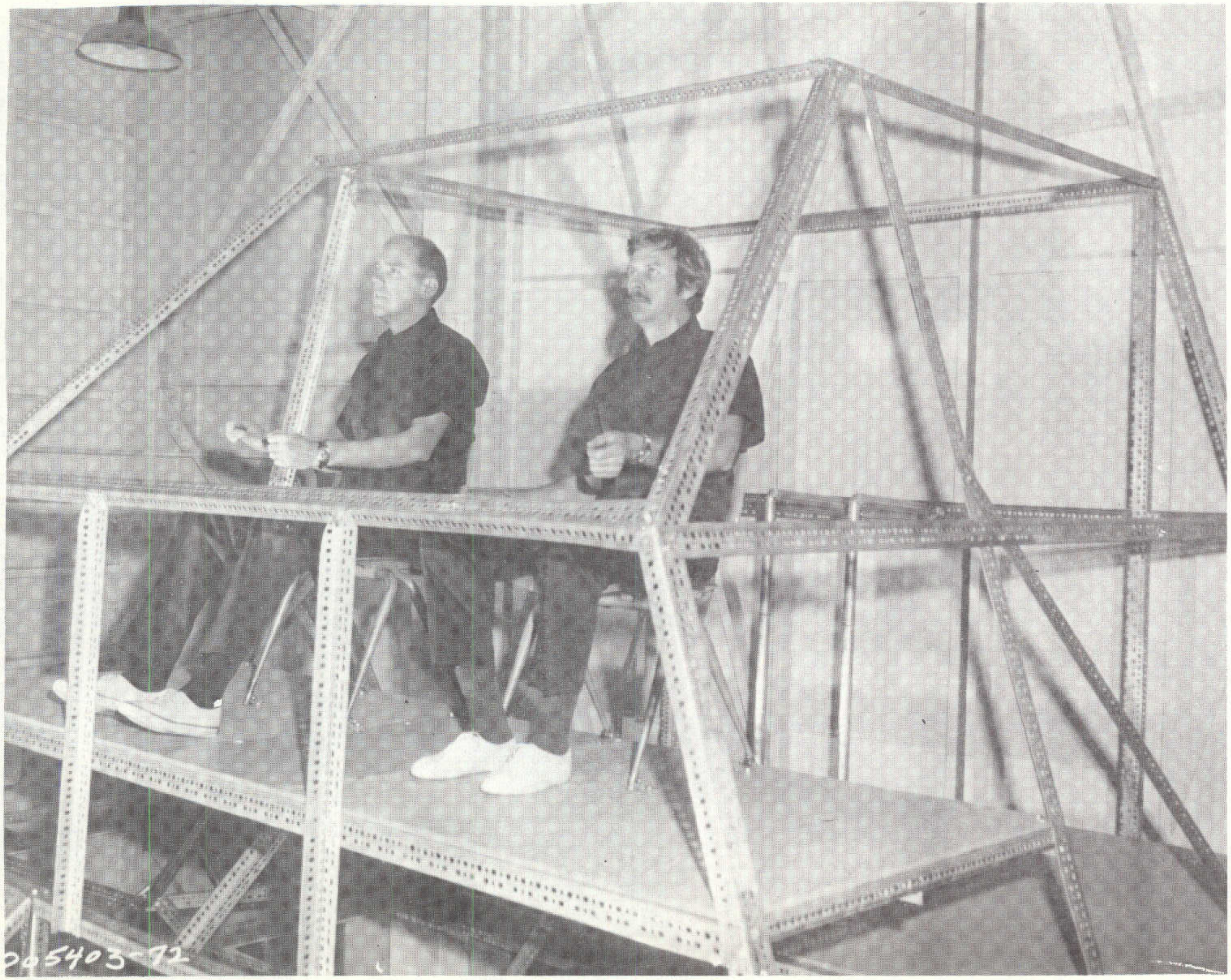


Figure III-12 Shuttle Orbiter Flight Deck Mockup

IV. MOCK-UP DEVELOPMENT, TESTING, AND EVALUATION

During this portion the structure and mockup modules designed in the previous tasks were fabricated, tested, and evaluated in both one-g and simulated zero-g neutral buoyancy tests. The one-g tests included testing with the Orbiter x-axis vertical for the launch mode, and horizontal for the re-entry/landing/ferry flight modes. The neutral buoyancy tests to simulate the zero-g mode were conducted with the Orbiter x-axis on the horizontal in the neutral buoyancy tank.

A. SHUTTLE NOSE FABRICATION

The development and fabrication of the shuttle nose incorporated the design concepts for the individual component modules into a workable test unit. The Shuttle nose mockup not only considered the most appropriate design aspects of the Shuttle (as it was known at the time), but also considered the demands for best test coverage and documentation. To provide maximum coverage for the data recording equipment, one side and the front of the crew compartment were left open. Equipment that occupied space on the left wall forward of the systems engineer station was outlined by supporting structure. When the major modules, galley, or personal hygiene areas were tested, coverage was from the front and side. All modules and equipment were mounted so they could be easily moved to provide for better space utilization and an orientation that allows maximum efficiency. This basic concept, which followed the original NASA design layout, is depicted by Figure IV-1. Figure IV-2 depicts the general layout details of the actual crew compartment and flight deck mockup. The internal modules were constructed in a manner that allowed for complete flexibility in alternate arrangements. Figure III-1 illustrated the actual mockup as fabricated.

An analysis was made to determine optimum operational test equipment to facilitate the evaluation of arrangements, operations and sequencing. This provided a certain degree of realism to the actions of the test subjects and increased the usefulness of the test results. Table IV-1 gives the operational and simulated areas of the mockups.

The integral crew compartment and flight deck were tested with the x-axis horizontal for ingress/egress, convenience, nuisance factors, internal arrangement, traffic patterns, and restraint devices to accommodate re-entry, landing, and ferry flights. After the most optimum configuration was determined from these tests, the complete structure was reoriented with the x-axis vertical to assume

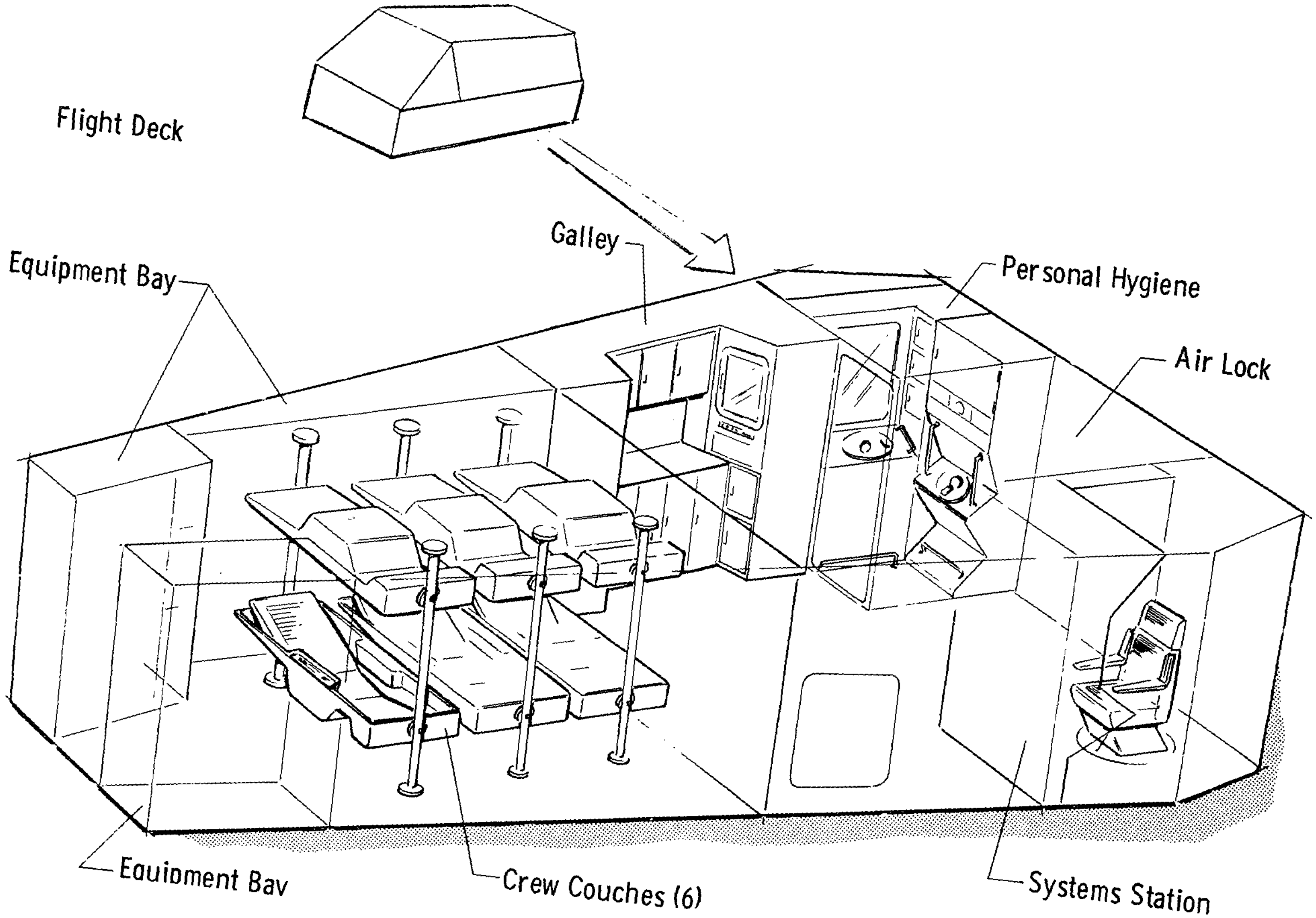
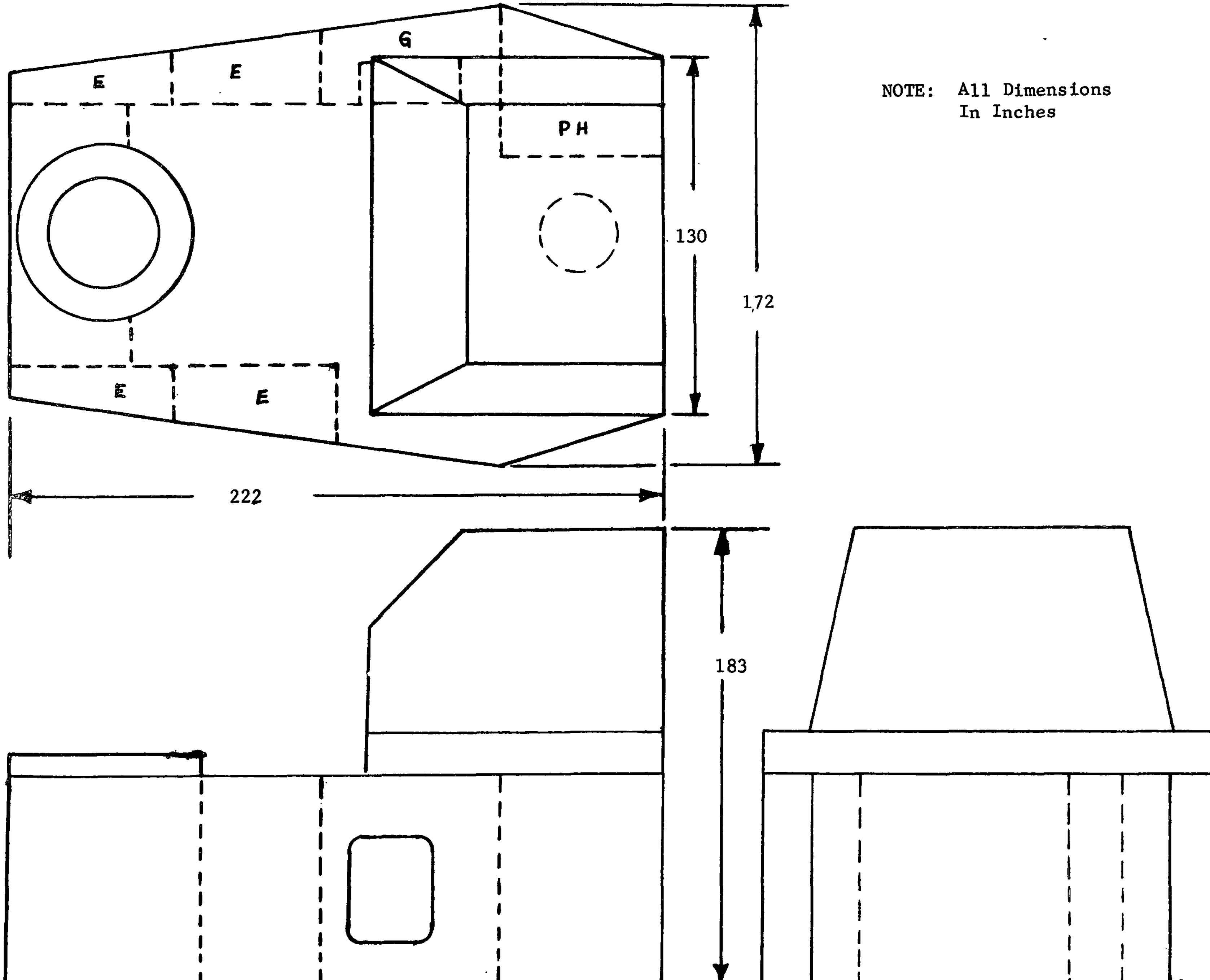


Figure IV-1 Shuttle Orbiter Mockup



NOTE: All Dimensions
In Inches

Figure IV-2 Shuttle Orbiter Mockup

Table IV-1 Mockups of Crew Compartment Modules

Area	MODE	
	Operational	Simulated
1. Galley		
Tray Storage	For 5 trays	For 5 trays
Oven	For 2 trays	-----
Food Storage	3 lockers	6 lockers
Restraints	Crewman, tray, food, etc.	-----
Housekeeping	Wipes, waste disposal, vacuum hose	-----
2. Personal Hygiene		
Entrance	Sliding door	-----
Restraints	Feet and hand at commode/urinal & sink	-----
Controls	Sink (foot operated) commode/urinal (hand operated)	Waste water
Wipes Dispenser	Sink, commode/urinal	-----
Grooming		Mirror, sink
3. Airlock		
Size	5 ft dia x 7 ft high	
Hatches	2 one-meter (top & side)	
Access	2 men in airlock procedure from ingress to egress	
Controls		Airlock operation
4. Couches		
Size	2 semi-operational couches sitting and laying	4 couches of max. envelop dimensions
Stowage	In one couch	
Housekeeping	Wipes, waste disposal, etc.	

a launch mode. In this position the activities associated with a launch mode were performed to determine accessibility for servicing equipment, restraint devices for launch, and ingress/egress to the stations occupied for both normal and emergency launch conditions.

Test subjects were dressed in two-piece uniforms of a dark color with white shoes. The crew compartment was predominantly of a light color, which gave the feeling of spaciousness and provided the required photographic light for coverage of the test sequences. As an aid in evaluating the equipment and other devices, the items were of contrasting colors with the background and the test subject. Test data was recorded by 16-mm movie film, still photographs, observer comments, and test subject comments. Detailed test procedures listing step-by-step tasks were prepared for each separate mockup attitude. These procedures ensured that each component item, as well as the total component volume, was evaluated by the testing. Activities were performed or simulated in more than one mockup attitude as required by launch, ferry/landing, or zero-g modes of operation. Each test sequence provided data for evaluation of specific factors. Table IV-2 summarizes the tasks that were performed in each crew area, along with the test factors that were evaluated for each step of the task. Actual test procedures and plans were prepared at completion of the mockup design and were approved by the NASA prior to implementation.

At the conclusion of each series of tests, the tests were evaluated and analyzed to assess the merits and deficiencies of the design concept, its applicability, and access factors, and any other factors that limited, enhanced, or compromised the design. In addition, the design was assessed with regard to safety, performance, and comfort. This included such aspects as ease of locomotion, use of mobility aids and restraint devices, traffic patterns, accessibility, ingress/egress, arrangement/orientation, nuisance factors, servicing, and convenience. All furnishings were evaluated for the man interface with reference to height, angle, location, and ease of operation. The evaluation analyzed the recorded data and the observers' and test subjects' comments.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table IV-2 Tasks vs Test Evaluation Factors

		FACTORS TESTED									MOCKUP ATTITUDE		
AREA	FUNCTION/TASK	INGRESS/EGRESS	MOBILITY/RESTRAINT	ACCESSIBILITY	SPACE UTILIZATION	ARRANGEMENT*	CONVENIENCE	NUISANCE FACTORS	CONFIGURATION*	ORIENTATION*	VERTICAL 1-G	HORIZONTAL 1-G	NEUTRAL BUOYANCY ZERO-G SIMULATION
PASSENGER COMPARTMENT	1) Enter area, transfer to couch	X	X		X	X			X	X	X	X	X
	2) Occupy couch, change couch position/orientation while restrained		X	X			X	X		X	X	X	X
	3) Open and simulate using storage volumes at or in couch			X	X	X	X	X			X	X	X
	4) Simulate sleeping						X	X				X	X
	5) Simulate reading, writing, etc in couch			X	X		X	X			X	X	X
	6) Depart couch, leave area	X	X		X	X			X	X	X	X	X
	1) Enter area, transfer to clothing storage area	X	X		X	X			X	X		X	X
	2) Remove clothing, place in temporary storage area		X	X	X	X						X	X
	3) Remove new clothing article from storage, don clothing, leave area	X	X	X	X	X			X	X		X	X
	1) Enter area carrying food tray, transfer to couch	X	X		X	X	X	X	X	X		X	X
	2) Occupy couch, simulate eating		X	X			X	X				X	X
	3) Depart couch with food tray, leave area	X	X		X	X			X	X		X	X
	1) Enter area, transfer to housekeeping storage area	X	X		X	X			X	X		X	X
	2) Remove equipment from storage, simulate area cleanup		X	X	X	X						X	X
	3) Replace equipment, leave area	X	X	X	X	X			X	X		X	X
GALLEY	1) Enter area, simulate preparing meals	X	X	X	X	X	X	X	X	X		X	X
	2) Simulate operating oven, water dispensers, etc			X	X	X						X	X
	3) Simulate removing food trays, food, utensils, etc from storage			X	X	X						X	X
	4) Simulate area cleanup, leave area (normal & emergency procedures)	X	X	X	X	X	X	X	X	X		X	X
	1) Enter galley area, transfer to tray pickup point	X	X	X			X	X	X	X		X	X
	2) Pickup completed meal in food tray		X	X		X	X	X				X	X
	3) Transfer with tray to eating area	X	X						X	X		X	X
PERSONAL HYGIENE SYSTEM	1) Enter area	X	X						X	X	X	X	X
	2) Doff clothing, temporarily store clothing		X	X	X	X				X	X	X	X
	3) Simulate taking a sponge bath		X		X		X	X		X			X
	4) Remove clothing from storage, don clothing		X	X	X	X				X	X	X	X
	5) Simulate urination and defecation		X	X		X	X	X		X	X	X	X
	6) Simulate handwashing and other personal grooming procedures		X	X	X	X	X	X		X	X	X	X
	7) Simulate area housekeeping procedures		X	X	X	X				X	X	X	X
	8) Leave area (normal & emergency procedures)	X	X		X	X			X	X	X	X	X
FLIGHT DECK	1) Enter area, take flight crew position	X	X		X	X			X	X	X	X	X
	2) Simulate launch, orbital operations, & landing procedures (crew restraint positions may change)		X	X		X	X	X			X	X	X
	3) Leave area (normal & emergency procedures	X	X		X	X			X	X	X	X	X
	1) Enter area, take RMS operator position	X	X		X	X			X	X			X
	2) Simulate RMS procedures		X	X	X	X	X	X					X
	3) Leave area (normal & emergency procedures	X	X		X	X			X	X			X
AIRLOCK	1) Enter airlock from crew compartment side (2 men plus equipment)	X	X		X	X			X	X			X
	2) Simulate donning pressure suits, depressurization procedures		X	X	X	X	X	X					X
	3) Leave airlock through exterior hatch (1 meter)	X	X		X	X							X
	1) Enter airlock from exterior hatch	X	X		X	X							X
	2) Simulate pressurization procedures & pressure suit doffing		X	X	X	X	X	X					X
	3) Leave airlock, transfer into crew compartment (normal & emergency procedures)	X	X		X	X			X	X			X
STATIONS	1) Enter area	X	X		X	X			X	X	X	X	X
	2) Simulate station operations		X	X	X	X	X	X		X	X	X	X
	3) Leave area (normal & emergency procedures)	X	X		X	X			X	X	X	X	X
AVIONICS/ EQUIPMENT	1) Transfer to avionics/equipment area (located in several different areas)	X	X		X	X			X	X		X	X
	2) Simulate use/maintenance of equipment		X	X	X	X			X	X		X	X
	3) Leave area (normal & emergency procedures	X	X		X	X			X	X		X	X
TRANSFER PROCEDURES (SHIRT-SLEEVE & SUITED)	Simulate transfer to and from all crew compartment areas (up to three crewmen simultaneously) in both normal & emergency modes	X	X		X	X			X	X	X	X	X

*DEFINITIONS:

Arrangement - Relationship of furniture items, equipment, hatches, etc to each other within a given contiguous area.

Configuration - Relationship of various rooms/areas to each other (e.g., location of galley with relation to flight deck).

Orientation - Relationship of "task vectors" to each other in separate areas or within a given area/room on different surfaces.

During the course of the shuttle evaluation process a number of design alerts were written to identify probable design problems. Those design alerts that were generated during the contract study period include the following:

1. Footrail on couch.
2. Contaminated wipes.
3. Carrying package up ladder in vertical one-g.
4. Access to Flight Deck in vertical one-g.
5. Access ladders and platforms in various locations.
6. Anthropometric growth dimensions.
7. Mobility aids for hands around couch locomotion.
8. Couch traffic patterns with tray.
9. Z-axis couch mounting for visual
10. Personal hygiene door counterbalance for different modes of operation.
11. Furnishings Safety Devices
12. Crew Equipment Surface Protection
13. Location of Airlock Hatches
14. Tamboured Doors

These design alerts are presented in the appropriate test and evaluation Sections IV B, IV C, IV D and each has been submitted to the NASA for inclusion within the total NASA design alert system. Three design alert problems which are applicable to all areas, are presented as follows:

TITLE: Anthropometry Dimensions NUMBER: 1

DESIGN PROBLEM: As indicated by the data shown in Table IV-3, the height of man changes as a result of attitude and time. These findings have been substantiated as typical changes by other studies conducted by the Physical Anthropology Section at Wright-Patterson Air Force Base. In a zero-gravity environment, the additional height will be evidenced in any stretched body attitude. However, in zero-gravity the extra length may be compensated by the tendency for the legs and back to bend slightly when free standing. If the person is restrained, as in a sleep restraint, then the extra length must be considered.

This data was investigated under neutral buoyancy conditions during the 17 January 1973 performance testing. Table IV-4 is a summary of that test data.

TITLE: Contaminated Urine Wipes NUMBER: 3

DESIGN PROBLEM:

After a urination, wipes are utilized for personal hygiene cleanliness. These wipes will not necessarily be placed in the

DESIGN ALERT #1 **Anthropometry Dimensions**

Table IV-3 **Male Height Changes for Attitude and Time**

Subjects	Weight	Percentile Male by	ONE-G HEIGHT, inches					
			Morning (AM)			Evening (PM)		
	Pounds	Height	Standing	Prone	Delta	Standing	Prone	Delta
C. Council	165	65	70-3/4	71-1/2	3/4	70-1/4	71-9/16	1-5/16
D. Parker	190	94	73-9/16	74-7/16	7/8	73-3/16	74-1/16	7/8
A. Rosener	170	65	70-5/8	71-1/2	7/8	70-1/8	71-9/16	1-7/16
G. Rysavy	140	10	65-1/2	66-7/8	1-3/8	65-1/4	66-3/4	1-1/2
J. Shea	190	95	74	75	1	73-1/2	74-5/8	1-1/8
D. Spencer	180	60	69-1/2	70-3/4	1-1/4	69	70-1/2	1-1/2
M. Stephenson	180	92	73-7/16	75	1-9/16	73-1/8	75	1-7/8
M. Tevebaugh	185	95	74	75	1	73-5/8	74-7/8	1-1/4

Table IV-4 Anthropometry Dimensions in Simulated Zero-G

Subject	Percentile Male by Height	One-G Height	Neutral Buoyancy		Max. Delta
			Vertical	Horizontal	
P. Garber	65	72	72	72-5/8	5/8
D. Stegeman	70	72-3/4	73	73-1/4	1/2
H. Maddera	95	74-3/4	75-1/2	75-1/2	3/4
J. Shea	95	74-1/4	75-1/8	75-1/16	7/8

fecal collector each time due to loss of cabin atmosphere. These wipes, contaminated with urine, will grow microorganisms with time. It is, therefore, necessary to place these wipes in a separate container with a suitable bactericide.

TITLE: Couch Mounting for Visual Contact NUMBER: 9

DESIGN PROBLEM:

With the couches mounted on a close centerline-to-centerline, occupants of couches across from each other have difficulty in achieving eye-to-eye contact. This becomes a problem when individuals are engaged in social conversation since eye-to-eye contact is desirable. This is due to the angle of the couch seat back within the couch mounting frame being at approximately 30 degrees from the vertical. With the occupants head against the head rest, the eyes in a straight ahead position would be directed to the opposing couch occupants waist.

B. HORIZONTAL ONE-G TESTING AND EVALUATION

Upon completion of the Shuttle nose mockup, the man-machine interface tests were begun. The first series of tests were directed at the conditions which exist under a horizontal one gravity operational mode. The data obtained from these tests were then used to verify the design concepts of the crew compartment for horizontal X-axis 1-g habitability in the post orbital flight, ferry flights and landing attitude. Testing was performed to determine accessability of equipment, restraint devices for re-entry, post orbiter flight and landing and ingress/egress to the stations occupied for both normal and emergency landing conditions.

The data which was obtained may be applied directly to the design of architectural concepts and furnishings of the Shuttle orbiter crew compartment as documented in section VI of this report.

The following items generally summarize the test parameters of the horizontal one-gravity test setup:

Task: Evaluation of the passenger compartment area and flight deck of the Shuttle Orbiter crew compartment in the X-axis horizontal orientation. Tasks accomplished included ingress and evaluation of passenger compartment, galley, personal hygiene system, flight deck, systems station, avionics/equipment, and transfer procedures.

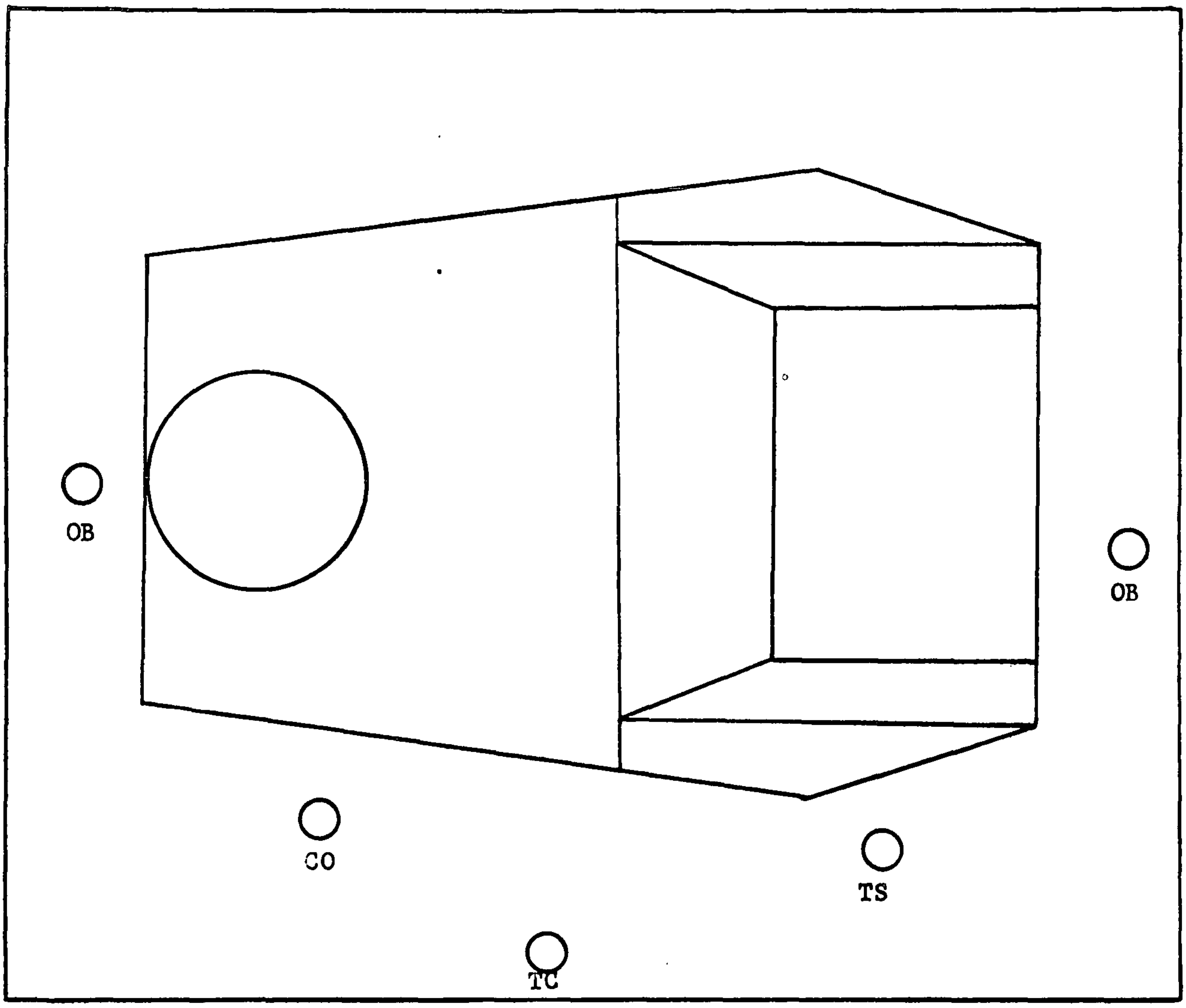
Test Setup: The Shuttle Orbiter crew compartment was located in the VTF Cell P-7 Level 3. It was oriented within the test area so that its X-axis was horizontal as shown in Figure IV-3. A portable work platform was available to provide access to mockup hatches.

Test Personnel: Test Conductor - Located in the area of the mockup, he monitored the tests in person and read test procedures to test subject (s) during tests. The test conductor had overall responsibility of conducting the test.

Observers - Watched the progress of the test from the area adjacent to the mockup and requested changes to test procedures during test operations with concurrence of the test conductor and safety.

Camera Operator - Located adjacent to and in the mockup, he took still photographs and motion pictures of the test as directed by the test conductor.

Test Subject (s) - Located adjacent to and within the mockup, he/she was responsible for performing the assigned test in accordance with the test procedures and the direction of the test conductor. Test subjects were dressed in all purpose garments.



Legend:

TS - Test Subject
CO - Camera Operator
OB - Observer
TC - Test Conductor

Figure IV-3 Horizontal 1-G Test Setup

Safety - Assessed personnel and test setup safety prior to the beginning of tests and was notified of any changes from the prescribed tests in procedure for concurrence.

Date Recording: Movie camera; still camera; test subjects and observers' comment sheets.

Items tested: A. Passenger Compartment

1. Area Ingress
2. Couch Ingress and Adjustment
3. Use of Storage Volumes in Couch Area
4. Simulation of Reading, Writing, etc. in Couch
5. Egress from Couch and Area
6. Entrance to Clothing Storage Area
7. Removal of Clothing from Permanent Stowage Area and Transfer to Temporary Stowage Area
8. Entrance to Housekeeping Stowage Area
9. Removal of Housekeeping Equipment from Stowage and Simulation of Area Cleanup
10. Replacement of Housekeeping Equipment and Area Egress

The following items were tested but not recorded as they were recorded during Neutral Buoyancy Testing:

1. Simulation of Sleeping
2. Donning of Clothing Previously Placed in Temporary Stowage and Egress from Area
3. Entrance to Area Carrying Food Trays and Transfer to Couch
4. Couch Ingress with Food Tray and Simulation of Eating
5. Egress from Couch with Food Tray and Departure from Area

B. Galley

1. Area Ingress and Simulation of Meal Preparation

2. Simulation of Galley Equipment Operation
3. Simulation of Area Cleanup and Egress (Normal and Emergency Procedures)
4. Area Ingress to Tray Pickup Point
5. Pickup of Complete Meal in Food Tray
6. Transfer with Tray to Eating Area

C. Personal Hygience System

1. Area Ingress
2. Removal and Temporary Stowage of Clothing
3. Removal from Temporary Stowage and Donning of Clothing
4. Simulation of Urination and Defecation
5. Simulation of Handwashing and Other Personal Grooming Procedures
6. Simulation of Area Housekeeping Procedures
7. Normal and Emergency Egress from Area
8. Door Operation
9. Control Locations, Procedure
10. Wipe Location, Procedure

D. Systems Station

1. Area Ingress
2. Simulation of Station Operations
3. Normal and Emergency Egress from Area

E. Avionics/Equipment

1. Area Ingress (Avionics/Equipment Located in Several Different Areas)
2. Simulation of Use and Maintenance of Avionics/Equipment
3. Normal and Emergency/Egress from Area

F. Transfer Procedures (Shirtsleeve)

1. Simulation of Transfer to and from all Crew Compartments (Up to Three Crewmen Simultaneously in Both Normal and Emergency Modes)

G. Flight Deck

1. Area Ingress and Entry to Flight Crew Positions
2. Normal and Emergency Egress from Area

The testing was conducted in accordance with the test plan defined in MMC Report No. MCR-72-246 (DRL #T-784) entitled "Performance Test Plan for the Shuttle Orbiter Crew Compartment," September, 1972. The testing was directed specifically at determining the problems which could be expected when the Shuttle was in the horizontal service mode or in operation during ferry flights and re-entry. The basic evaluation factors of performance, safety and comfort were used in analyzing the test procedures. Figures IV-4 through IV-18 illustrate the mockup, horizontal test setup and test subject task performance.

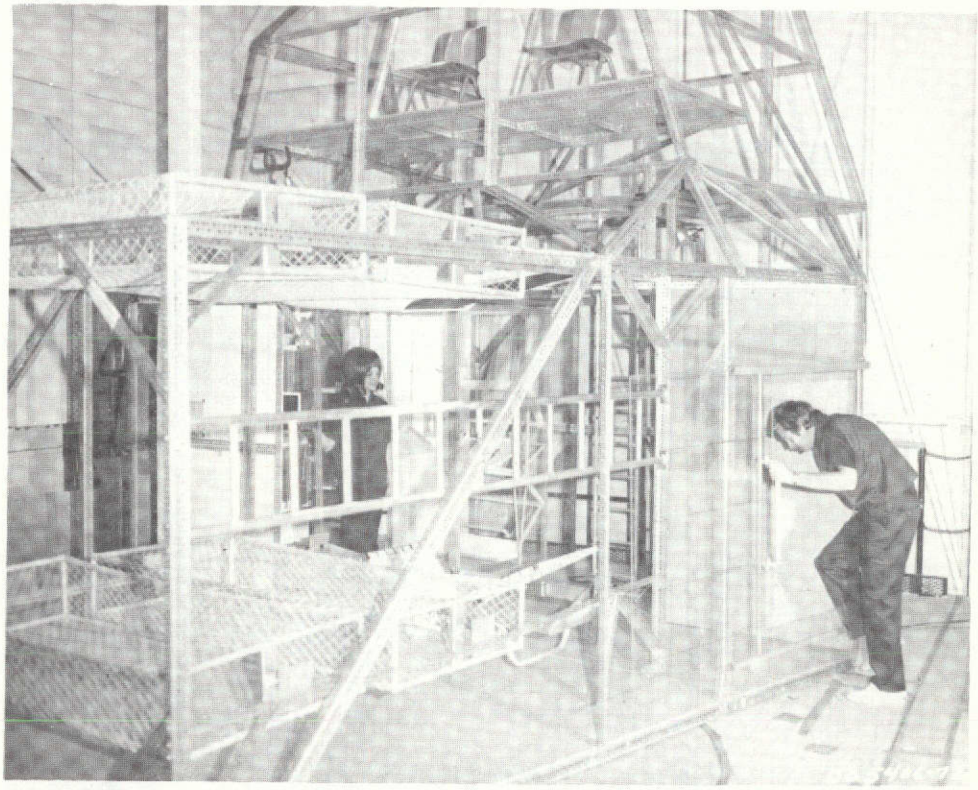


Figure IV-4 Overview of Shuttle Mockup in Horizontal Test Position

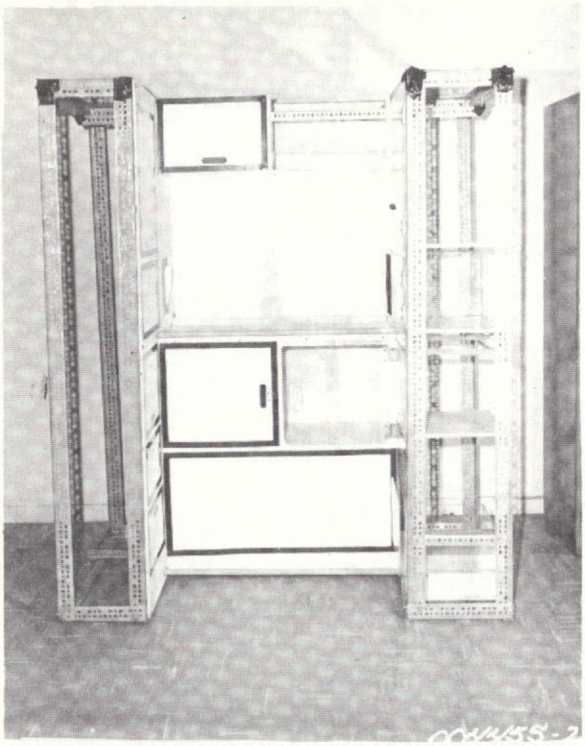


Figure IV-5 Shuttle Galley Modular Mockup

Figure IV-6 Female Test Subject in Galley Mockup During Food Preparation

Figure IV-7 Male Test Subject in Galley Reaching for food Containers.

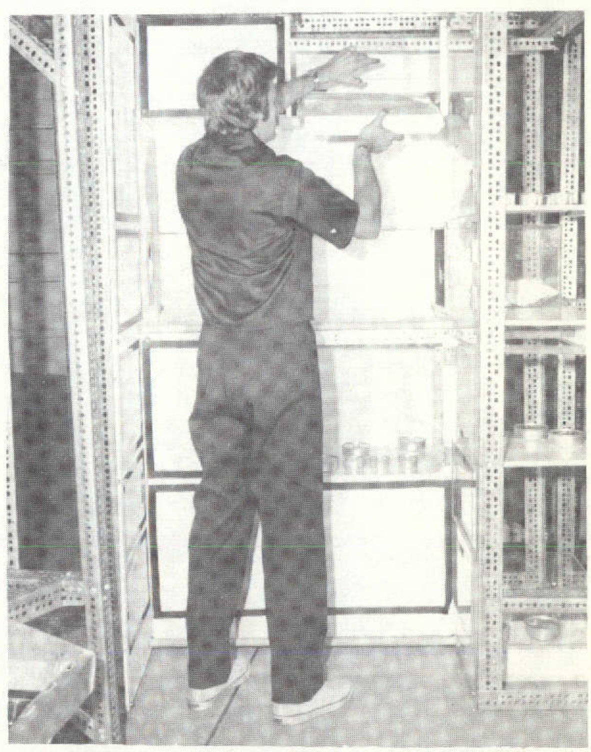


Figure IV-8 Male Test Subject in Galley Storing Food Tray

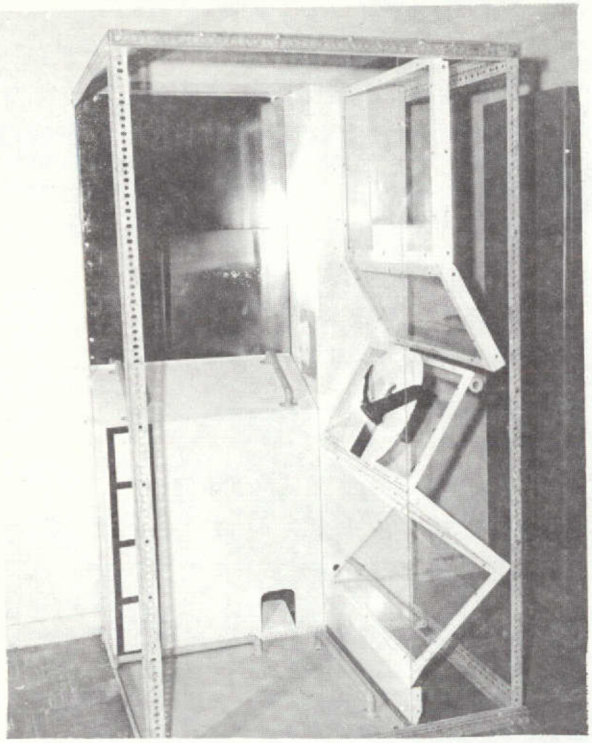


Figure IV-9 Shuttle Personal Hygiene Module Mockup

Figure IV-10 Female Test Subject With Personal Hygiene Kit

Figure IV-11 Male Test Subject Simulating Hand Washing

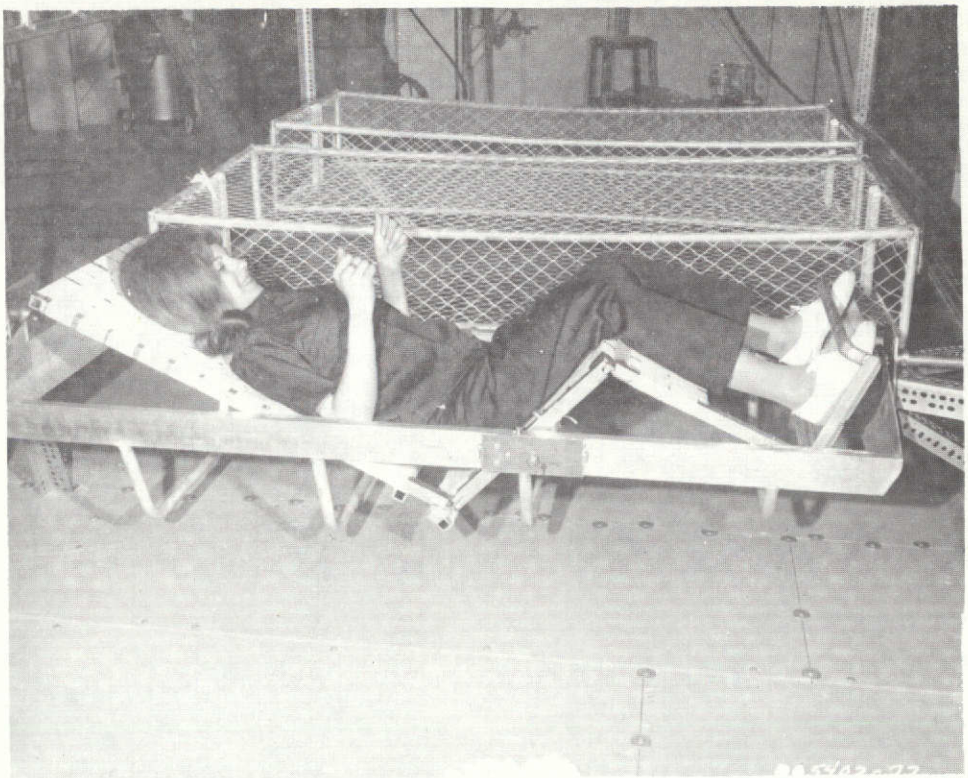


Figure IV-12 Female Test Subject Reading in Couch/Crew Area Mockup

Figure IV-13 Male Test Subject Relaxing in Couch/Crew Area Mockup

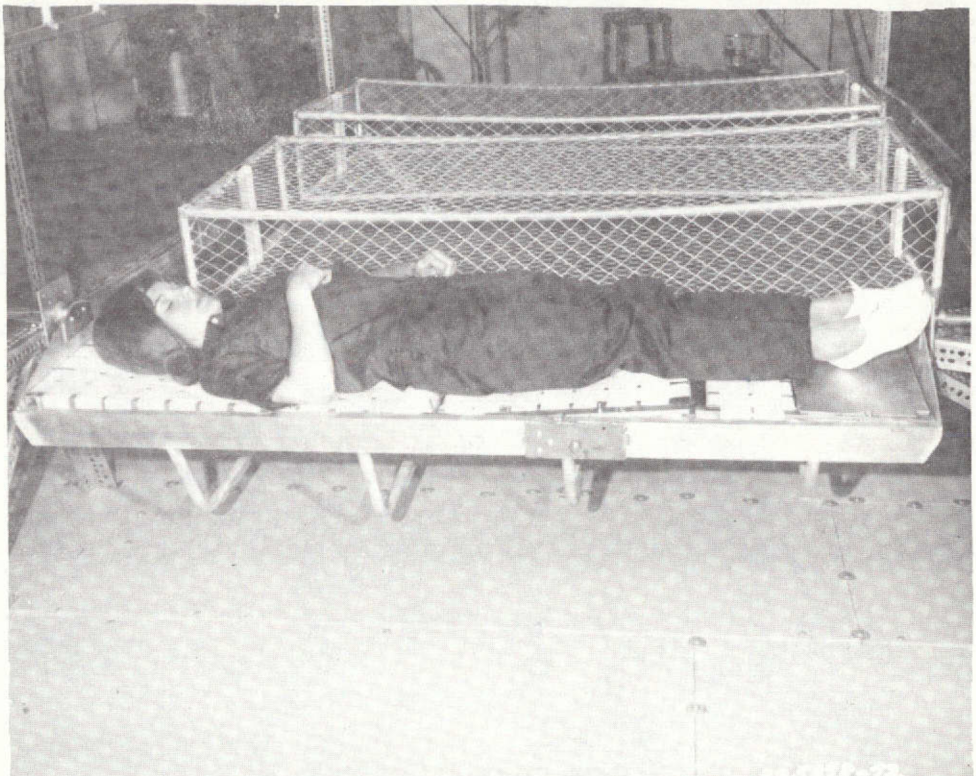


Figure IV-14 Female Test Subject Sleeping in Couch

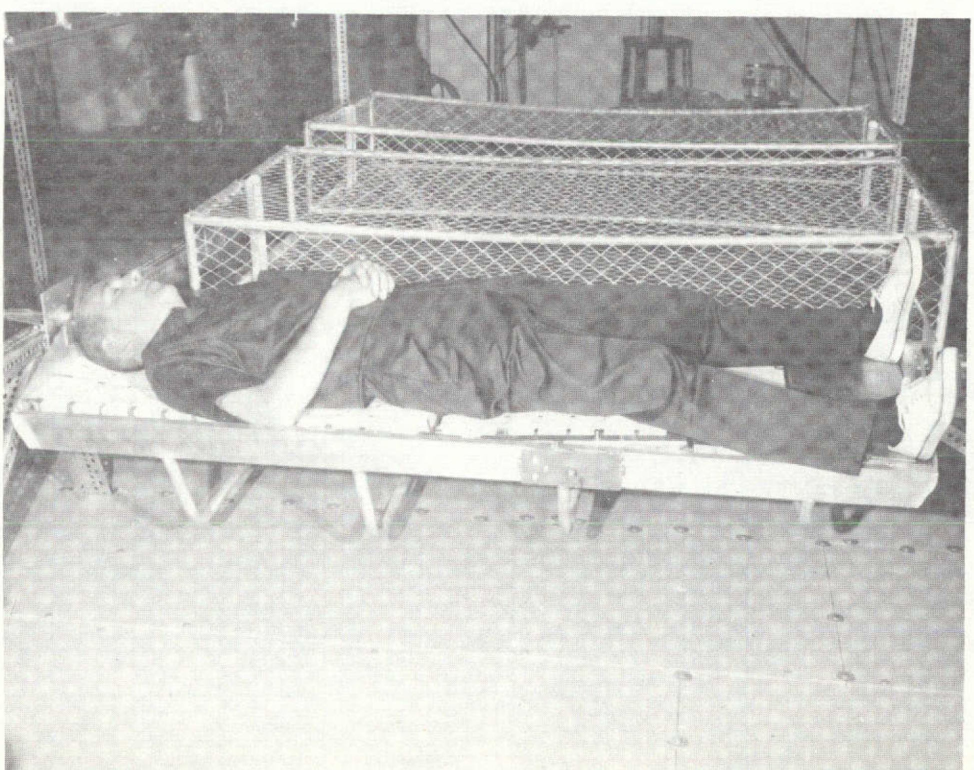


Figure IV-15 95th Percentile Male Test Subject Sleeping in Crew Couch

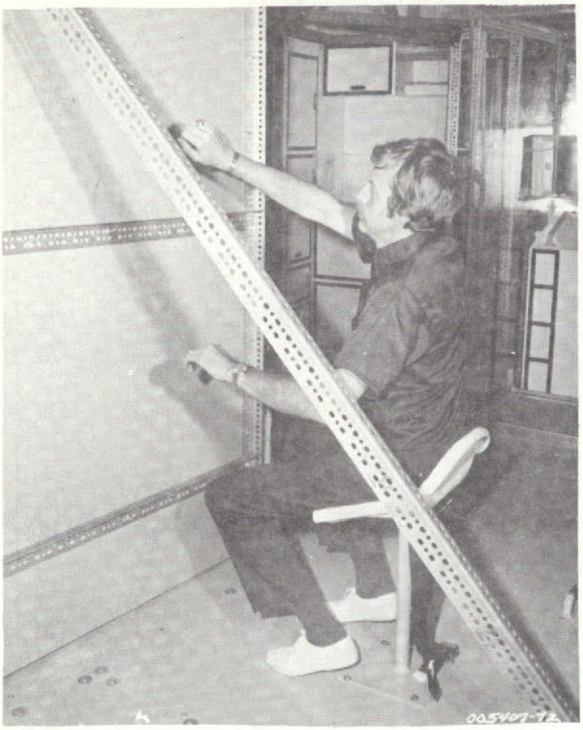


Figure IV-16 Male Test Subject Simulating Activities in Payload Specialist Station

Figure IV-17 Crew Entry into Flight Deck Area

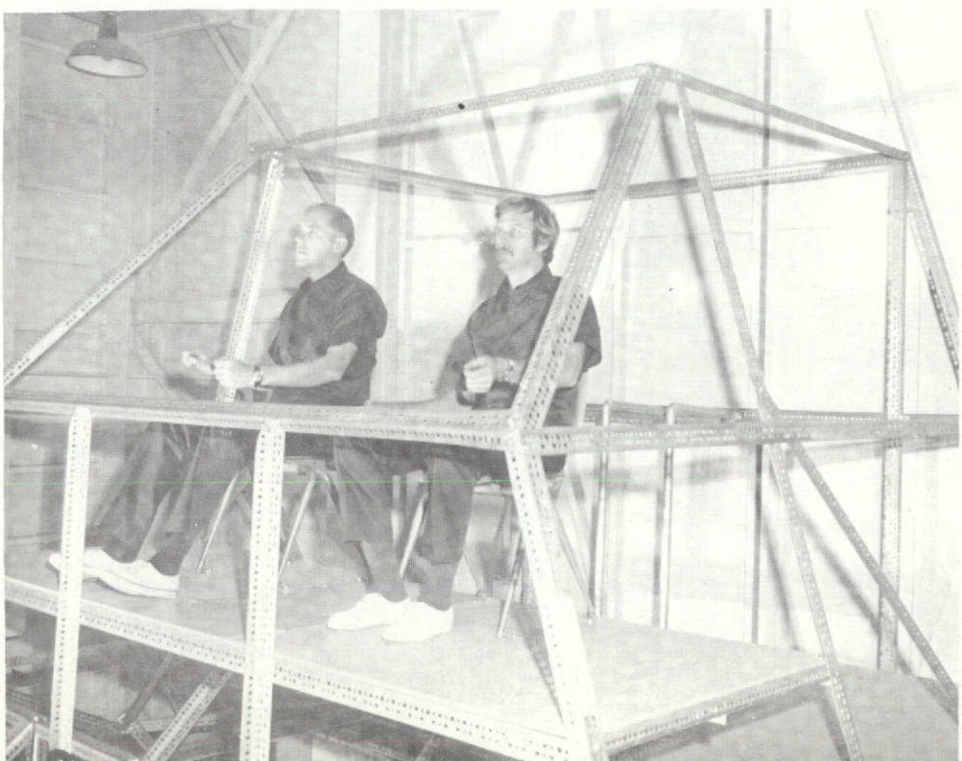


Figure IV-18 Simulated Operations in Flight Deck Area

As each element of the Shuttle nose was tested in the horizontal one-gravity mode, the activities were documented with film, and by the observers records. The test subjects aferwards recorded their opinions and comments in regard to each specific sequence. Table IV-5 outlines the component evaluation factors and the general comments which apply to each module and function. Sections IV-F and IV-G describe in depth the design aspects of volume and mobility/restraint aids. The other subjects (or evaluation factors) which resulted in design associated criteria may be discussed under the general heading of nuisance factors. Looking at the evaluation results in this light, the following significant items appear for consideration under the condition of horizontal one-gravity operations:

1) Personal Hygiene Unit - The seat angle must not exceed 30^o from the horizontal and should be less than 10^o for assured comfort. At a seat angle of 30^o, a lap belt restraint is required. Operations of controls become difficult and the wipe up procedures require the user to stand up and away from the seat. This also requires the equipment to operate at a tilt. If the seat angle exceeds 30^o, it becomes almost impossible to use the collector unit. This condition of seat angle is a definate nuisance. A solution to this would be to rotate the seat from horizontal to vertical when changing Shuttle operational modes; however, this would entail a considerable design change in the personal hygiene collection unit and very poor volume utilization. The more practical solution would be to orient the seat for either vertical or horizontal one gravity usage, ruling out one or the other or orient the seat for optimum collection unit efficiency in one mode of one-gravity while maintaining volume utilization considering zero-gravity operation.

2) Crew/Passenger Couches - Access to the upper crew couches was noted as a real problem. There was not enough space to easily obtain entry and also exit especially under emergency conditions. If the couches had been lower this problem would have been alleviated, but then the space envelope of the lower couch would have been violated. This lowering would also produce other problems in the vertical launch mode. If the problem is to be eliminated, either the ceiling height must be revised or the upper couches must be capable of assuming two positions - an upper for vertical operations, a lower for horizontal operations. The upper couches also suffer from poor servicing and convenience conditions too. The same solutions would also relieve these problems. In conjunction with the couches, an associated problem also exists

with the passageway space from forward to aft. If adequate walking space is provided, valuable equipment bay space is lost. If on the other hand such passage is not provided, a safety hazard would then exist. It must be for the NASA to decide rather the nuisance of climbing over crew couches is acceptable for the horizontal position or if passageway space must be allotted. It appears from the testing that for the short duration of horizontal operations, the nuisance could certainly be tolerated if the safety aspects do not override this condition.

3) Flight Deck - Another nuisance factor which became obvious during testing was the ceiling height within the flight deck (64 inches). This condition will require considerable safety features in all equipment and controls placed in the ceiling. This is especially true for ingress/egress from the pilot and co-pilot seats. The center console further reduces the useable head height during such movements and acts as an effective obstruction. The seats should be moveable forward and back to assist in this area . If the tested head height is maintained, the operations in the horizontal mode will probably be noted as a real "headache," literally.

4) Mobility Aids - Ladders may become nuisance or safety hazards under the horizontal mode of operation. For instance, the ladder rungs attached to the "wall" during the on-pad launch mode are located on the "floor" during horizontal orientation. These represent safety hazards and would require special markings to avoid tripping. Ladders up the walk also produce protrusions from the wall which may interfere with passage or mobility. The ladder used between the crew area and the flight deck must be removable if entry is to be made into the payload bay. This would provide a nuisance for horizontal servicing if the ladder must be frequently moved.

5) Walls vs Floors - Walls used as flooring in the vertical position will require special grid or walk areas. Any controls cabinets, equipment, etc. located on these walls must be sufficiently protected to prevent damage from shoes or the full weight of a 95th percentile man. These problems are interchangeable between the two one-gravity modes.

It is noteworthy that there are no nuisance factors or obstructions within the galley area or airlock. No design alerts became evident from the horizontal test either, which gave the test setup for this mode of operation a fairly good rating overall.

Table IV-5 One-Gravity Horizontal Test Evaluation Factors Analysis

	PERFORMANCE							SAFETY				COMFORT
Module/Function	Volume (Size)	Arrangement/ Orientation	Nuisance Factors	Access/User Volume	Access	Servicing	Convenience	Locomotion Ease	Mobility/Restraint Aids	Visibility	Obstructions	Furnishings
Galley	78hx38wx18d											
Meal Preparation	User Volume	Excellent-Conventional Functional & Readily Usable.	None	Readily Usable	E	E	E	Excellent	None	E		Food compart., oven
Equipment Operation	26hx38wx18d ($3.1\ ft^3$) counter vol (Ref. Fig. IV-5)		None	All used	E	E	E	Easy	None required	G	None	Oven, wipes, disp.
Area Cleanup			None	All areas used &	E	G	E	Excellent	None required	E	None	Wipes, disposer
Area Ingress			None	Adequate	E	G	E	Excellent	None-vertical walkin	E	None	Work area
Area Egress			None	Adequate	E	G	E	Excellent	Vertical walking	E	None	Work area
Servicing/Repair			None	Uses area not used for food	E	N/A	G	Excellent	Vertical-squatting	E	None	Service area
Personal Hygiene	Total - 55 x60 x78	Very good, except incline on fecal/ urine collector										
Handwashing/Grooming	Use or Access 31 x30 x78 Equip. 12 x 30 x42 (Ref. Fig. IV-9)		Seat angle should not exceed 30° off horizontal	Shared access volume with commode access volume,	E	E	E	Very easy	None required	E	None	Handwash, mirror, wipes
Defecating/Urination	Equip. 30 x 14 x34 nom.		None	Shared access volume with handwasher	E	G	G	Easy	None required	G	None	Commode/ urinal
Changing Clothes	Use Open. 31 x30 x78		None	Shared access volume with commode and handwasher	E	G	G	Easy	None required	G	None	N/A
Ingress/Egress			None	Used well	E	N/A	G	Easy	None required	G	None	Sliding door
Couch Area	96x120x80 ($492\ ft^3$)											
Ingress/Egress Area	(Ref. Fig. IV-12)	Excellent - Mounted in y-axis	Access to upper couches	Used existing passageway	G rear area P front area	P	P	Easy to rear couches, D to forward couches	Short ladder required	G	None	Requires room at one end
Ingress/Egress Couches		2 rows of 3 each	Upper couches	Requires additional space	G lwr couch P upr couch	P	F	D upper couches E lower couches	None required	G	None	Ladder to reach upper couch
Flight Deck	105 x 130 x 82 ($450\ ft^3$) (Ref. Fig. IV-18)	Very good Directly above crew	None	More than adequate volume for these tasks	G	F	G	Very Easy	Ladder provided adequate mobility aid	G	Head room in seat area	Hatch
Seat Occupancy			Low ceiling height (64) required crewmen to duck when in seat area	N/A	G	G	G	Easy	None required	G	Center console	Seats

Legend: E-Excellent; G-Good; F-Fair; P-Poor; All Dimensions in Inches

Table IV-5 One-Gravity Horizontal Test Evaluation Factors Analysis Cont'd.

	PERFORMANCE							SAFETY				COMFORT
Module/Function	**Volume (Size)**	**Arrangement/ Orientation**	**Nuisance Factors**	**Access/User Volume**	**Access**	**Servic-ing**	**Conven-ience**	**Locomotion Ease**	**Mobility/Restraint Aids**	**Visibi-lity**	**Obstruc-tions**	**Furnishings**
Airlock	60 dia x 84 L ($138\ ft^3$)											
Service/Maintenance	Due to 84 height some support stands may be required	Hatch location enhances servicing; equipment arrangement will determine maintenance philosophy	N/A	N/A	G	G	G	Easy	Not required	G	None	N/A

Legend: E-Excellent; G-Good; F-Fair; P-Poor; All Dimensions in Inches

C. VERTICAL ONE-G TESTING AND EVALUATION

The second series of tests conducted on the Shuttle nose mockup addressed the launch mode or vertical one-gravity condition. The entire mockup was rotated without disassembly or modifications. The data obtained from these tests were used to verify the design concepts of the crew compartment for vertical X-axis 1-g habitability in the prelaunch and launch attitude. Testing was performed to determine accessability for operating and servicing equipment, restraint devices for launch, and ingress/egress to the stations occupied for both normal and emergency conditions.

The data which was obtained may be applied directly to the design of architectural concepts and furnishings of the Shuttle orbiter crew compartment as documented in section VI of this report.

The following items generally summarize the test parameters of the vertical one-gravity test setup:

Task: Evaluation of the passenger compartment area of the Shuttle orbiter crew compartment in the X-axis vertical orientation. Tasks accomplished included ingress to areas, ingress to couches adjustment of couches, use of storage volumes in or adjacent to couches, simulation of tasks performed in couch, and egress from couch and area. Ingress/egress to the flight deck area in normal and emergency conditions.

Test Setup: The Shuttle orbiter crew compartment was located in the VTF Cell P-7 Level 3. It was oriented within the test area so that its X-axis was vertical as shown in Figure IV-19. A portable work platform was set up to provide access to the mockup.

Test Personnel: Test Conductor - Located in the area of the mockup, he monitored the tests in person and read test procedures to test subject(s) during tests. The test

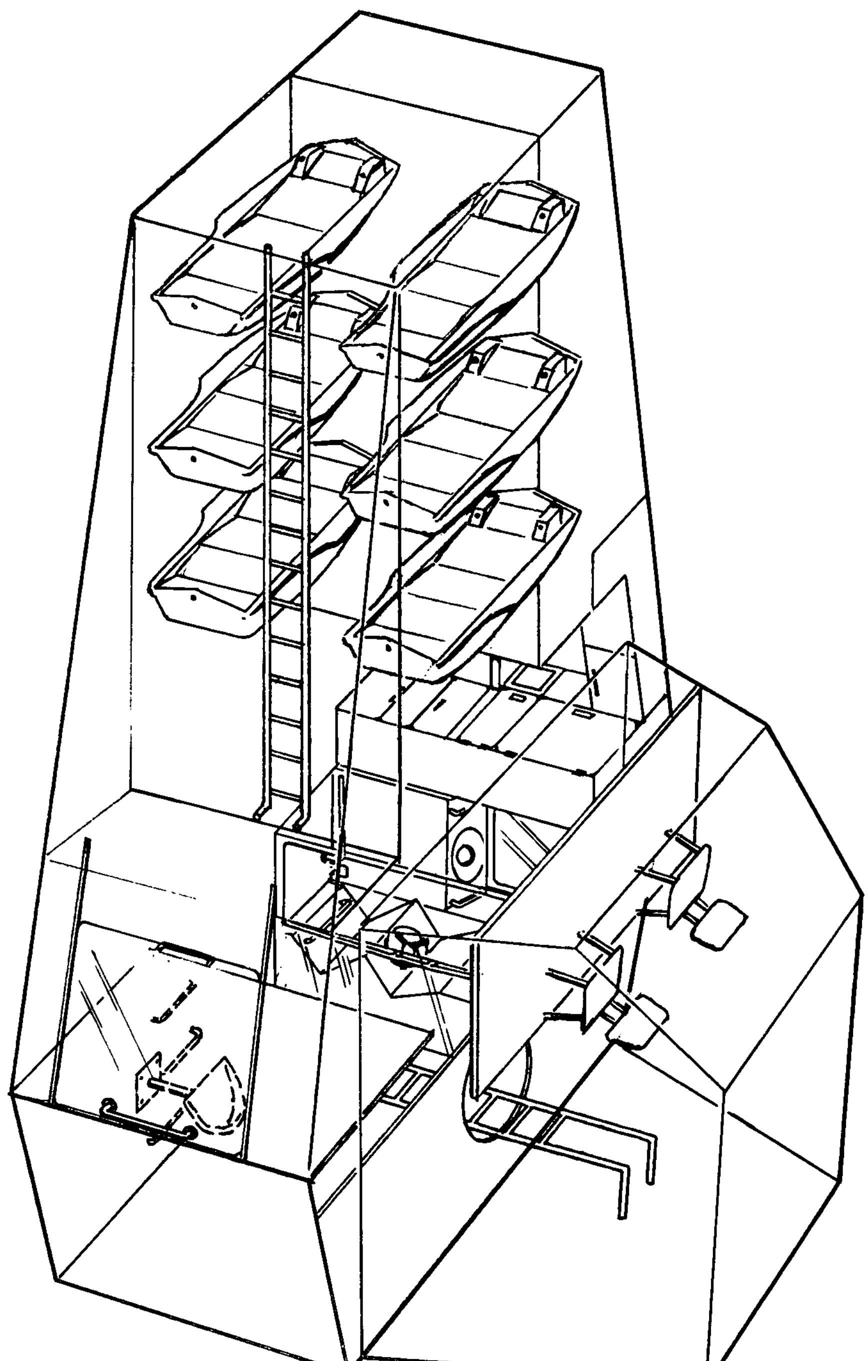


Figure IV-19 Vertical 1-G Test Setup

conductor had overall responsibility of conducting the test.

Observers - Watched the progress of the test from the area adjacent to the mockup and requested changes to test procedures during test operations with concurrence of the test conductor and safety.

Camera Operator - Located adjacent to and in the mockup. He takes still photographs and motion pictures of the test as directed by the test conductor.

Test Subject(s) - Located adjacent to and within the mockup, he/she is responsible to perform the assigned test in accordance with the test procedures and the direction of the test conductor. He/she will be dressed in all purpose garment or (simulated) pressure suit.

Safety - Assess personnel and test setup safety prior to the beginning of tests and shall be notified of any changes from the prescribed tests in this procedure for concurrence.

Date Recording: Movie Camera; still camera; test subjects' and observers' comment sheets.

Items tested: A. Passenger Compartment

1. Area Ingress
2. Couch Ingress and Adjustment
3. Use of Storage Volumes in Couch Area
4. Simulated Reading, Writing, etc. in Couch
5. Egress from Couch and Area

B. Personal Hygiene System

1. Area Ingress
2. Simulation of Urination
3. Simulation of Handwashing and Other Personal Grooming Procedures
4. Simulation of Area Housekeeping Procedures
5. Normal and Emergency Egress from Area

C. Flight Deck

1. Area Ingress and Entry to Flight Crew Position
2. Simulated Launch and Orbital Operations
3. Normal and Emergency Egress from Area

D. Systems Station

1. Area Ingress
2. Simulation of Station Operations
3. Normal and Emergency Egress from Area

E. Transfer Procedures (Shirtsleeve and Suited)

1. Simulation of Transfer to and from all Crew Compartments (Up to three crewmen simultaneously) in Both Normal and Emergency Modes

The Shuttle mockup was studied in the vertical position for possible design or operational problems associated with launch mode conditions. It was quickly apparent that the most significant problems involved access and general mobility. Figures IV-20 through IV-29 illustrate the activities and problems encountered by the various male and female test subjects. Basically, there was no difference between the performance of the male and female test subjects. Each performed their task sequences equally well. The only possible difference noted so far as tasks were those of maximum reach or step length.

Figure IV-20 Female Test Subject Climbing from Aft Bulkhead to Exit Hatch Deck

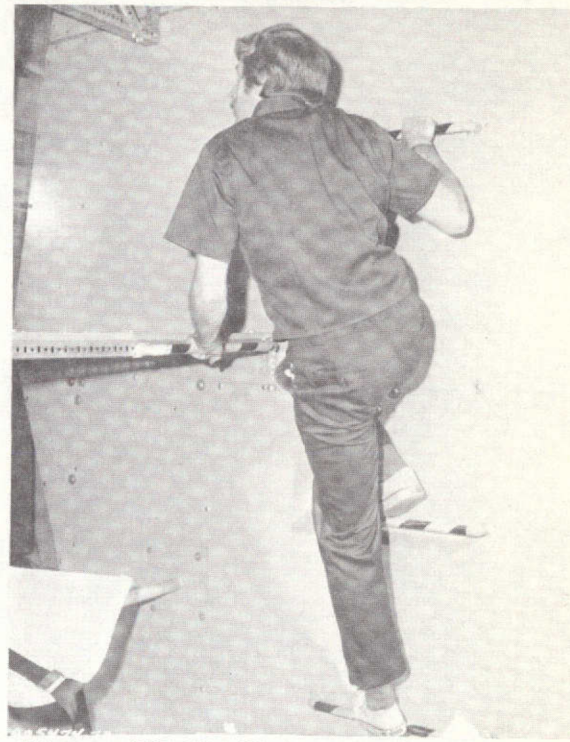


Figure IV-21 Male Test Subject Climbing from Aft Bulkhead to Exit Hatch Deck

Figure IV-22 Female Test Subject Climbing from exit Hatch Deck to Upper Crew Compartment Area

Figure IV-23 Male Test Subject Climbing from Exit Hatch Deck to Upper Crew Compartment Area

Figure IV-24 Entrance into Forward Crew Couch from Ladder

Figure IV-25 Female Test Subject in Lower Crew Couch (From Above)

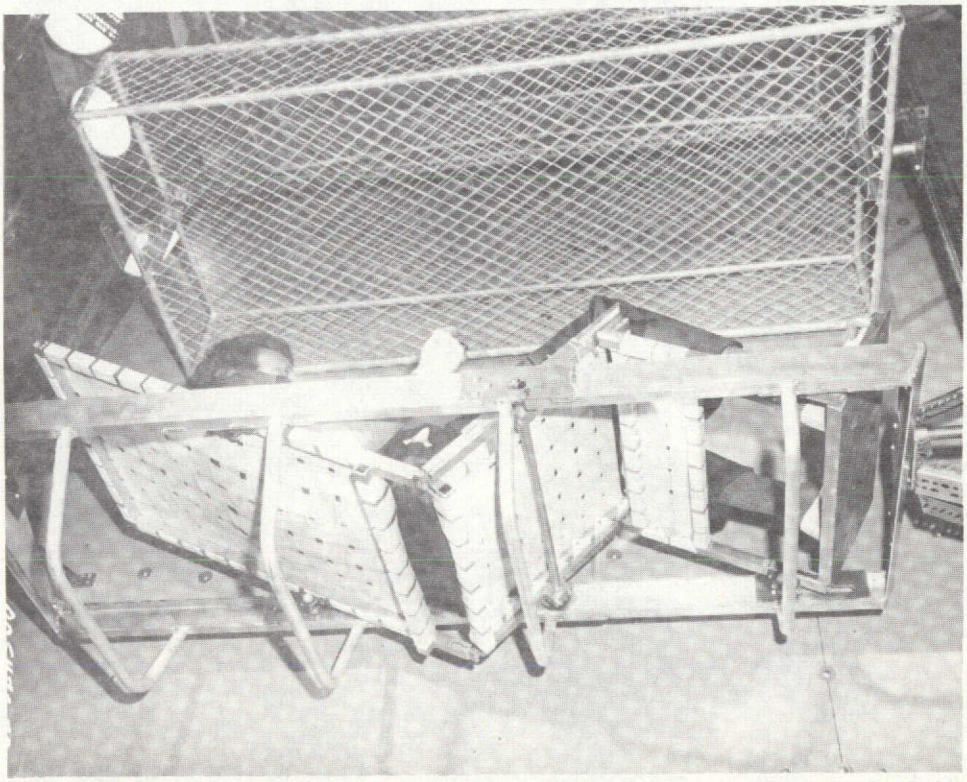


Figure IV-26 Male Test Subject in Lower Crew Couch (from below)

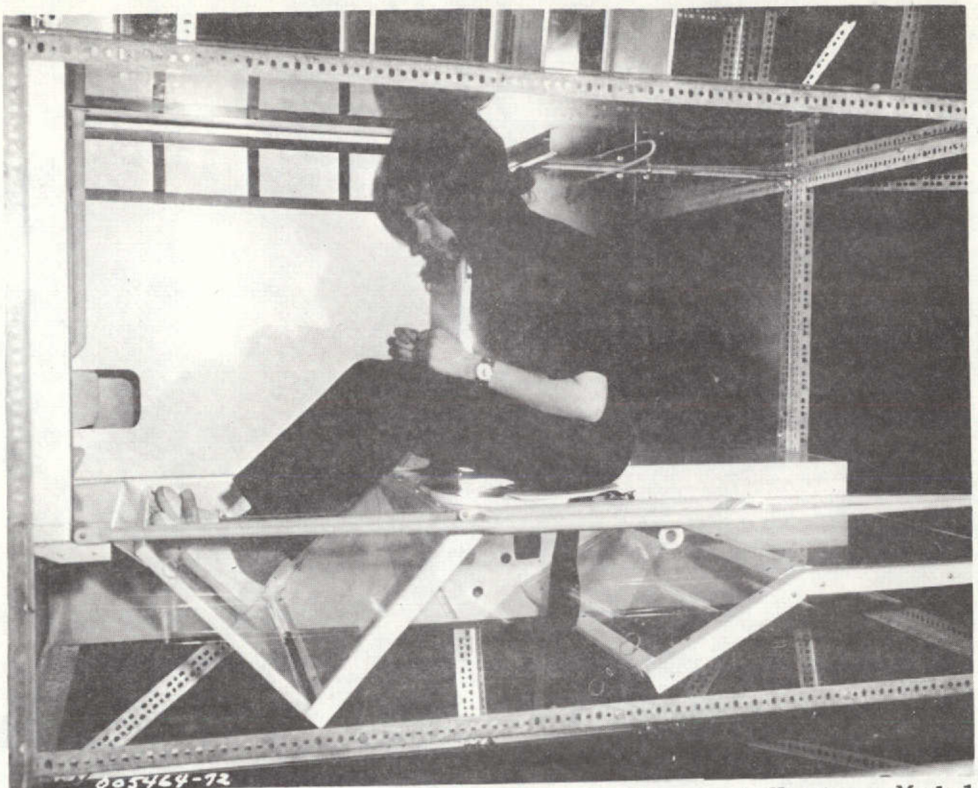


Figure IV-27 Female Test Subject in Personal Hygiene Module

Figure IV-28 Male Test Subject in Personal Hygiene Module

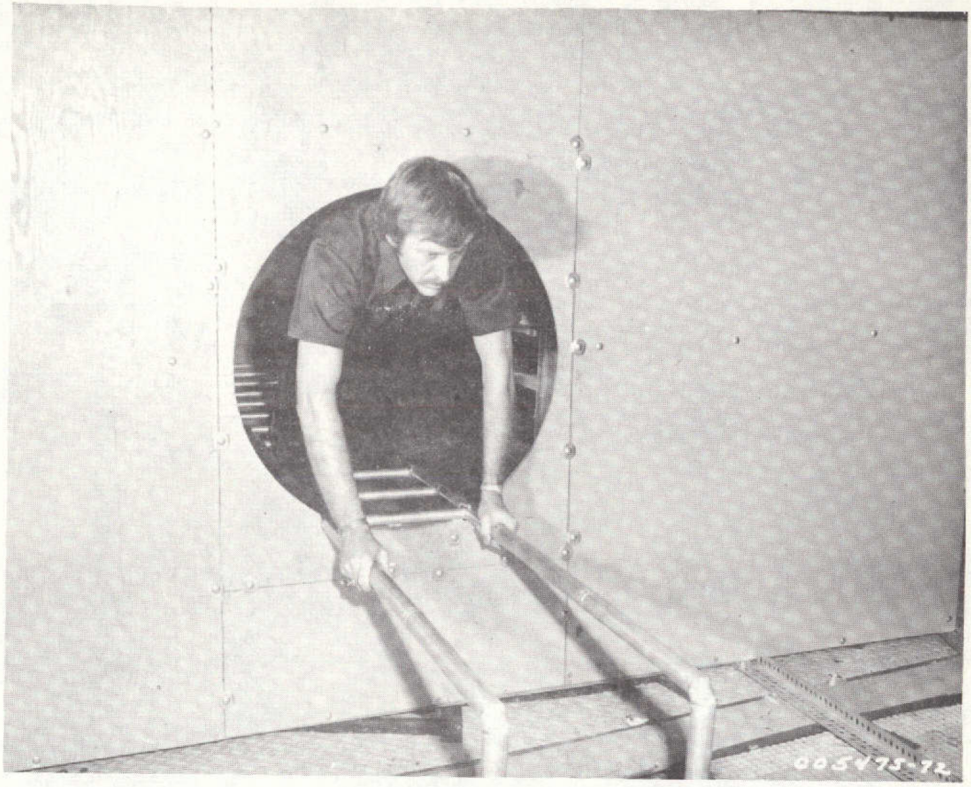


Figure IV-29 Entrance to Flight Deck from Crew Compartment

The safety hazards of climbing, stooping, bending and carrying equipment were greatly magnified as the height was increased from a normal distance to that distance from the forward end to the aft bulkhead. The access to the upper (forward) couches was especially hampered when carrying any type of gear and only using one hand to climb. The use of the personal hygiene unit was greatly reduced (to the fecal/urinal collector only), and the use of the galley was totally voided.

A detailed outline of the test evaluation factors is presented in Table IV-6. These results illustrate rather graphically the large number of problems arising from placing the Shuttle is a vertical position. The large number of poor ratings given to access, servicing and convenience indicate this position to be the worst for prelaunch installation, checkout, repair or replacement. All prelaunch work inside the Shuttle nose which could be accomplished in the horizontal position prior to attachment to the booster would be advantageous in both time and money expenditures.

The most significant problems for the entire Shuttle Nose Testing occurred when the mockup was in the vertical position to simulate the launch mode. These problems included: the inability to carry packages up the ladder to the top couches; the lack of sufficient ladders and handholds; the use of walls or control consoles as surfaces for walking; the inability to utilize all personal hygiene facilities; the total inability to use the galley; extremely difficult access to equipment bays; and the marginal access for ingress/egress to the couches for normal usage and the inadequacy for emergency situations. The following paragraphs address each problem and attempt to define the most suitable solutions:

1. Ladders and Packages

The test results proved that the climb up to the upper couches was greatly hampered when attempting to carry packages. This held true for both male and female test subjects. The problem stems from the limitation of one hand to climb with when the other hand is holding an object. This is therefore a real safety hazard as well as a nuisance. It is obvious too that if a Shuttle passenger enters in a suited condition, he will have difficulty in the same manner. One solution to this problem may be the addition of transfer devices, but this would add weight and take valuable space. Another answer which would have the least impact on the Shuttle, would be to provide

Table IV-6 One Gravity Vertical Test Evaluation Factors Analysis

	PERFORMANCE							SAFETY				COMFORT
Module/Function	(Volume) Size	Arrangement/ Orientation	Nuisance Factors	Access/User Volume	Access	Servic-ing	Conveni-ence	Locomotion Ease	Mobility/Restraint Aids	Visibi-lity	Obstruc-tions	Furnishings
Galley	78hx38wx18d											
Meal Preparation	Access volume 26hx38wx18d (3.1 ft^3) counter vol	Not usable	N/A	Not usable	P	P	P	Very difficult	N/A	N/A		N/A
Equipment Operation	(Ref. Fig. IV-5)	Not usable	N/A	N/A	P	P	P	N/A	N/A	N/A	N/A	N/A
Area Cleanup		Not usable	Not usable	Not usable	P	P	P	N/A		N/A	N/A	N/A
Area Ingress		90° to Normal Usage	Not usable	N/A	P	N/A	P	N/A	N/A	N/A	N/A	N/A
Area Egress		90° to Normal Usage	N/A	N/A	P	N/A	P	N/A	N/A	N/A	N/A	N/A
Servicing/Repair		90° to Normal Usage	N/A	N/A	P	N/A	P	N/A	N/A	N/A	N/A	N/A
Personal Hygiene	Total Vol. 55 x60 x78 Access Vol. 31 x30 x78 (Ref. Figs. IV-27 and 28)											
Handwashing/Grooming	Equip. 12 x 30 x42	90° to normal usage	Not usable	Not usable	P	P	Very poor	Difficult	None required	P	Wall	Handwash, mirror, wipes
Defecating/Urination	Equip. 30 x 14 x34 nom.	90° to normal usage	Head interference with wall	Upper area not used	P	P	P	Difficult	None required	P	Wall	Commode/urinal
Changing Clothes	Use 31 x 30 x78	90° to normal usage	Must sit on commode	Very poor	P	P	P	Difficult	None required	P	Wall	N/A
Ingress/Egress	N/A	90° to normal usage	Door could not be operated	Some volume wasted	P	N/A	P	Difficult	None required	G	Wall	Sliding door
Couch Area	96x120x80 (482 ft^3)											
Ingress/Egress Area	(Ref. Figs. IV-25 and 26)	Mounted in y-axis	High steps	Used existing passageway	F	P	P	Difficult	Long ladder required	G	Lower ladder support	Center aisle is adequate
Ingress/Egress Couches		2 rows of 3 each	Getting into couches	Aisle used for both rows	P	P	P	Difficult	Platform required	G	None	Ladder to reach all couches

Legend: E-Excellent; G-Good; F-Fair; P-Poor; All Dimensions in Inches

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table IV-6 One Gravity Vertical Test Evaluation Factors Analysis Cont'd.

	PERFORMANCE							SAFETY				COMFORT
Module/Function	Volume (Size)	Arrangement/ Orientation	Nuisance Factors	Access/User Volume	Access	Servic-ing	Conveni-ence	Locomotion Ease	Mobility/Restraint Aids	Visibi-lity	Obstruc-tions	Furnishings
Flight Deck	105 x 130 x 82 (450 ft^3) (Ref. Fig. IV-29)											
Ingress/Egress		Horizontal mode walls are now the floor; ladder is not easy to crawl on	Crawling through hatch on ladder, gaining access to seats	Configuration lends itself to good volume utilization with adequate head room	P	P	P	Fair	Addition handholds & platforms or stepping areas required	G		
Seat Occupancy		90° to normal Usage (Earth Gravity)	Seat was not designed for this type usage	N/A	Very Poor	P	P	Poor	Seat used was not designed for this orientation	G	Center console	
Airlock	60 dia x 84 L (138 ft^3)											
Service/Maintenance		Hatch location enhances servicing; equipment arrangement will determine maintenance philosophy	N/A	N/A	G	G	G	Easy	Not required	G	None	

Legend: E-Excellent; G-Good; F-Fair; P-Poor; All Dimensions in Inches

special GSE platforms capable of being removed by launch technicians after the passengers are fully situated and prior to closing the hatch. Any attempt to provide stairs in place of the ladder would only prove completely unsatisfactory from the spacecraft systems requirements.

2. Ladders and Handholds

A brief review of Table IV-6 in regard to access, servicing, locomotion ease and convenience will fully illustrate the inadequacy of ladders and handholds throughout the Shuttle Nose when in the vertical position. This condition is created by the increase in height for access above the aft bulkhead. The most logical solution to this inadequacy is to provide additional ladders and handholds in the form of GSE for complete vertical mode servicing. This solution is a valid one in that after all equipment has been checked out, there is no need for extensive equipment access. The crew compartment would only need provision for access to the various launch seats or couches. Also, after launch, any added ladders or handholds would become superfluous in zero gravity or the horizontal flight mode.

3. Walls vs Floors

The multiple use of wall or floor surfaces must be considered, especially where such surfaces contain control consoles or equipment bays. These surfaces should provide safe walking paths and all controls or protrusions must be well protected. This, of course, must be accounted for in zero gravity design also since all surfaces may be contacted by a crewman. However, this is more critical in the one gravity operational modes because of the increased loads. This is a structural problem which may be easily solved by proper surface design, but the designers must be aware of the conditions.

4. Hygiene Unit

The design of the hygiene facilities and the operational characteristics of the equipment did not permit the unit to be used without some major changes in the vertical mode. Using the configuration tested, if the seat was rotated to a comfortable position (horizontal), there would be interference with the user's head. The other equipment is totally unusable since it is 90° out of plane for normal.

operation. There are only two possible solutions to these conditions - eliminate the requirement to use the hygiene unit while in the vertical position, or make the necessary operable equipment rotate and provide sufficient head and leg room for proper functioning. Access to the hygiene unit in the vertical mode is also an associated problem since it is 90° out of place. This problem was minor though and could be alleviated by a proper door design and entry mobility aids.

5. Galley

The galley was simply not designed for vertical on pad usage. Since no crew usage is anticipated in this mode of operation, it represents no real problem to them. However, it does strongly suggest that all galley servicing be concluded when the Shuttle is in the horizontal position prior to mating with the booster.

6. Equipment Bay Access

This problem is directly related to items 1. and 2. The solutions are also the same - provide as much servicing to the equipment bay prior to placing the Shuttle in the vertical position, as possible and using GSE to gain access while on the pad.

7. Couch Access

The problem with access to the upper (forward) couches is more than just the ladders. The test subjects had to reach over to the couch and swing or crawl over to position themselves in the couch. This is quite hazardous from heights up to 16 feet. It appeared that additional handholds would have helped, but a relocation of the ladders would have helped even more. One possible solution would have been to have had a ladder capable of being located in an option location for the vertical position and relocated after orbit insertion. Locating the ladder in the center of the couch rather than the end position would aid considerably in gaining access. The ladder should be placed against the side of the couch. Another possible solution would be to have access platforms at each couch level.

After the completion of the testing and analysis of the vertical one gravity conditions and associated problems, five design alerts were generated and submitted to the NASA. These design alerts defined specific areas of concern which should be understood or taken into account for the final Shuttle design. A summary of these design alerts follows:

1. Title: Carrying Package up Ladder in Vertical One-G   Number: 4

   Design Problem:

   If the crew couches are installed in the front of the Shuttle crew compartment, an access ladder will be required to gain access when the crew compartment is in a vertical position such as on the launch pad. A crewman ascending and decending the ladder must utilize both hands and therefore, cannot carry any package. This requires that necessary packages, such a clothing module or clerical module, be installed prior to vertical positioning or that special handling devices be utilized to handle packages.

2. Title: Access to Flight Deck in Vertical One-G   Number: 5

   Design Problem:

   When the Shuttle Orbiter is in a vertical position (on pad), access to the flight deck from the crew compartment/lower deck will require special platforms and ladders to prevent ingressing crewmen from stepping or standing on control panels/equipment. Crewmen will crawl through the hatch and then must stand vertically to obtain access to the pilot/copilot seats. However, if flight controls/electronic packages are installed between the seats, special restraint/mobility aids must be provided to gain access to the seats.

3. Title: Access Ladders and Platforms   Number: 6

   Design Problem:

   When designing the Shuttle Orbiter lower compartment, consideration must be given to the placement of partitions and mobility/restraint aids. When the Orbiter is placed vertically on the launch pad, floors become partitions and partitions become floors. Mobility/restraint aids must be carefully located to serve both orientations of the vehicle without interference when in any particular orientation. Particular attention must be given to placement of partitions to be utilized as maintenance platforms for the equipment bays, ingress/egress to couches, servicing of personal hygiene and galley modules, and entrance into the Orbiter lower deck. Foot rails must be placed to assist in egress/ingress to the platforms.

4. Title: Personal Hygiene Door Counterbalance   Number: 10

Design Problem:

When a door or hatch must be operable in two orientations, 90 degrees apart, in the one gravity mode, the door must be designed to allow a crewman to operate the door in a safe and efficient manner.

During one gravity testing the Shuttle Crew Compartment, the personal hygiene door was almost impossible to close when the crew compartment was in the vertical (on-pad simulation) position.

5. Title: Safety Locks   Number: 11

Design Problem:

Compartments or drawers that contain stored items such as food, clothing, equipment, etc. will require a safety device to preclude the possibility of high "G" loads overcoming the normal locking mechanism and allowing the stored items to be free within the crew/passenger compartment.

D. NEUTRAL BUOYANCY TESTING AND EVALUATION

The last major series of tests considered the zero gravity flight mode. Neutral buoyancy testing was utilized to simulate the zero gravity mode of operation. Since zero gravity deletes the reference for either vertical or horizontal, the Shuttle nose was placed in the neutral buoyancy tank in the horizontal plane to provide better photographic coverage of the activities within the compartments and to allow the test subjects to maintain a more neutrally buoyant condition. The tests that were conducted in the simulated zero-gravity environment are outlined in subsection 3 of the Test Procedures and Plans (MCR-72-246). Of specific interest were the personal hygiene, galley, and work stations volume and associated equipment for functional use by the crewmen. Other items of interest included traffic patterns in the various modes of operation, servicing access, restraint devices, and mobility aids.

Male test subjects for the neutral buoyancy tests met the less than 50 percentile through the 95 percentile man. A female test subject, over 50 percentile in size, demonstrated the adaptability of the design concepts for women. Three male subjects performed the tasks outlined in the test procedures for the crew compartment, galley, personal hygiene, etc.

The female test subject demonstrated the acceptability of the equipment in the crew compartment. Only male subjects were used to test the flight deck area. Simulated pressure-suited test subjects were used to test for emergency conditions. This involved movement throughout the crew compartment, to the flight deck area, through the airlock system, and through all hatches. Traffic patterns through each hatch and passageway were tested for multiple crewman usage in the shirtsleeve environment. For pressure-suited crewmen, only the airlock was tested for multiple occupancy.

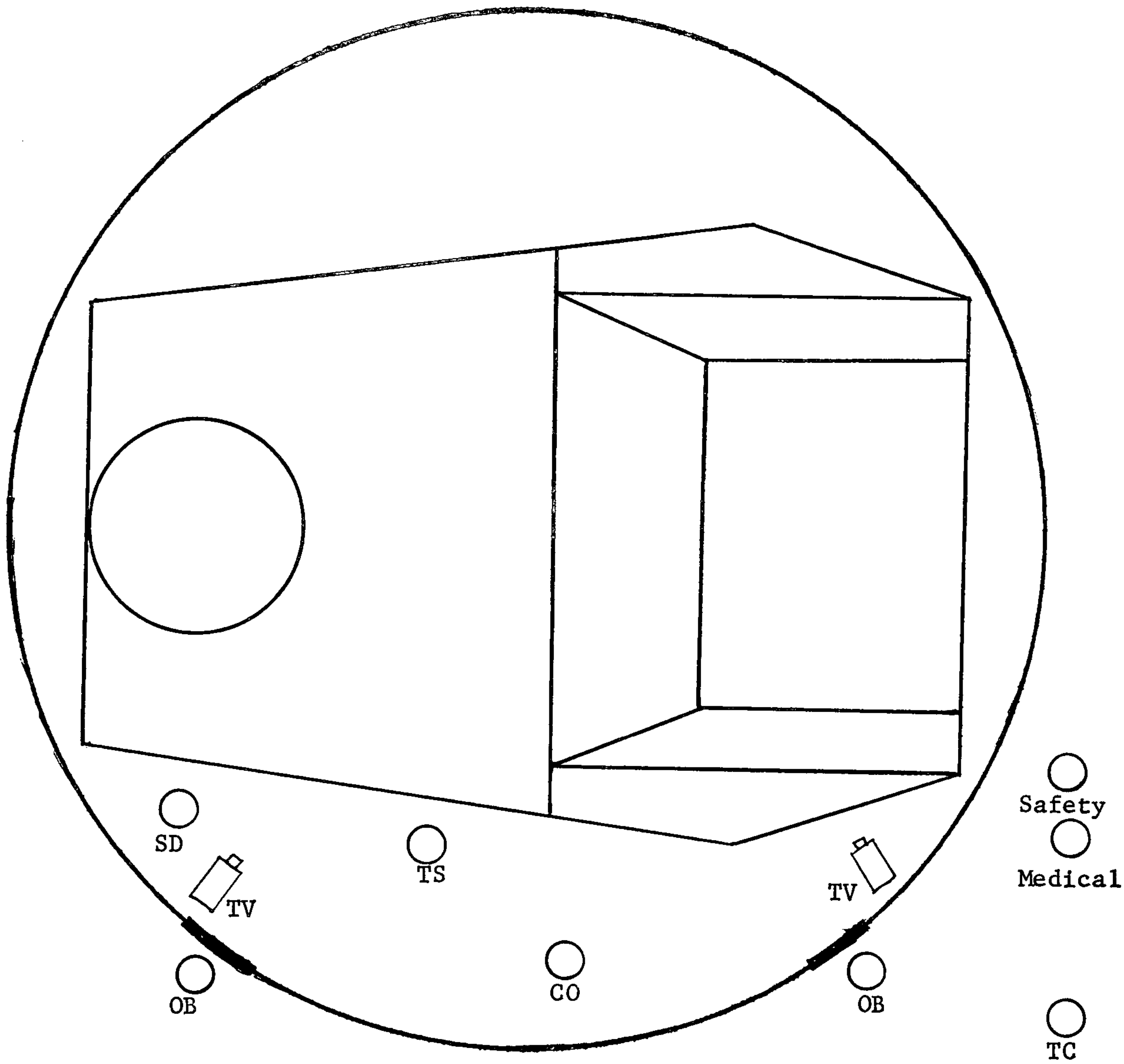
Special attention was given to problem areas encountered during the dry one-gravity test and problems that were peculiar to a zero-gravity condition. Areas that were emphasized included restraint devices, mobility aids incorporated into furnishings, access to equipment, orientation, space utilization, visual space, point-to-point transfer, safety, and nuisance factors.

A large inventory of diving equipment was utilized to meet the simulation requirements of the contract. The test subjects' dress and the data recording were the same as described in the dry testing, with the addition of videotape from a fixed and movable TV camera located in the neutral buoyancy tank. The videotape was analyzed after testing by stopping the tape at specific points and tracing the scene on paper. Voice communications between the test conductor and the test subject were recorded on the videotape during some test sequences. This aided in the evaluation as the test subjects' comments were recorded during the test and thereby eliminated the possibility of missing some important data by post test reviews. The data obtained from these tests were used to verify the design concepts of the crew compartment for zero gravity habitability in the orbital flight mode.

The data which was obtained from neutral buoyancy testing may be applied to the design of architectural concepts and furnishings of the Shuttle orbiter crew compartment for the zero-gravity conditions. These applications are documented in section VI of this report.

The following items generally summarize the test parameters of the zero gravity neutral buoyance simulation test setup:

Task:	Evaluation of the passenger compartment area, flight deck and airlock of the Shuttle orbiter crew compartment in the simulated zero gravity of neutral buoyancy. Tasks accomplished include ingress and evaluation of passenger compartment, galley, personal hygiene system, flight deck systems station, avionics/equipment, airlock, and transfer procedures.
Test Setup:	The Shuttle orbiter crew compartment was located in the neutral buoyancy tank with its X-axis horizontal as shown in Figure IV-30.
Test Personnel:	Test Conductor - Located at console, he monitored the test on TV and reads test procedure to test subject(s) during tests over underwater PA system. The test conductor had overall respon-



Legend:

TS - Test Subject
SD - Safety Diver
CO - Camera Operator
OB - Observer
TC - Test Conductor
TV - Television Camera

Figure IV-30 Shuttle Orbiter Crew Compartment Neutral Buoyancy Setup sibility of conducting the test.

TV Operator - Located at console, he monitored test TV and operated the TV system to obtain optimum coverage. He responded to the directions of the test conductor.

Medical Doctor - Assessed personnel physical condition and stood by during testing with HLR 50/90 and emergency medical gear in case of medical emergency.

Observers - Watched progress of testing from surface or through viewing ports. Requested changes to test procedures during test operations with concurrence of test conductor and safety.

Camera Operator - Located underwater, he took movies and still photographs of the test as directed by the test conductor.

Safety Diver - Located underwater in SCUBA gear, he observed test subject constantly. He was primarily responsible for the physical safety of the test subject(s). He had the authority to stop the test, if in his judgment, the test subject(s) were in any danger, i.e., unsafe test setup, fatigue, etc.

Test Subject(s) - Located underwater, he was responsible to perform the assigned test in accordance with the test procedures and the direction of the test conductor. He utilized HOOKAH and/or chest bottle during operations to simulate a shirtsleeve environment.

Safety - Assessed personnel and test setup safety prior to the beginning of tests and has notified of any changes from the prescribed tests in procedure for concurrence.

Hyperbaric Chamber Operator - He was a qualified, certified person capable of performing in all hyperbaric chamber functional operations in accordance with the requirements and procedures of NB 140 and stand by during all testing.

Date Recording: Movie camera; still camera; TV monitoring tape; test subjects and observers' comment sheets.

Items tested: A. Passenger Compartment

1. Area Ingress
2. Couch Ingress and Adjustment
3. Use of Storage Volumes in Couch Area
4. Simulation of Sleeping
5. Simulation of Reading, Writing, etc. in Couch
6. Egress from Couch and Area
7. Removal of Clothing from Area
8. Donning of Clothing Previously Placed in Stowage and Egress from Area
9. Entrance to Area Carrying Food Trays and Transfer to Couch
10. Couch Ingress with Food Tray and Simulation of Eating
11. Egress from Couch with Food Tray and Departure from Area
12. Entrance to Housekeeping Stowage Area
13. Removal of Housekeeping Equipment from Stowage and Simulation of Area Cleanup
14. Replacement of Housekeeping Equipment and Area Egress

B. Galley

1. Area Ingress and Simulation of Meal Preparation
2. Simulation of Galley Equipment Operation
3. Simulation of Area Cleanup and Egress (Normal and Emergency Procedures)
4. Area Ingress to Tray Pickup Point
5. Pickup of Complete Meal in Food Tray
6. Transfer with Tray to Eating Area

C. Personal Hygiene System

1. Area Ingress
2. Removal and Temporary Stowage of Clothing
3. Simulation of Taking Sponge Bath
4. Removal from Temporary Stowage and Donning of Clothing
5. Simulation of Urination and Defecation
6. Simulation of Handwashing and Other Personal Grooming Procedures
7. Simulation of Area Housekeeping Procedures
8. Normal and Emergency Egress from Area

D. Systems Station

1. Area Ingress
2. Simulation of Station Operations
3. Normal and Emergency Egress from Area

E. Avionics/Equipment

1. Area Ingress (Avionics/Equipment Located in Several Different Areas)
2. Simulation of Use and Maintenance of Avionics/Equipment
3. Normal and Emergency Egress from Area

F. Transfer Procedures (Shirtsleeve and Suited)

1. Simulation of Transfer to and from all Crew Compartments (Up to Three Crewmen Simultaneously) in Both Normal and Emergency Modes

G. Flight Deck

1. Area Ingress and Entry to Flight Crew Positions
2. Simulated Launch and Orbital Operations
3. Normal and Emergency Egress from Area
4. Area Ingress and Transfer to Remote Manipulator Station (RMS) Operator Position
5. Simulation of RMS Procedures
6. Normal and Emergency Egress from Area

H. Airlock

1. Area Ingress from Crew Compartment (2 Men Plus Equipment)
2. Simulated Pressure Suit Donning and Depressurization Procedure
3. Egress from Airlock Through Exterior Hatch
4. Ingress to Airlock from Exterior Hatch
5. Simulation of Pressurization Procedure and Pressure Suit Doffing
6. Egress from Airlock into Crew Compartment (Normal and Emergency)
7. Mobility/restraint Aids - Type and Location
8. Control Panels

During the neutral buoyancy testing of the Shuttle crew/passenger compartment and the associated modules, the observers and data recording personnel paid particular attention to the following areas of the man-equipment interface:

1. Passenger Compartment

   a. The body, hands, and legs position and orientation as test subject approaches couch.

   b. The method used to enter couch, especially the hands, feet, and mobility aids used.

   c. The technique used to fasten restraint system.

   d. What the hands and feet do, as test subject performed various tasks while restrained in couch, plus any interference with other couches or equipment.

   e. The method used to exit couch and transfer to the side of the couch to remove items from storage areas. The restraints, mobility aids, and body orientation used throughout procedure.

   f. The body, leg, and arm position during sleep portion of test.

   g. The technique used to enter and exit couch while carrying objects such as food tray. Especially what mobility aids and restraints were used.

   h. What mobility aids and restraints are utilized during housekeeping tasks body position and orientation.

   i. The body orientation, mobility aids, restraint devices, hand and feet usage and any equipment interferences during translation to the various areas in the compartment such as from couch area to galley, personal hygiene, airlock, or flight deck hatch. Especially the location and orientation of mobility/restraint devices and how the test subject used them.

   j. In general, the position of the body, hands, and feet when tasks required straight push-pull force and torque applications.

2. Galley

a. The test subject orientation as they approached the galley.

b. The mobility aids used to enter galley and the technique for stabilizing himself to free both hands to do galley tasks.

c. How the test subject opened the various storage areas and retrieved food cans. Especially the hands, feet, and body position and the aids used.

d. How the test subject obtained food tray from stowed position and inserted it in the preparation area.

e. How the test subject opened the cans and disposed of the lid, which hand held the can, and how the lid was put into the disposer.

f. The body and feet position when using either waist restraint or toe rail and when using both toe rail and waist restraint.

g. The body and feet position as test subject obtained a wipe and wiped all front surfaces in the preparation area and food storage areas then disposed of wipe. Especially the mobility aids and restraint devices.

h. The test subject leaving galley area carrying food tray in one hand. Which hand used and what he did with the other hand and his feet. Any interference with other equipment.

i. The position and orientation of body as test subject approached galley carrying tray in one hand. The hands and feet movements used to determine mobility aid and restraint device usage and location.

j. Any changes of hands with food tray to provide more efficient translation.

k. Reach and accessibility to all storage areas, cleanup supplies, controls, etc.

3. <u>Personal Hygiene System</u>

a. Body position and orientation as the test subject approached the personal hygiene unit from the couch area.

b. What mobility aids/restraint devices were used and their location during translation and opening the door to the hygiene unit, (walls and furniture items were considered mobility aids/restraint devices).

c. The position of body and hands as the test subject opened the door. Especially if door handle provided adequate restraint and grasping area without groping.

d. The position of body and technique employed as test subject entered hygiene unit and closed door.

e. The body orientation and restraints used for clothing removal.

f. The accessibility to temporary clothing storage without moving from restraints used for doffing clothes.

g. During the simulation of taking a sponge bath. Any interferences with the body or anything that prohibits reaching all parts of the body. Also what restraints were used, such as walls or special handholds/toeholds.

h. The technique used to don clothing with special emphasis on interference and restraints used.

i. The body position and orientation as test subjects (male and female) prepared for urinating. Which restraints were used and location with the hands and feet. Also, the leg movement and if the legs were used to help stabilize the body.

j. The controls accessible and readable, with the test subject (male) in the urination position. The restraints used for complete procedure.

k. The controls and wipes accessible and what restraints were used, i.e., lap belt, handholds, feet with the test subject (female) in the urination position during the complete procedure.

l. The same items listed under i, j, and k above for the defecation procedure.

m. On completion of urination and defecation procedure, the body position and orientation, mobility aids/restraint devices used, and interference while readjusting clothing and exiting the hygiene unit.

n. During handwashing and other personal grooming tasks, the body position, restraints used, accessibility to foot control, convenience of wipe dispenser, location of waste disposer, and interference conditions. Also, the temporary storage of items such as the personal toiletry kit, etc.

o. The accessibility to all surfaces during cleanup with hand wipe. The orientation of body during this task.

4. <u>System Station</u>

a. The mobility aids/restraint devices used and their location as the test subjects translated to the system station. Whether feet and/or hands were used to propel the test subject.

b. The technique used by the test subject to enter the restraint device.

c. What the hands and feet used for mobility aids/restraint devices.

d. The technique used by the test subject to exit the restraint device and area.

5. <u>Avionics/Equipment</u>

a. The translation techniques employed by the test subjects as they went to the various avionics/equipment areas.

b. The mobility aids/restraint devices used by both the feet and hands.

c. The location and orientation of the mobility aids/restraint devices.

d. Any interference with the body and other equipment and the ease of accessibility.

6. Transfer Procedures

a. The orientation of the test subjects as they translated from area to area.

b. The methods the test subjects used to propel themselves about the crew compartment.

c. What techniques were used to change directions such as maneuvering through the hatches, around the couches, in and out of the galley and personal hygiene unit, etc.

7. Flight Deck

a. Any interferences as three test subjects entered and assumed positions of pilot, co-pilot, and navigator.

b. The mobility aids/restraint devices used during ingress and egress to specific locations for both normal and emergency conditions.

c. The accessibility to equipment associated with a flight deck.

8. Airlock

a. The mobility aids/restraint devices used by test subjects as they approached and opened the hatch from the crew compartment.

b. As two crewmen entered airlock and closed the hatch, what mobility aids/restraint devices were used and any interferences with equipment.

c. As test subjects donned the pressure suit, what restraints used, position in airlock, and technique employed.

d. If second crewman in airlock was able to help the other crewman don pressure suit. The position, restraints used, and technique used by second crewman.

e. If one suited crewman was able to help second get into a pressure suit.

f. The position of the two test subjects as they opened exterior (top) hatch.

g. The location and orientation of the airlock pressure control panel.

h. Any interferences and mobility aids used during egress from the airlock to the exterior.

i. As two test subjects ingress through the top hatch into the airlock, the body orientation (i.e., feet or head first) and what mobility aids were used. The location and orientation of all mobility/restraint devices utilized.

j. The position of the two test subjects as they closed the exterior (top) hatch and simulated pressurization of the airlock.

k. The restraints used as test subjects doffed pressure suits and prepared to egress from the airlock into the crew compartment.

l. The location and orientation of all mobility and restraint devices used during the egress operation.

Figures IV-31 through IV-56 illustrate the neutral buoyance testing elements and test subject tasks. Figures IV-31 through IV-35 show the two design development components tested prior to Shuttle Mockup installation into the tank and the beginning of actual crew compartment or flight deck testing. These items were the foot restraint, which has proved to be a universal restraint device suitable for most applications where low to

Figure IV-31 Toe Bar Checkout With Zero "g" Seat

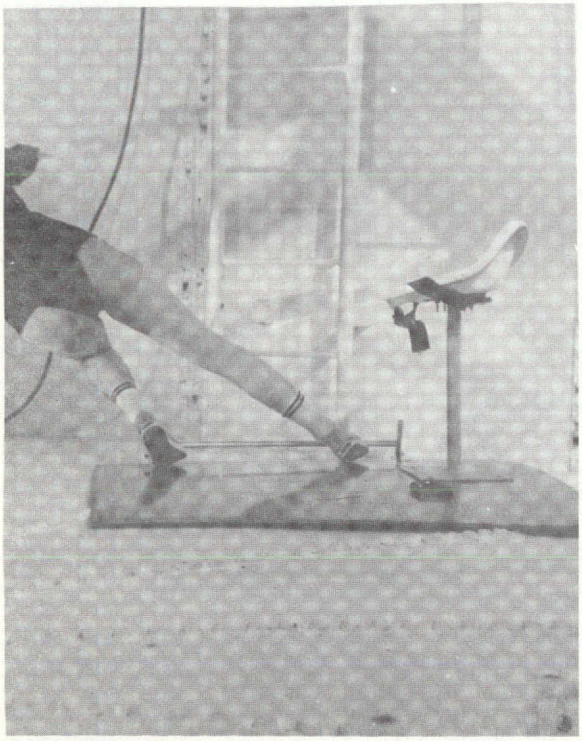


Figure IV-32 Toe Bar Checkout - Lateral Movement

Figure IV-33 Toe Bar Checkout Forward Restraint

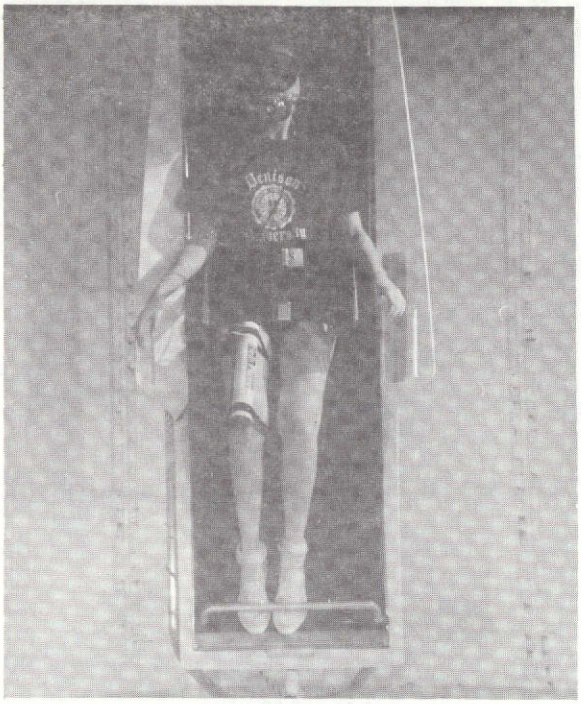


Figure IV-34 Female Test Subject Relaxed in Crew Couch

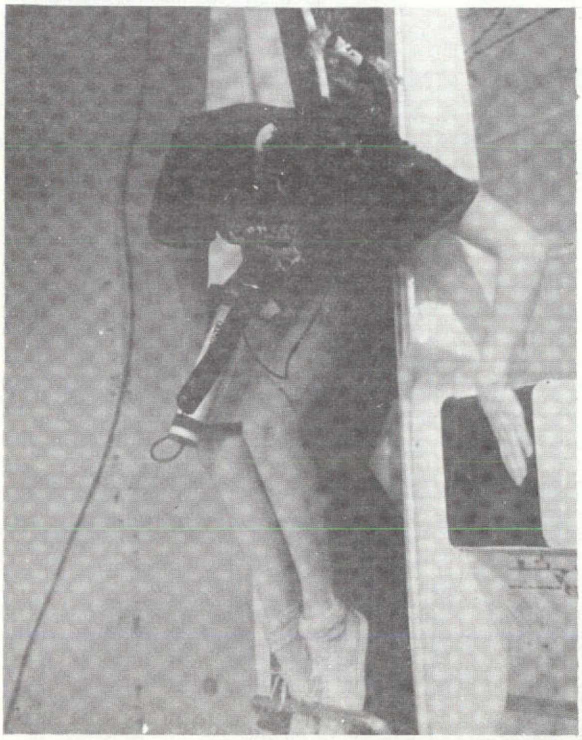


Figure IV-35 Female Test Subject in Crew Couch-Drawer Access

Figure IV-36 Access Tests in Galley During Food Preparation

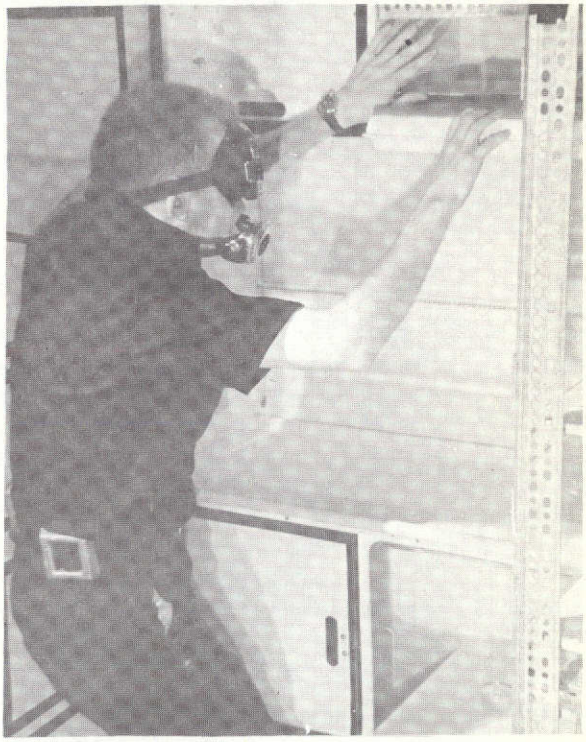


Figure IV-37 Galley, Reaching for Food Tray

Figure IV-38 Galley, Restraining Food Tray

Figure IV-39 Galley, Use of Waist Restraints

Figure IV-40 Egress From Galley With Food Tray

Figure IV-41 Personal Hygiene Unit, Hand Washing

Figure IV-42 Male Test Subject After Defecation, Wipe Sequence

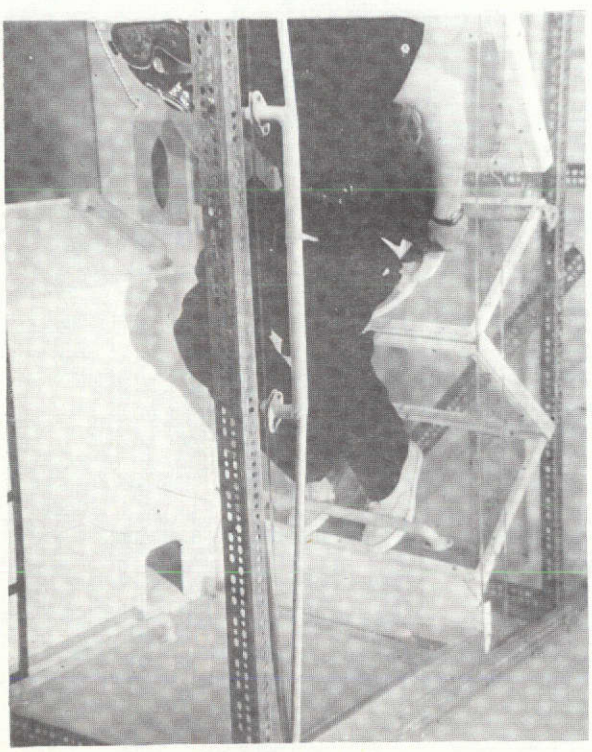


Figure IV-43 Male Test Subject During Defecation - Side View

Figure IV-44 Male Test Subject During Defecation - Front View

Figure IV-45 95th Percentile Male Test Subject During Urination

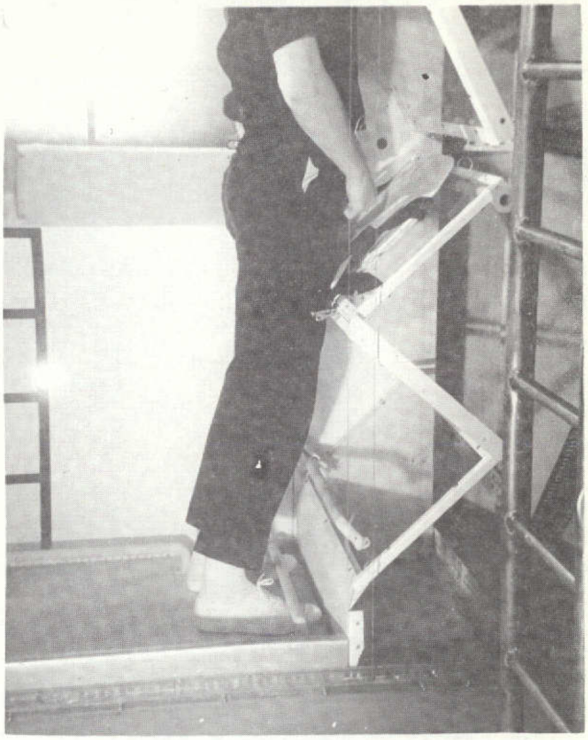


Figure IV-46 50th Percentile Male Test Subject During Urination

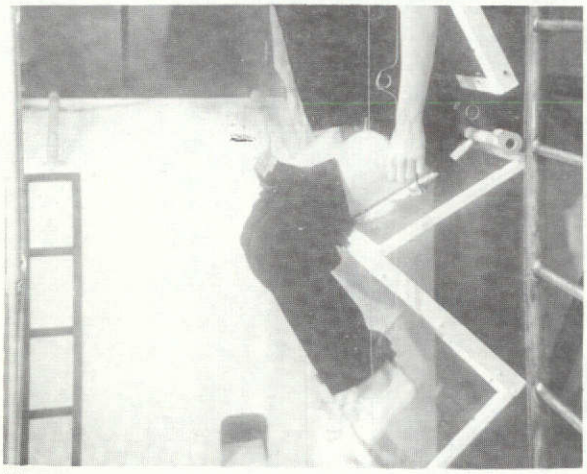


Figure IV-47 Female Test Subject During Defecation/Urination - Side View

Figure IV-48 Female Test Subject During Defecation/Urination Front View

C2

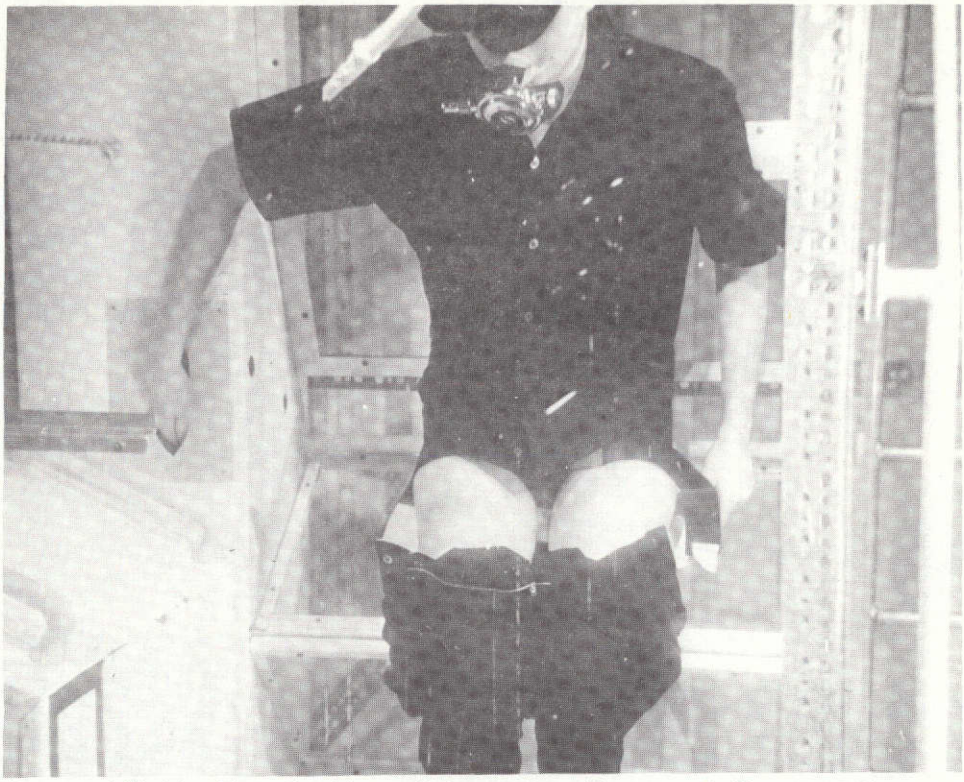


Figure IV-49 Female Test Subject in Personal Hygiene Unit Wipe Sequence

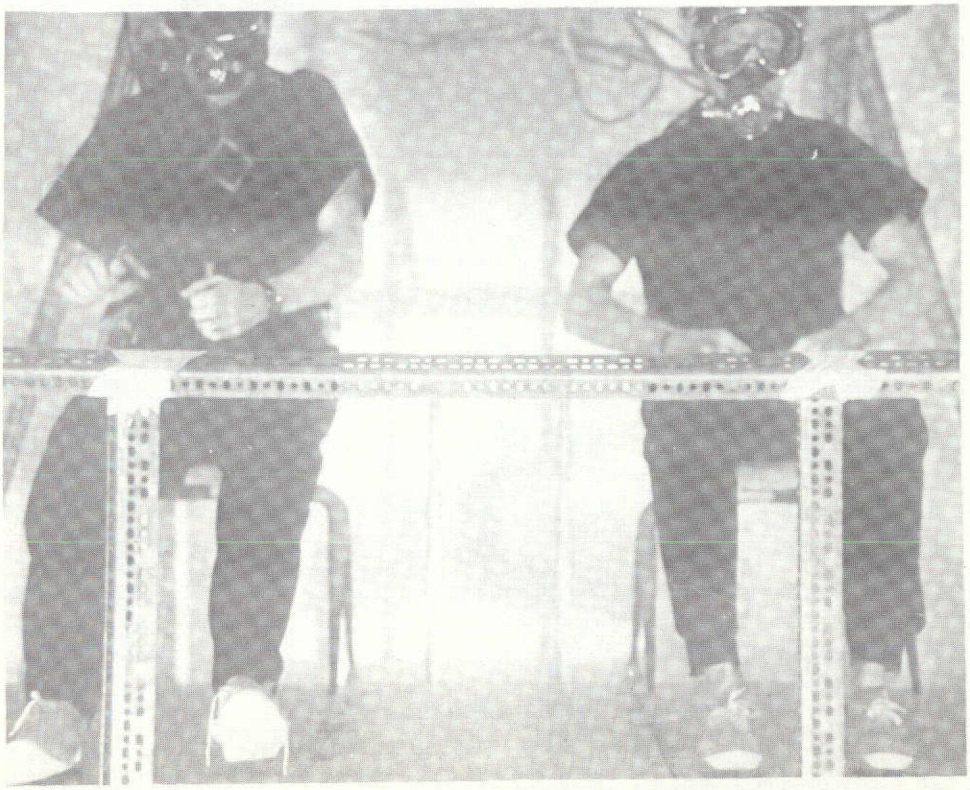


Figure IV-50 Test Subjects in Flight Deck Area

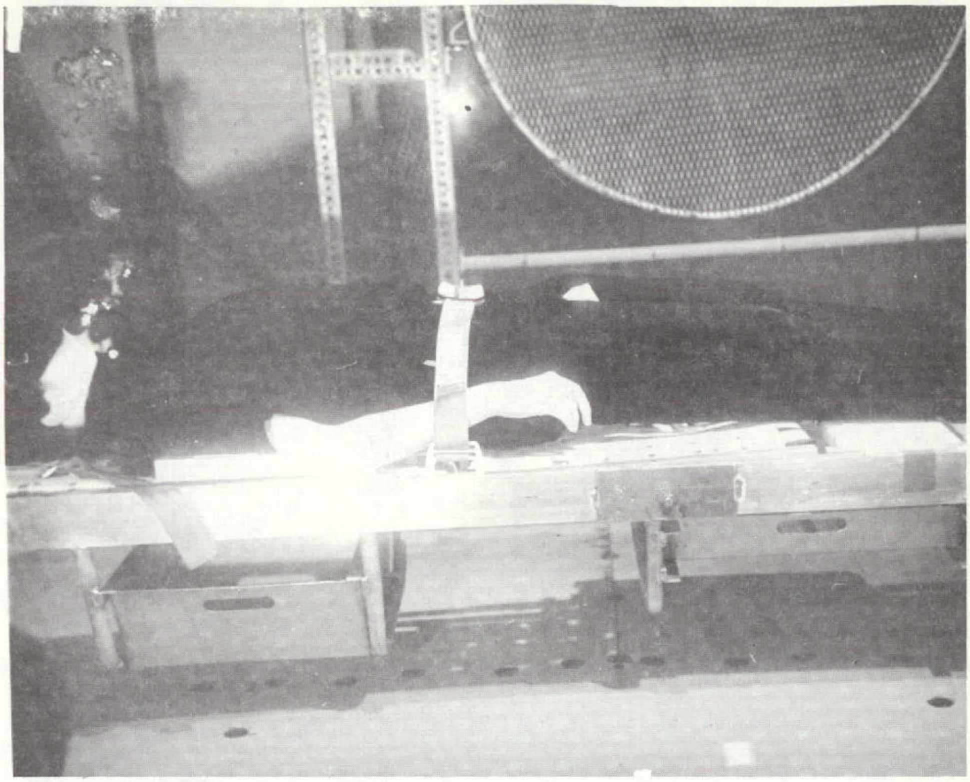


Figure IV-51 Female Test Subject Sleeping in Crew Couch

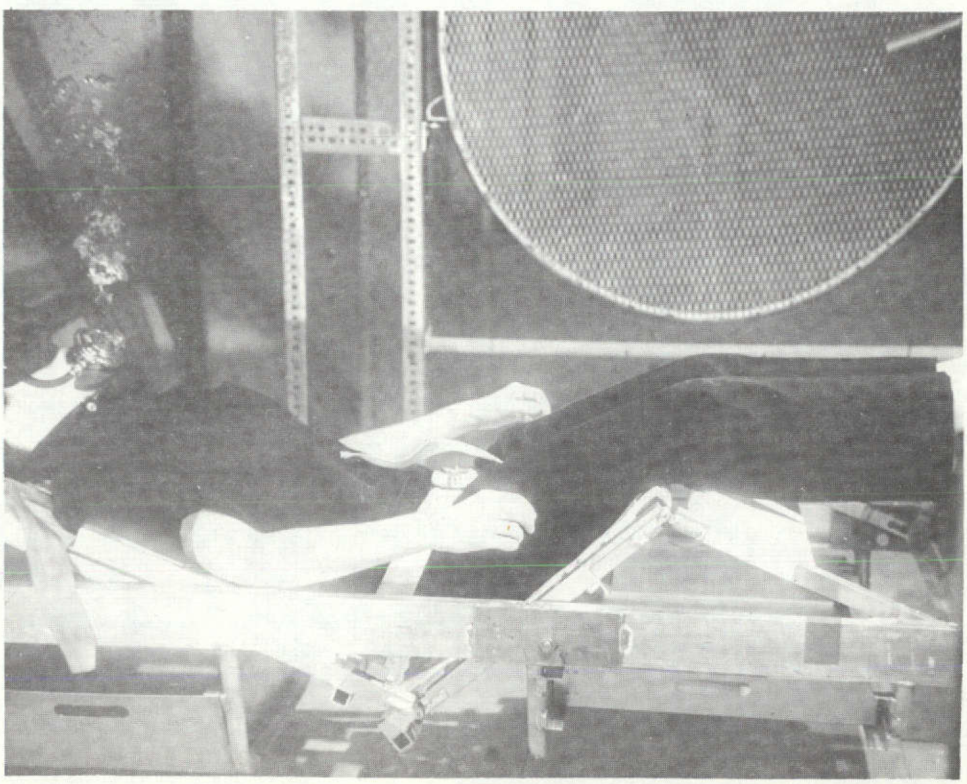


Figure IV-52 Female Test Subject Relaxing in Crew Couch

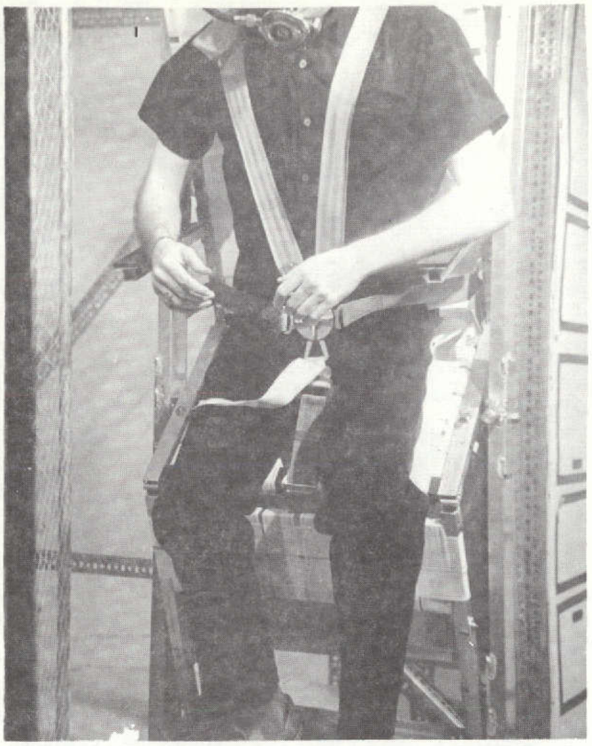


Figure IV-53 Male Test Subject Restrained in Crew Couch

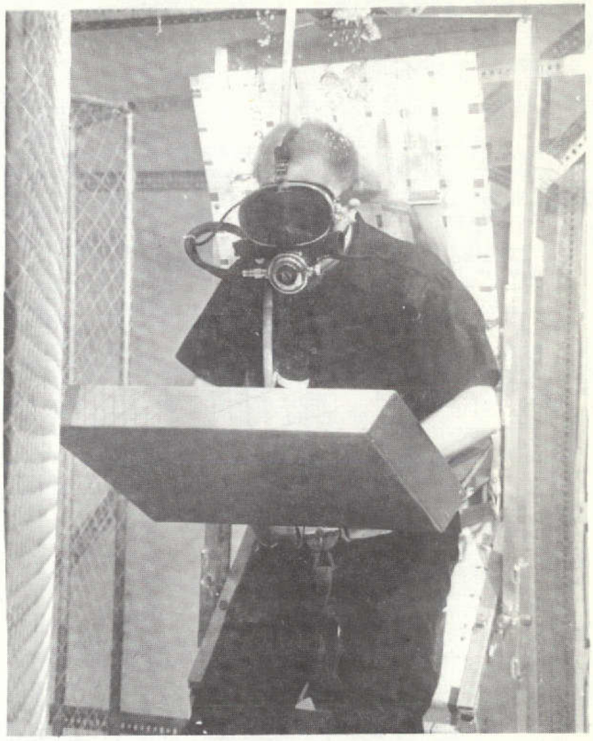


Figure IV-54 Crew Couch with Clerical Tray Attached

Figure IV-55 Crew Compartment Area With Couches Mounted in Y Direction

Figure IV-56 Suited Test Subject Egressing Airlock moderate torque is needed, and the NASA designed Shuttle passenger/crew couch. Both of these developmental items were tested by male and female test subjects. Pretesting established the optimum slope of the toe bar cross section and lengths; the couch test helped establish basic reach, location and ingress/egress techniques. From the pretests the component designs placed in the Shuttle mockup was enhanced considerably.

The performance test data were analyzed to extract quantitative data relative to the Shuttle Orbiter Crew Compartment (Ref. Table IV-7). This effort consisted of reviewing and editing the movie film recordings of the performance testing. The film was edited into three major sequences as follows: 2100 feet of neutral buoyancy testing utilizing male subjects and 750 feet of neutral buoyancy testing utilizing a female subject. The following is a brief summary of the neutral buoyancy testing:

1. Couch Area

   - Couch mounting orientation was not dictated by zero-g and was usable in either the y-axis or z-axis mounting.

   - All couch belt restraints could be operated in zero-g, however, the lap belt in conjunction with the foot rail was necessary to provide complete body stabilization and control.

   - The couches provided adequate mobility aids required in the couch area.

   - The couch controls must be accessible in all modes of operation.

2. Galley

   - The foot rail and hand rail in front of counter provided adequate restraint and mobility aids.

   - The galley operations were comfortable and very efficient.

3. Personal Hygiene Unit

   - The volume of the unit was sufficient for all tasks performed in the area.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table IV-7 Zero Gravity Test Evaluation Factors Analysis

	PERFORMANCE							SAFETY				COMFORT
Module/Function	Volume (Size)	Arrangement/ Orientation	Nuisance Factors	Access/User Volume	Access	Servic-ing	Conveni-ence	Locomotion Ease	Mobility/Restraint Aids	Visibi-lity	Obstruc-tions	Furnishings
Galley	78hx38wx18d Access Volume											
Meal Preparation	(3.1 ft^3) 26hx38wx18d counter vol (Ref. Figs. IV-34 thru IV-38)	Excellent (consistent with crew area)	Waist restraint hampered move-ment	All drawers & equipment accessible within access vol.	E	E	E	Excellent	Foot rail & counter hand rail	E		Food compart., oven
Equipment Operation		excellent	None	All used	E	E	E	Easy	Toe rail, hand rail	G	None	Oven, wipes, disp.
Area Cleanup		excellent	None	All areas accessible	E	G	E	Excellent	Toe bar w/assist from counter rail, food tray flat counter bungee chord	E	None	Wipes, disposer
Area Ingress		excellent	None	Adequate	E	G	E	Excellent	Side structures, counter rail, toe rail	E	None	Work area
Area Egress		excellent	None	Adequate	E	G	E	Excellent	Toe rail, walls, equipment	E	None	Work area
Servicing/Repair			None	Uses area not used for food	E	N/A	G	Excellent		E	None	Service area
Personal Hygiene	Total - 55 x60 x78 Use or Access - 31 x30 x78											
Handwashing/Grooming	Equip. 12 x 30 x42 (Ref. Figs. IV-39 thru IV-47)	Same as crew com-part. & 90° to crew compartment	Foot controlled water valve	All areas used & were adequate	E	E	G	Easy	Toe rails & hand holds ade.	E	None	Handwash, mirror, wipes
Defecating/Urination	Equip. 30 x	Same as crew com-part. & 90° to crew compartment	Urinal height for 95% males too low	All areas used	E	G	G	Easy	Toe rails, seat rim, lap belt	G	None	Commode/urinal
Changing Clothes	Use 31 x	Same as crew com-part. & 90° to crew compartment	None	All area used	E	G	G	Easy	Toe rails, hand hold, walls	G	None	N/A
Ingress/Egress	N/A	Same as crew com-part. & 90° to crew compartment	Lack of hand hold by door	All area used	G	N/A	G	Easy	Hand hold re-quired by door	G	None	Sliding door

Legend: E-Excellent; G-Good; F-Fair; P-Poor; All Dimensions in Inches

Table IV- 7 Zero Gravity Test Evaluation Factors Analysis Cont'd.

	PERFORMANCE							SAFETY				COMFORT
Module/Function	Size (Volume)	Arrangement/ Orientation	Nuisance Factors	Access/User Volume	Access	Servic-ing	Conveni-ence	Locomotion Ease	Mobility/Restraint Aids	Visibi-lity	Obstruc-tions	Furnishings
Couch Area	96x120x80 482 ft^3) (Ref. Figs. IV-49 thru IV-53)											
Ingress/Egress Area		Mounted in z-axis	None	Used existing passageway	E	G	G	Very Easy	Incorporated aids adequate	G	None	Center aisle is adequate
Ingress/Egress Couches		2 rows of 3 each	None	Aisle used for both rows	E	G	G	Very Easy	Incorporated aids adequate	G	None	Adequate room & mobility aids
Flight Deck	105 x 130 x 82 (450 ft^3) (Ref. Fig. IV-48)											
Ingress/Egress		This is dictated by the function of the flight deck	None	Low fidelity did not allow utilization of volume	E	N/A	E	Very Easy	Ladder provided excellent mobility aid for translation	G	None	N/A
Seat Occupancy		Same as crew compartment and facing forward	With fixed seats the crewmen had to swing their feet up over center console	N/A	G	G	G	Easy	Adequate mobility aids using equipment and furnishings	G	Center console	Seats
Airlock	60 dia x 84 L (138 ft^3) (Ref. Fig. IV-54)											
Ingress/Egress from Crew Compartment	N/A	Oriented for direct access & the same as crew compartment	Umbilical line (air hose)	Hatch opened on same side as end hatch for better equipment placement utilization	E	G	E	Very Easy	Hatch handle, hand holds, & walls provided adequate translation aids	G	None	None
Donning/Doffing Pressure Suit	More than adequate although ancillary equipment was not in the vol.	Same as crew compartment	Lack of restraints; takes two people	Task could be performed in smaller volume	N/A	N/A	G	N/A	Needed additional toe rails for second crewman & toe rail near center to facilitate task	G	None	None

Legend: E - Excellent; G-Good; F-Fair; P-Poor; All Dimensions in Inches

Table IV- 7 Zero Gravity Test Evaluation Factors Analysis Cont'd.

	PERFORMANCE							SAFETY				COMFORT
Module/Function	Volume (Size)	Arrangement/ Orientation	Nuisance Factors	Access/User Volume	Access	Servic-ing	Conveni-ence	Locomotion Ease	Mobility/Restraint Aids	Visibi-lity	Obstruc-tions	Furnishings
Ingress/Egress from Shuttle Exterior	N/A	Exterior hatch swings into the airlock	Umbilical line (air hose)	Hatch opened on the same side as interior hatch	E	G	E	Very Easy	Hatch handle, hand holds, & surrounding structure provided adequate translation aids	G	None	N/A

Legend: E-Excellent; G-Good; F-Fair; P-Poor;

- Donning and doffing of clothes depended on individual techniques.

- More positive body control when operating the hand washer control valve could be achieved with a valve that was actuated by lifting the toes.

- A centrally located foot rail would provide better stabilization for changing clothes and preparation for urination and defecation.

- Temporary clothing storage areas were required to hold a minimum of one change of clothing.

- Toilet seat angle for defecation can be at any angle that provides a minimum of 40 inches of open space normal to and above the toilet seat.

- A lap belt was required to maintain body contact with the toilet seat with both hands free.

- Urination collection device facility for males should be flexible in design to allow for the height of the 5 to 95 percentile males.

4. Flight Deck

- The ladder required in one gravity provided a very good mobility aid to the zero-g simulation.

- No problems were encountered in the low fidelity mockup.

5. Work Station

- A work station of this kind will require a sitting restraint with freedom to move the upper torso considerably to permit full operation of a large console.

6. Mobility Aids/Restraints

- Some specific mobility aids were required to supplement the aids incorporated into the equipment design.

- Handholds must be designed to permit a torque to be applied by the hand.

- All surfaces within the volume must be able to withstand an impact force of the crewman and/or the force of the crewman pushing off from the surface.

7. Traffic Patterns

- Traffic patterns were dictated by equipment location and orientation in conjunction with the tasks to be performed.

- Body positions could be changed during translation to be properly oriented to the area that was being approached.

From these evaluation results and the problems recognized, a number of design alerts (6) were generated and submitted to the NASA. These design problems were encountered and should be noted for actual Shuttle design development. A summary of the design alerts for zero gravity conditions follows:

1. Title: Foot Restraints Number: 2

Design Problem:

A foot restraint provides necessary body stability and control in a zero gravity environment to perform habitability tasks of short durations. This permits the hands to remain free to perform such tasks as connecting restraints, light torquing operations, small package handling, temporary short term control panel monitoring, food and scullary functions in the galley, and personal grooming in the hygiene facility. It is best to design these foot restraints as part of the equipment design such as on cabinets, chairs, couches or personal hygiene units. It is to be cautioned that a three point restraint (foot restraint and lap belt or hand restraint) is required for long duration tasks such as control panel monitoring or precise man-machine interfacing such as male urination.

2. Title: Mobility Aids for Hands Around Passenger Couch — Number: 7

Design Problem:

In the Shuttle Orbiter Crew Compartment, passenger couches are located in one area. Mobility aids for hand usage is required since the feet cannot be readily used due to the occupants of the other couches. These mobility aids are best incorporated into the couch design by the use of a curved lip around the couch shell. The crewman can grasp this lip to control his body attitude as well as providing him with a mobility aid.

3. Title: Couch Traffic Patterns with Tray — Number: 8

Design Problem:

In the couch area of the Shuttle Crew Compartment, two rows of couches facing each other with clerical trays deployed presents a locomotion problem. If the crewman translates over the deployed trays, he interferes with the seated crewman. Therefore, traffic patterns should be established below the deployed trays. This can be controlled by providing the mobility/restraint aids in that area.

4. Title: Crew Equipment Surface Protection — Number: 12

Design Problem:

When egressing various areas of the crew compartment, crewmen will utilize their hands and feet to orientate and propel themselves to other areas. In pushing off with their feet, little care or thought is given to what areas they are contacting. Therefore, it is necessary that all equipment and instrument panels be protected. In addition, these areas must be able to withstand an impact force of the crewman and/or the force of the crewman pushing off from the surface.

5. Title: Location of Airlock Hatches   Number: 13

Design Problem:

Airlock hatch-swing concepts should consider crewman operations and equipment placement. Consideration should be given to designing hatch hinges to be located on the same side such as to preserve a larger interior area for equipment and restraint/mobility aid placement. The location of the hinges on the same side will also provide maximum volume utilization for crewman operations inside the airlock.

6. Title: Tamboured Doors   Number: 14

Design Problem:

Tamboured sliding doors provide an advantage for volume utilization and as an aid to the crewman in egressing and ingressing an area. With hand rails on each side of the doors, the crewman can utilize the hand rails for stability as well as a mobility aid through the door. The length of the hand rails should be about 18 inches with a clearance height of two inches off the surface. This permits the doors to be opened and shut without the use of a separate restraint aid, and also provides the crewman with equal opposing forces thus aiding in stabilization.

E. DEFINITION OF NOMINAL ARRANGEMENT/ORIENTATION

It was concluded from the evaluation that a number of factors would effect any attempt to establish a "nominal" arrangement and orientation for the Shuttle crew compartment at this time. This became particularly apparent as the differences in the actual Shuttle design and the design parameters tested were analyzed. The main factors which greatly effect a firm definition of arrangement/orientation of the tested components are:

- Location of the airlock/docking mechanism.
- Reduction of the crew size to four (4) maximum (although the crew/passenger size is still vacillating between 4 and 8)
- Elimination of the use of the crew couches or the reduction to seats/mini-couches
- Placing four crew stations onthe flight deck and possibly seating crew members on the flight deck for launch and reentry
- Reducing the crew compartment to token size while increasing the equipment bays by a factor of more than two
- Reducing the galley size and possibly utilizing an Apollo type food system in place of a Skylab type food system
- Placement of the personal hygiene unit in a passageway instead of separating the area in a modular enclosure

Table IV-8 summarizes the Shuttle component design parameters which resulted from the test evaluation. These parameters relate to the original contract mission model, but several comparisons to current Shuttle design concepts may be made. These comparisons are covered in section VI-A. A number

Table IV-8 Summary of Shuttle Component Design Parameters

Galley Summary

Merits: Layout of module permits simple foot rail and counter hand rail as only mobility/restraint aids required to perform all tasks.

Deficiencies: On module egress, it would be desirable to have mobility aids built into the structure on each side; waist restraint was unsatisfactory as it pulled the body against counter which restricted movement, and view; the galley module usage and serving is restricted in the Shuttle vertical position without an access platform.

Applicability: Galley module layout applicable to Shuttle horizontal (ferry) flight mode and weightless (zero gravity) mode as tested.

Access Factors: Equipment storage areas below knee level (22inches) should be pull-out drawers for visibility and accessibility of contents; storage areas about 54 inches from floor should be swing-out doors for access; storage areas between 22 inches and 54 inches from the floor can be of any type access (swing-out, sliding, drawer); counter space height should be located 40 inches above floor. Personal usage and high usage areas and equipment should be placed between 30 inches and 54 inches from the floor.

Factors Affecting Design Concept: Test subjects utilized three different modes of egress; some utilized the foot rail by squatting, orientating body toward desired direction and pushing off with hands/arms extended straight out; others pushed off the front refrigerator/freezer door in same manner; the third technique was to turn and grasp the galley side structure at entrance and pulled with their hands.

Probable Design Problems: Swing-out hinged doors to cabinets, equipment and storage areas should not be lower than 22 inches crewman will utilize all surfaces within volume for mobility aid; therefore, controls must be protected and surfaces must be able to withstand an impact force of the crewman.

Personal Hygiene Summary

Merits: Module is optimum in a weightless environment, usable in one gravity horizontal position, and almost non-usable in vertical one gravity position; provided good temporary clothes stowage; toiletry kit display area good for one-G and zero-G.

Table IV-8 Summary of Shuttle Component Design Parameters Cont'd.

Deficiencies: In the vertical on-pad position, handwasher basin is rotated 90° to normal and is therefore unusable; mirror is usable only by subject turning head 90° and leaning far back when seated on commode; entire 78 inch height is wasted; very difficult to perform any servicing/maintenance since height is 30 inches, the egress/ingress in this position is difficult due to not being able to stand vertical in only a 30 inch height. Subjects cannot seat comfortable on commode due to 30 inch head height, feet are on angle and therefore subject cannot raise to perform wiping act; pulling up clothes must be effectively accomplished outside the module.

Applicability: Shuttle personal hygiene module in horizontal one-G and zero-G modes only as tested.

Access Factors: Door design and operation; wipes location; controls location and operation mode.

Factors Affecting Design Concept: Areas below knee level 22 inches shall be pull-out drawers; urinal height to be a nominal 36.4 inches; maximum angle of commode seat for one-gravity usage is 30 degrees from the horizontal (with leg restraint); use of tambour doors alleviate need for restraint handhold by door; requires two toerails at different elevations to accommodate the 5 thru 95 percentile male for urination.

Probable Design Problems: Commode seat design to incorporate restraint system and accommodate both male and female.

Couch Area Summary

Merits: Area provides adequate mounting provisions and ample room for all couch functions; all controls were within easy reach and good visibility; toe rail and lap belt provided adequate support in simulated zero-g; both male and female subjects were able to operate equipment and gain access to the couches.

Deficiencies: In one-g horizontal mode, it was difficult to gain access to the forward and upper couches; could not use clerical tray for eating in the one-g mode; it was difficult to gain access to and enter the couches; no package handling or servicing could be accomplished in the forward section; Backward foot pan adjustment, poor seat pan adjustment control.

Applicability: Shuttle

Access Factors: Aisle size, mobility aids, and access volume for each couch.

Table IV-8 Summary of Shuttle Component Design Parameters Cont'd.

Factors Affecting Design Concept: Incorporation of restraint/mobility aids in the couch and surrounding structures; couch positioning devices and control location; access ladders and servicing platforms.

Probable Design Problems: Easily deployable or built in ladders; service platforms; package handling techniques.

Flight Deck Summary

Merits: The 30 inch diameter hatch provided adequate access to flight deck area.

Deficiencies: In the vertical one-gravity mode, it was difficult to gain access to the flight deck area and to occupy the seats; low fidelity of mockup prevented true evaluation of the area.

Applicability: Shuttle

Access Factors: Different orientations dictate special access techniques.

Factors Affecting Design Concept: Access for the on-pad launch mode.

Probable Design Problems: Access due to center console between pilot and copilot seats; platforms to protect equipment and window area when on pad.

Airlock Summary

Merits: The one meter hatch size was more than adequate for ingress/egress in either shirtsleeve or pressure suit; volume was more than adequate for two people and the donning/doffing of pressure suits; the large (1 inch diameter) operating hatch lock was easy to operate even with pressure suit.

Deficiencies: Lack of ancilliary equipment within the airlock prevented a true evaluation of the interior volume; required more restraints in the form of toe rails and handholds.

Applicability: Shuttle airlock.

Factors Affecting Design Concept: Ancilliary equipment; hatch size and opening technique; location and type of restraint/mobility aids; hatches must be positioned in a manner that allows maximum volume utilization.

Probable Design Problems: Hatches must be positioned in a manner that allows maximum volume utilization by opening on the same side; location of adequate restraint/mobility aids.

of similarities do become evident, particularly in the use of certain mobility and restraint aids used for the specific functions performed. Tables IV-9 and IV-10 reflect general evaluation factors on the couch and recommend component design/ fabrication methods for the sections analyzed.

The design parameters summarized for the various Shuttle components may be generalized for arrangement and orientation in that the tested configuration did prove that all tasks could be accomplished with the volume of the mockup comfortably and efficiently. The volumetric allotments were acceptable and in general the mobility and restraint aids proved sufficient except in the vertical launch mode of operation. The chief difficulties did arise in the vertical position as previously noted under section IV-C. Specific guidelines must be established to denote functions performed during each operational mode, before firm recommendations for a good layout could be formulated. An attempt to illustrate one possible layout based on test results and current knowledge of the Shuttle design status is shown and discussed in section VI-A.

Within each module, the arrangement/orientation may be summarized as follows:

- Galley - The horseshoe shape and the location of the various food preparation elements proved completely acceptable. No specific changes are recommended.

- Personal Hygiene Unit - The arrangement/orientation of the personal hygiene module is only usable in the horizontal one-gravity mode (provided that the angles of the commode seat is not over 30° from the horizontal) and the zero-gravity mode. If the module is required for the on-pad orientation an extensive design effort would be required to rotate the commode 90° such that a crewman could sit similiar to the normal one-gravity arrangement. This would also require providing a minimum 40 inch clearance above the top of the commode seat to allow a 95 percentile man to sit on the fecal collector without interference with the opposite wall.

- Couch/Crew Area - The volume and layout tested for the couches and their associated area proved to be more than adequate. The arrangement gave ready access with no interference even when transferring food trays or clothing kits. Again, the only exception to this came during tests in the vertical mode. Nominal conditions

Table IV-9 Couch Area Test Evaluation Factors Analysis

	PERFORMANCE							SAFETY				COMFORT	
Area/Function	Volume (Size)	Arrangement/ Orientation	Nuisance Factors	Access/ User Volume	Access	Servicing	Convenience	Locomotion Ease	Mobility/Restraint Aids	Visibility	Obstructions	Furnishings	Privacy
<u>Couch Controls</u>		On occupants right side of couch	None	All within couch envelope	E, except for foot pan control	G	E, except for foot pan control	N/A	N/A	E	None	N/A	N/A
<u>Couch Functional Use</u>													
Sleep		Flat 180° position	None	Stays within 36 inch dia. envelope	G	N/A	F	N/A	Special restraint	G	None	Sleep restraint	Privacy curtain required
Eating		In 90° position	None	Uses existing aisle space	G - zero-g P - one-g	N/A	G	N/A	Lap belt & toe rail	G	None	Restraints & tray	Social contact possible
Relaxing		Any position from 90° - 180°	None	Uses existing aisle space	G	N/A	G	N/A	Lap belt & toe rail	G	None	Restraints, tray, stereo	Privacy curtain social contact
Working		In 90 - 120° position	None	Uses existing aisle space	G	N/A	G	N/A	Lap belt & toe rail	G	None	Restraints, tray	Priv. curtain social contact
Launch		In 120° position	None	N/A	G	N/A	G	N/A	5 belt & toe rail restraint system	G	None	Restraints	N/A
<u>Couch-Man Interface</u>													
Male		90 - 180°	Foot pan adjustment	Available space used	G	N/A	G	Easy	All systems usable	N/A	None	5-95% subjects	Couch positioning possible
Female		90 - 180°	Foot pan adjustment	Available space used	G	N/A	G	Easy	All systems usable	N/A	None	50% subjects	Couch positioning possible

Legend: E-Excellent; G-Good; F-Fair; P-Poor;

Table IV-10 Recommended Component Design/Fabrication Methods

Section	Structural Technique
Personal Hygiene	Modular
Galley/Housekeeping	Modular
Couches	Modular
Crew Area/Passageway	Integral
Equipment Bays 1	Integral
Equipment Bays 2	Integral
Equipment Bays 3	Integral
RCS - Equipment Bay	Integral
Wheel Well	Integral
Airlock	Integral
Docking Mechanism	Modular
Storage	Modular
Flight Deck	Integral

could be defined as a slightly smaller rectangular volume (especially if smaller couches are used) with a movable access ladder located in the center of the paired couches. This definition is based on the use of six crew couches.

- Flight Deck - Since there had been no input to the contract in so far as flight deck equipment, display, or overall shape/size, no specific definition of arrangement/orientation can be given. Generally, however, it may be noted that the vertical position will present the most difficult condition for mobility and equipment access. Therefore, any arrangement must provide adequate walk space and ladder/hand grips for the crew.

- Airlock - The restraint/mobility aids and the hinge - swing concept for the hatches are directly applicable on the final arrangement/orientation for the airlock.

- Equipment Bays and Storage - Location of the equipment bays and storage along any of the six peripheral surfaces would be acceptable in almost any crew compartment.

F. VOLUMETRIC SUMMARY

This section defines the volume requirements for specific activities and tasks performed in an area designed for both one and zero gravity. In a vehicle that must operate in two gravity modes as well as in two orientations in one gravity, the mode which is deemed the most restrictive will dictate the design of the area. Since the specific tasks to be performed in a given area are very strictly defined (e.g., galley, flight deck, personal hygiene unit), task definition and orientation requirements are very easily accomplished in most cases. For example, no reorientation is required for any tasks performed at the various stations, the equipment and storage areas and in the airlock. In the galley and personal hygiene unit, reorientation is limited to simple rotation and very minimal horizontal translation. Rotation or translation requirements in the flight deck are dependent upon the exact arrangement within the flight deck and upon the location of and the technique employed for docking.

The major impact on task and orientation requirements exists in the determination of traffic patterns between specific areas (e.g., passenger couch to galley) and ingress/egress procedures under normal and emergency conditions in all modes. Passage into or out of the passenger compartment from other internal orbiter areas is also greatly impacted by the exact location of the docking mechanism, since the total arrangement largely determines the routes used for transfer. Another parameter which helps establish the minimum passage dimensions and equipment positioning is the access requirement in each situation.

1. Task-Related Requirements

Volume requirements are based in whole or in part on the specific task being considered. Unrelated tasks can be performed in different orientations and can utilize part of all of the same volume since they would not be performed simultaneously. Related tasks require that no change in orientation occur during their performance; dual utilization of volume for these tasks may not be possible. These relationships may also change due to the change in gravity mode or the orientation of the overall vehicle in one gravity.

2. Gross Volume

Gross volume specifies the total room or area envelope, that is, the space within which the room must be placed in relation to the outer vehicle shell and other rooms. Table IV-11 gives the gross volume requirements as established for the individual modules and/or areas. The gross volume requirements for a specific room or area are determined by the following analyses.

All activities and tasks which are to be conducted within a given room are defined and the required volume for each is determined. The equipment and hardware, along with their volumes, required for the individual tasks are also established, as well as storage volumes. The maneuvering and orientation changes required in the performance of the tasks must then be identified. If a room is designed for multiple orientations in order that maximum volume-utilization occur, sufficient space must be provided to allow for the changes in orientation to be accomplished. The volume interface requirements between man and the furniture or equipment are then identified; that is, access dimensions are specified. These individual requirements are not necessarily additive but the interrelationships must be identified so that gross room volumes can be determined.

Table IV-11 Room Height and Volumes

SHUTTLE NOSE MOCKUP AS TESTED	CEILING HEIGHT, INCHES	VOLUME, FT^3	
		GROSS	NET
Crew/Passenger Couches	96	482	342
Galley	80	107	39
Personal Hygiene	80	150	54.7
Flight Deck	66 - 82	450	---
System Station	80	150	---
Airlock	84	138	---
Passageways	80	500	410
Equipment Bays	96	380	380
Avionics Area	96	320	320
Subtotal		2677	1545.7
Areas Not Considered			
Docking		200	
Payload Monitoring & Camera		200	
Aerodynamic Requirements		400	
Total		3477	
Habitability Units Minimized			
Minimum Passenger Couches	76	284	208
Galley	76	68	12*
Personal Hygiene	76	95	10*
Passageways	76	390	390
**Total		837	620

* Passageways also provide access volume of 52.7 cubic feet for personal hygiene and 23.8 cubic feet for the galley.

** This total compares with 1239 cubic feet of gross volume for the test configuration.

G. MOBILITY AND RESTRAINT DEFINITION

This section defines the mobility and restraint requirements for specific activities and tasks performed during the various vehicle orientations and gravity modes. During the performance testing of the crew compartment mock-up, the test subjects were closely observed during the performance of their tasks for the usage of the various mobility and restraint aids. Table IV-12 lists the mobility and restraint aids that were available in each of the three modes tested.

1. Performance Testing Results

Tables IV-12 through IV-18 are a summary of the mobility and restraint aids used during the performance testing in each mock-up area for the various functions. For each task the tables indicate which mobility/restraint aid was utilized. "M" indicates that the aid was utilized for mobility and "R" indicates it was utilized as a restraint aid.

a. Zero Gravity Mobility/Restraint Aids Test Results - The neutral buoyancy tests revealed the following:

- Where traffic patterns dictated a change in direction, a mobility/restraint aid was required.
- A simple toe rail was adequate to stabilize the test subject's body and permit the performance of a general habitability task with the subject's hands. This two point contact restraint permitted lateral, side bending, stooping, kneeling and squatting movements to perform tasks of meal preparation, body cleansing, don-doffing of clothes, equipment operation and general body stabilization.
- The optimum toe rail height while wearing shoes was different when sitting and standing. The testing indicated that a higher toe rail is required when sitting (2 inch height) than when standing (1.75 inch height). A triangular or an eliptical shape cross section was preferred over a round cross section on the toe rail.
- A waist restraint utilized in the galley area proved to be very limiting since it only permitted operations in a standing erect position. It did not permit lateral, side bending, stooping, kneeling and squatting movements necessary for obtaining access to food storage items below the subjects waist.

Table IV-12 Mobility and Restraint Aids Utilized During Performance Testing

Flight Mode	Restraint/Mobility Types
Neutral Bouyancy (zero gravity)	Specific toe rails hand rails waist restraint lap belt furniture lips equipment lips bungee cord/structure Non-Specific Wall surfaces structure equipment
Launch/on pad (verticle one gravity)	Specific Couch 5 belt restraint Access Platform Access ladders System Station chair Hand holds Pilot/Copilot Seats Step rungs bungee cord/structure
Ferry Flight (horizontal one gravity)	None

Table IV-13 Restraint/Mobility Aids Usage for Couch Functions

AREA: CREW PAGGENGER COUCH - See Figure IV-57 for Mobility/Restraint and Identification

Gravity Mode	Zero "G"					One "G" Verticle			One "G" Horizontal
	1	2	3	4	5	6	4	1	
FUNCTION \ MOBILITY/RESTRAINT	SHELL LIP	FOOT BAR	LAP BELT	LAUNCH BELTS	ARMS SUPPORT	ACCESS LADDER	5-BELT RESTR.	SHELL LIP	NONE
1. Couch ingress									
• approach couch	M				M	M/R			
• stabilize		R				R		R	
• Adjustments		R	R			None			
2. Equipment									
• re-entry/launch		R	R	R			R		
• tray deployment		R	R		R	None			
• sleep			R				R		
• relaxing		R	R			None			
3. Couch Egress									
• egress couch	R				R	M/R			
• egress area	M				M	M			
4. Couch ingress carrying food tray									
• approach					M	None			
• stabilization		R	R		R	None			

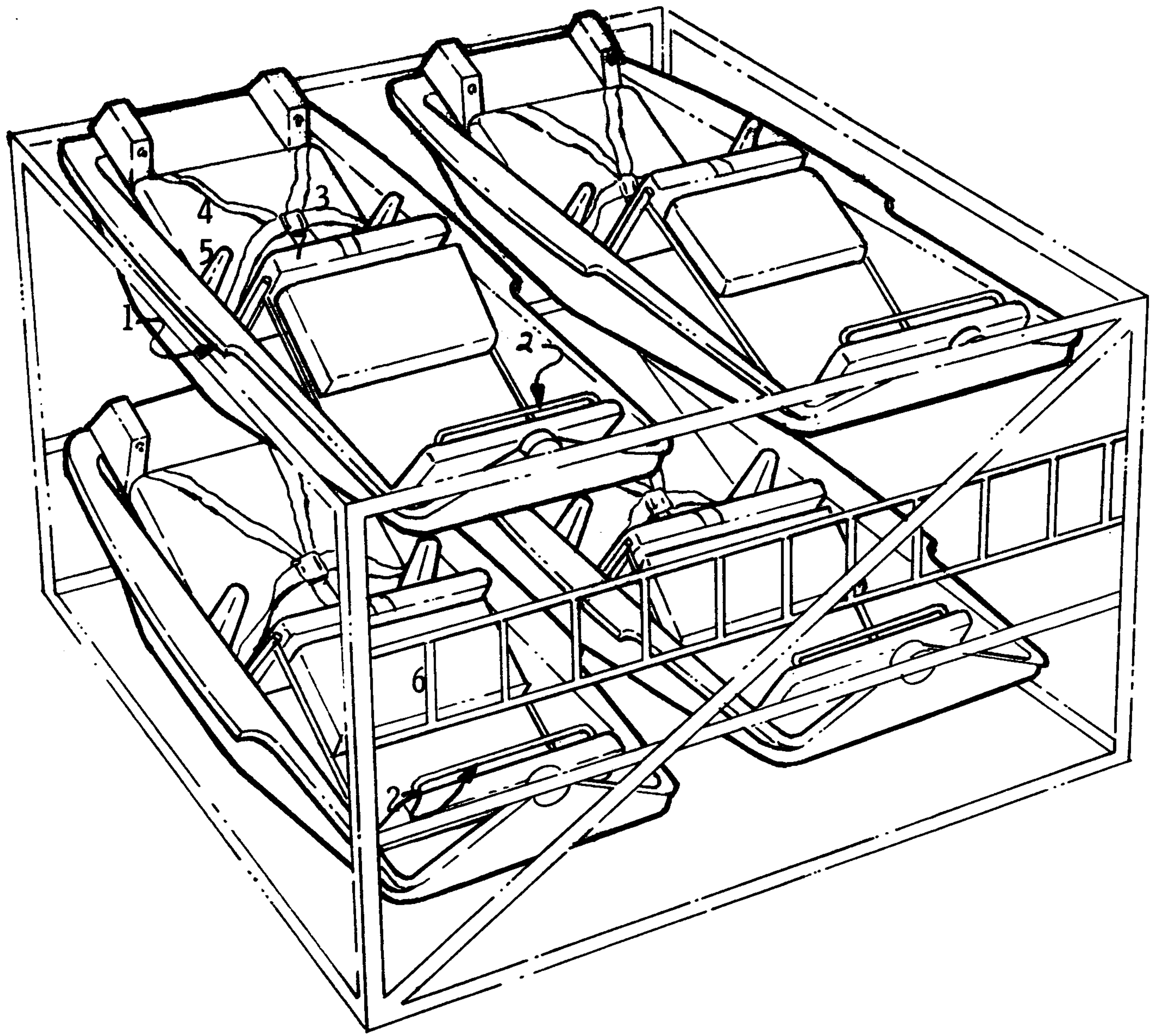


Figure IV-57 - Couch Area Mobility/Restraint Aid Identification

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table IV-14 Restraint/Mobility Aids Usage for Bathroom Module Functions

AREA: BATHROOM MODULE - See Figure IV-58 for Mobility/Restraint Aid Identification

GRAVITY MODE	ZERO "G"												ONE "G" VERTICLE	ONE "G" HORIZONTAL
MOBILITY/RESTRAINT	1	2	3	4	5	6	7	8	9	10	11	12	NOT USABLE	NONE
FUNCTION	TOE BAR	TOE BAR	LAP BELT	SEAT RIM	TOE BAR	HAND BAR	HAND BAR	DOOR HAND BAR	CLOTHES STOW.	EQUIP STOW	WALL	DOOR ANGLE		
1. Area Ingress														
• open door								R				R		
• enter area								M			M			
• close door								R			R			
2. Clothing Removal & Stowage														
• orientate						M	M				M			
• remove clothing					R	R	R							
• stow clothing					R				R					
3. Sponge bath														
• bath					R	R	R							
4. Donning of clothing														
• retrieve clothing					R				R					
• Don clothing					R						R			
5. Urination/Defecation														
• translate to WMU				M				M						
• garment preparation for urination (male)	R													
• garment preparation for urination/defection (female)		R		R										
• Urination simulation (male)	R			R										
• Urination/defectation simulation(female)		R	R	R										
• garment preparation for defecation(male)	R	R												
• defecation simulation (male)		R	R	R										
• don garments	R	R			R									
6. Handwashing/personal grooming														
• translate to handwasher						M	M				M			
• perform grooming					R	R	R							
• stow personal kit					R					R				
7. Housekeeping														
• wipe grooming area					R	R	R							
• wipe WMS area	R			R										
• wipe wall areas	R				R			R						
8. Area egress														
• translate to door								M			M			
• open door								R			R			
• area egress								M				M		
• close door								R				R		

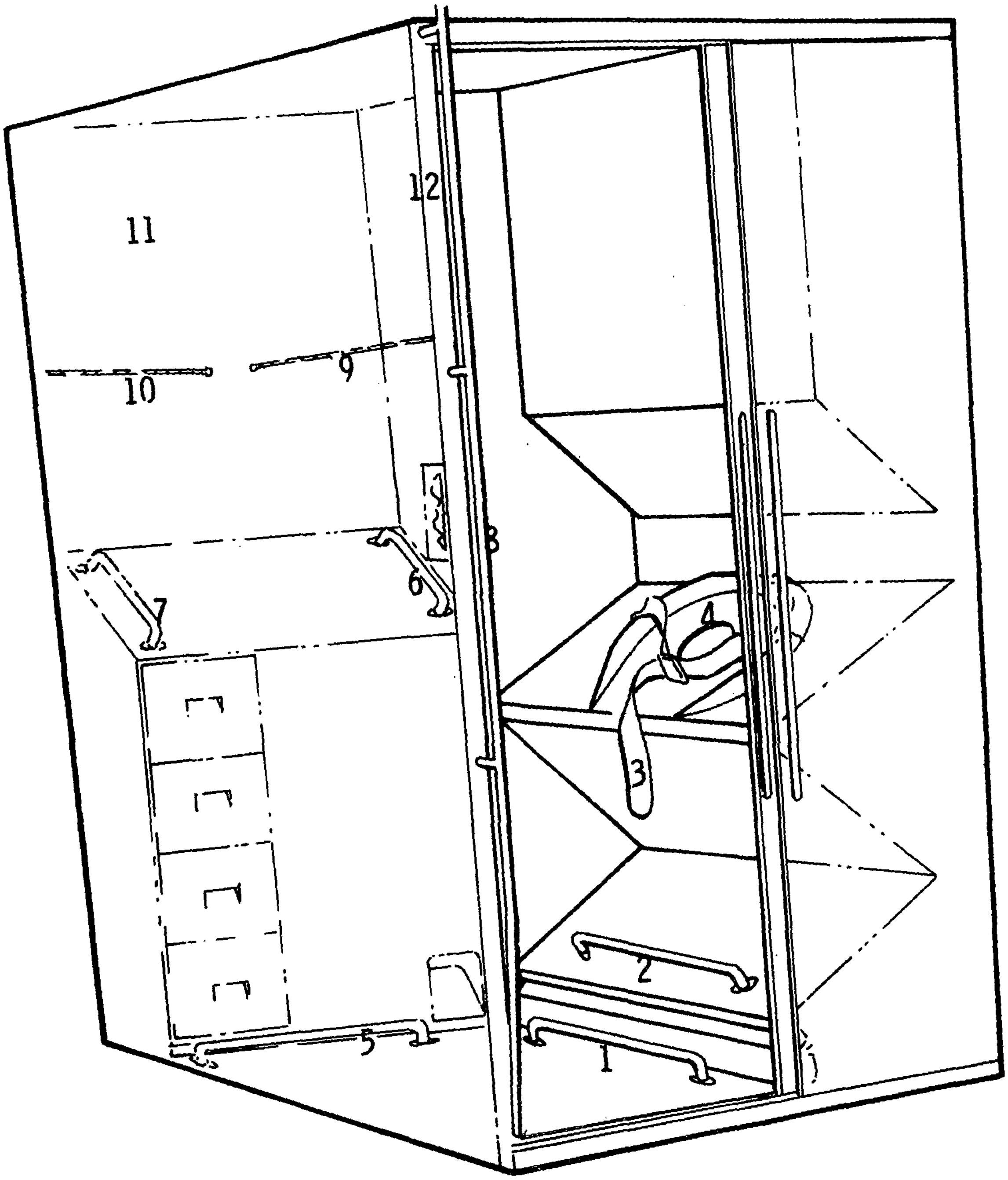


Figure IV-58 - Bathroom Module Mobility/Restraint Aid Identification

Table IV-15 Restraint/Mobility Aids Usage for Galley Functions

AREA: GALLEY MODULE - See Figure IV-59 for Mobility/Restraint Aid Identification

Gravity Mode / MOBILITY/RESTRAINT / FUNCTION	ZERO "G"											ONE "G" VERTICLE	ONE "G" HORIZONTAL
	1 Toe Bar	2 Hand Bar	3 Equip Surface	4 Tray Support	5 Module Edges	6 Tray Door	7 Food Door	8 Oven Door	9 Refrig Door	10 Trash Stowage	11 Wall Surf.		
1. Area ingress												None (Not Usable)	None
• ingress area		M			M								
• Stabilization	R	R											
2. Equipment Operation													
• remove food tray	R	R				R							
• placement of tray	R			R									
• remove food packages	R						R						
• place food in oven	R							R					
• refrigerator access	R								R				
• remove container lids and dispose	R									R			
3. Area cleanup													
• skullery functions	R												
• surface wipe down	R	R											
4. Area egress													
• orientate body		R									R		
• egress area	M		M		M								

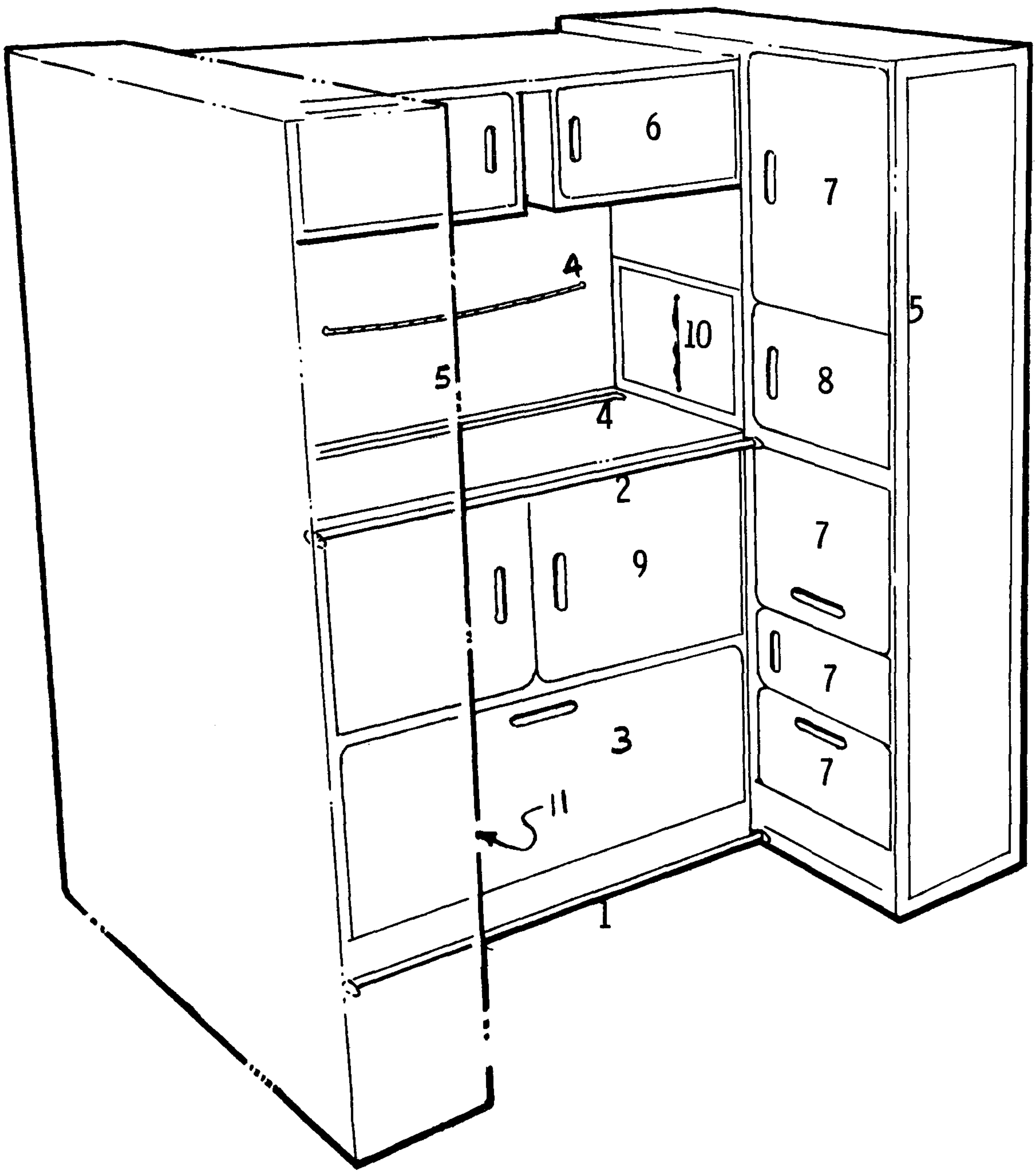


Figure IV-59 - Galley Module Mobility/Restraint Aid Identification

Table IV-16 Restraint/Mobility Aids Usage for Systems Station Functions

AREA: SYSTEM STATION - See Figure IV-60 for Mobility/Restraint Aid Identification									
GRAVITY MODE	Zero "G"					One "G" Vericle			One "G" Horizontal
Mobility/Restraint \ Function		1	2	3	4	5	6	7	
		Seat Lip	Toe Bar	Lap Belt	Wall Surface	Chair	Hand Holds	Step Rungs	None
1. Area Ingress • enter area • stability action		M	R	R	M	R	M/R	M/R	
2. Station Operations • Control Operations			R	R		R			
3. Area Egress • leave restraint • egress area		M M			M	R	M/R	M/R	

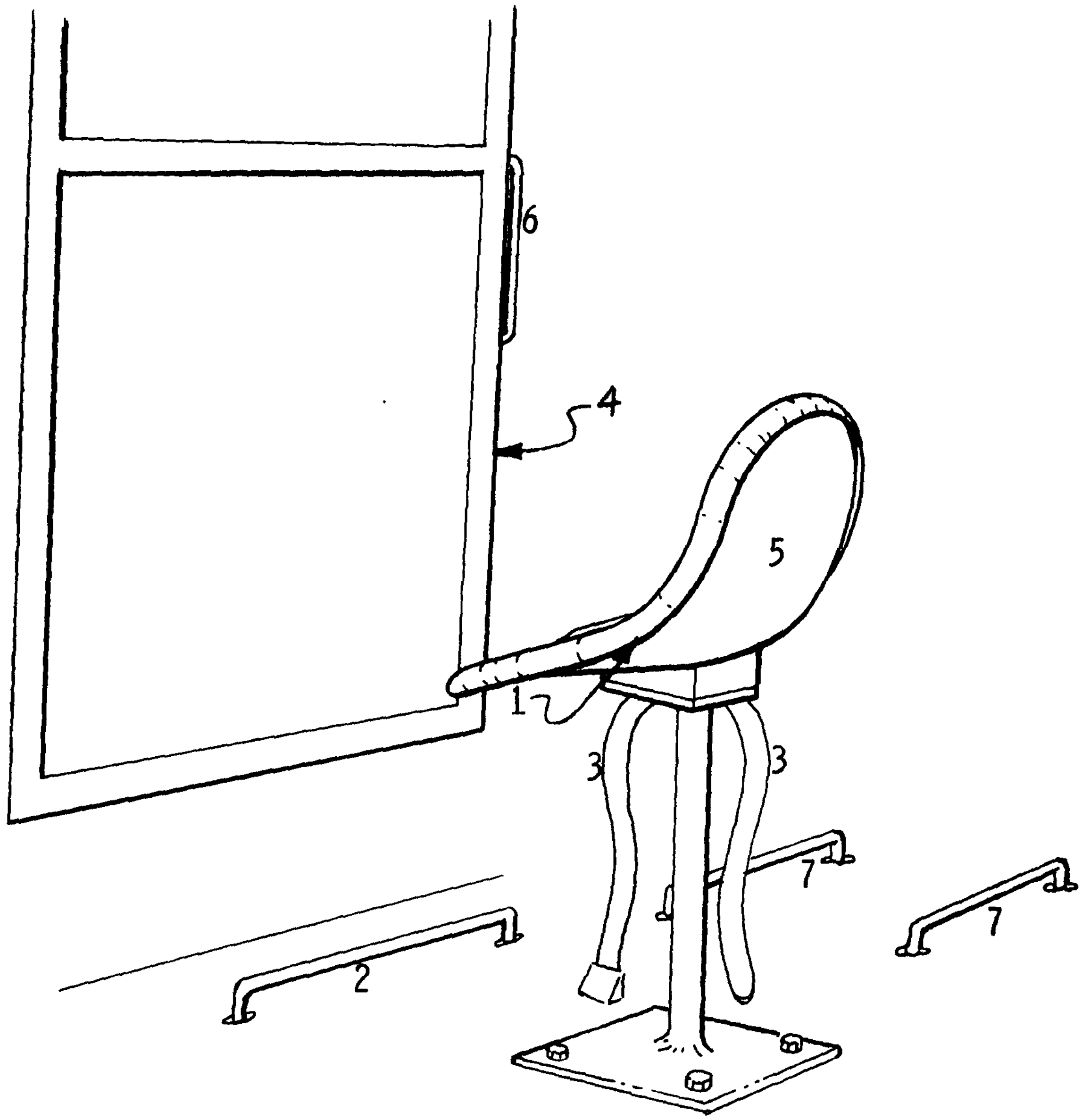
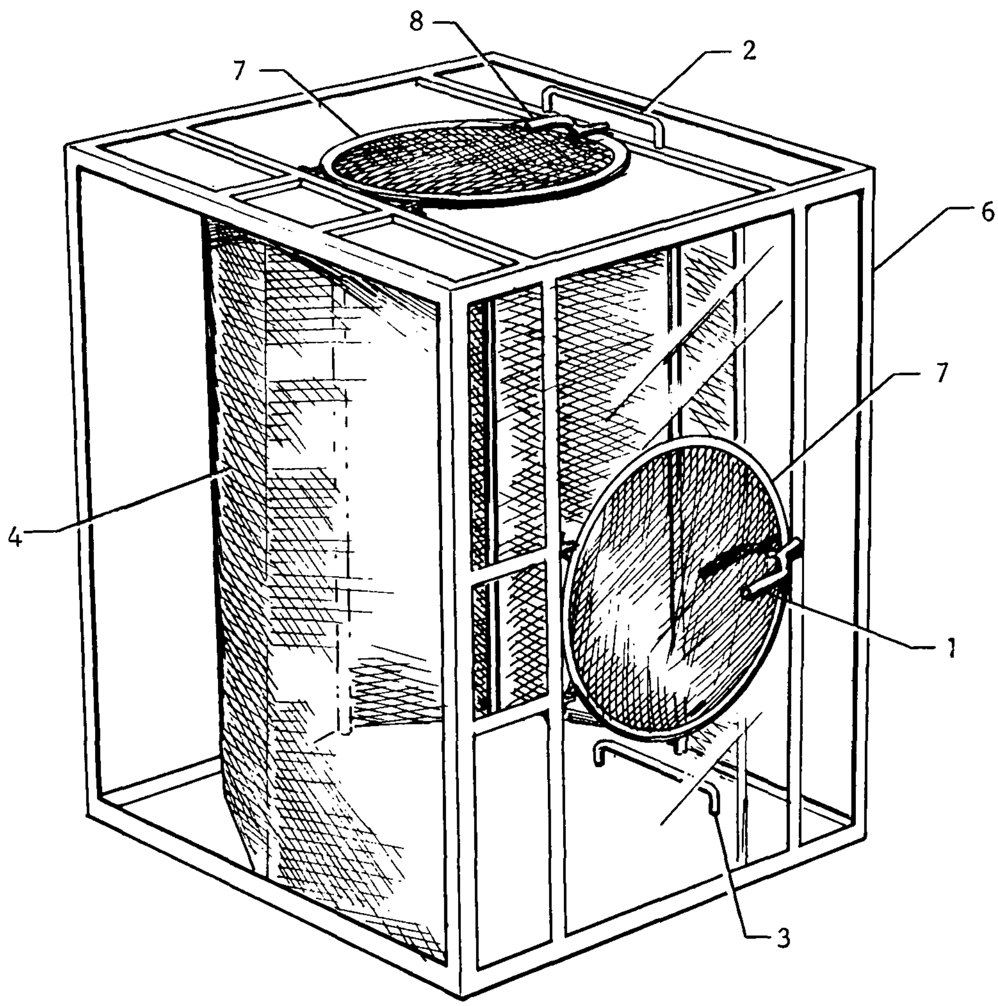


Figure IV-60 - System Station Mobility/Restraint Aid Identification

Table IV-17 Restraint/Mobility Aids Usage for Airlock Functions

AREA: AIRLOCK - See Figure IV-61 for Mobility/Restraint Identification

Gravity Mode	ZERO "G"								ONE "G" VERTICLE	ONE "G" HORIZONTAL
FUNCTION \ MOBILITY/RESTRAINT	1 Crew Comp Door Bar	2 Eva Door Bar	3 Foot Bar	4 Wall Inter	5 Crew-man	6 Module Wall	7 Door Struct	8 Eva Door Handle	None (Not Usable)	None
1. Area egress										
• approach module	M					M				
• open door	R					R				
• ingress area	M						M			
• stabilization			R							
2. Pressure Suit Donning										
• don pressure suit			R	R	R					
3. EVA egress										
• depressurize			R	R						
• open EVA door		R						R		
• egress							M	R		
• close door								R		
4. EVA ingress										
• open EVA door								R		
• ingress							M	R		
• close door		R						R		
• pressurize			R							
5. Pressure Suit doffing										
• doff pressure suit			R	R	R					
6. Egress area										
• open door	R			R						
• egress area	M						M			
• close door	R					R				



NOTE: ALL DIMENSIONS
IN INCHES

Figure IV-61 - Airlock Module Mobility/Restraint Aid Identification

Table IV-18 Restraint/Mobility Aids Usage for Transfer Procedures

AREA: CREW COMPARTMENT

Gravity Mode / MOBILITY/RESTRAINT / FUNCTION	Zero "G"						One "G" Verticle						One "G" Horizontal		
	1	2	3	4	5	6	7	8	9	10	11	12	13		
	COUCH LIP	GALLEY MODULE BAR	BATHRM DOOR BAR	BATHRM MODULE	SYSTEM STATION WALL	ACCESS LADDER	ACCESS LADDER	HAND HOLDS	STEP RUNGS	ACCESS PLATFORM	PILOT SEATS	SYSTEM CHAIR	ACCESS LADDER	NONE	
1. Transfer from couch															
• to galley module	M	M					M/R	M/R	M/R	M/R				X	
• to bathroom module	M		M				M/R	M/R	M/R	M/R				X	
• to systems station	M						M/R	M/R	M/R	M/R				X	
• to flight deck	M					M	M/R	M/R	M/R	M/R	R		M/R		
2. Transfer from flight deck															
• to couch area	M					M	M/R	M/R	M/R	M/R			M/R		
• to bathroom module			M			M	Not	Useable					M/R		
• to galley		M				M	Not	Useable					M/R		
• to system station						M						R			
• to airlock	M					M	Not	Useable					M/R		
3. Transfer from bathroom module							Not	Useable							
• to couch area	M			M		M								X	
• to galley module		M	M											X	
• to flight deck			M			M							M/R		
• to airlock	M			M		M								X	
• to system station			M		M									X	
4. Transfer from galley module							Not	Useable							
• to couch area	M	M												X	
• to bathroom module		M	M											X	
• to flight deck		M				M							M/R		
• to system station		M			M									X	

- The bathroom module hand washer water activation valve was operated by means of a foot control. When the foot control was activated by pushing down, it would torque the subject's body about the opposite foot contact point with the toe rail. This proved to be annoying. When the foot control was activated by lifting up, no torquing of the body was experienced and the technique proved to be satisfactory.

- Some delicate man/machine interfaces require a restraint system with three points of contact. One example of such a case was the urination task. The subject's comments stated that to maintain their body in constant contact for approximately one minute with the urinal opening it was helpful to utilize (in addition to the toe rail) a hand hold directly on centerline and behind the urinal opening. Utilizing a hand hold to either side would tend to torque their bodies away from the urinal interface.

- Hand holds that are as long as possible for a given area but need not exceed 18 inches proved to be most satisfactorily since the subjects did not have to "hunt" for them.

- Different techniques were utilized by the test subjects during the locomotion process. A typical example of this was when egressing the galley area, where different techniques were utilized:

  1) Subjects would turn, crouch and push off the galley toe rail leading with their hands.

  2) Subjects would turn and push off the front of the refrigerator door leading with their hands.

  3) Subjects would turn and grasp the module hand holds and pull and propel themselves with their hands.

- When subjects were maneuvering in congested areas (such as the passenger couch area), they would tend to propel and direct themselves by grasping the equipment with their hands.

- Mobility and restraint aids that could be simply interfaced with were more preferred over aids that had to be adjusted or had other preparation requirements. Particular criticism was noted from the test subjects if an aid required readjustment to fit the different percentile subjects.

- The bathroom had a single sliding door for access. The test subjects expressed criticism in opening this door since it required one hand on the door handle while stabilizing themselves on the structure of the bathroom. They favored the tamboured door concept where they could grasp each door handle and open/close the door while maintaining complete body stablization. In addition, these door handles would assist them as mobility aids to ingress/egress the area.

- The commode had, in addition to a foot restraint and a continuous rim around the commode seat, a waist restraint in case a crewman was ill and was not able to utilize the seat rim as a hand grasp. This worked effectively and it was felt by the female subject that a urination wipe could be accomplished while restrained. It would be required to be removed for a defecation wipe. In addition, it was noted that the commode seat rim was adequate for positioning the body with the equipment interface. After completion of the elimination act, subjects would then utilize the commode foot restraint to don their clothing.

- In the airlock mock-up, it was advantageous to have a second crewman to assist the first crewman in donning the pressure suit.

- The access ladder to the flight deck proved an able mobility/restraint aid in egressing and ingressing the area.

b. One Gravity Mobility/Restraint Aids - The one gravity horizontal (ferry flight mode) tests demonstrated that the test subjects required no special aids except for an access ladder to the flight deck. The verticle one gravity tests (launch mode) demonstrated the following:

- Wall partitions in the horizontal mode became valuable access platforms in the verticle mode. A typical example was the system station wall, which made an excellent platform for the entrance hatch.

- The access ladder to the upper couches was utilized for ingressing/egressing the area. Difficulty was experienced in transporting any package up this ladder. In addition, transferring from the ladder to the couch and back to the ladder was somewhat hazardous. An access platform would be more desirable due to the extreme heights.

- Special hand and foot rungs were necessary to negotiate from the entrance hatch platform down to the bathroom and the flight deck.

- When the subjects ingressed to the flight deck through the hatch, it became apparent that a special type of platform would be required to prevent damage to any controls/displays of the flight deck stations. A special type of mobility aid is required to gain access to the pilot/copilot seats.

- Considerable effort was required to move from one area to another as the subjects had to climb up and down ladders, duck under objects, walk stooped over, and/or crawl on their hands and knees.

- There was no direct path between any two areas.

V. DOCUMENTATION

A. STUDY PLAN, MSC-03775, ADDENDUM I

The study plan outlines Martin Marietta Corporation's approach, milestones, anticipated results, and workload allocation for Neutral Buoyancy Testing a Shuttle Orbiter Compartment. This DRL Number T-784 Line Item 6 was submitted to NASA-MSC and approved by Gordon Rysavy, Technical Monitor, NASA-MSC in May, 1972.

B. BIBLIOGRAPHY/SYNOPSIS REPORT, MSC-03771, ADDENDUM I

The bibliography/snyopsis report contains the results of an extensive search of available material pertaining to architectural and environmental concepts for a Shuttle Orbiter Crew Compartment. The report utilizer a subject index to categorize each of the 31 documents researched and cited in the report into one or more of nine subjects. The nine subject areas are: Extraterrestrial Habitability, Architectural Concepts, Shuttle Orbiter, Waste Management, Food Management, Passenger Couch, Mobility/Restraint Concepts, Volume, and Neutral Buoyancy. The data were obtained from government documents, professional societies, books, trade journals, Martin Marietta documents, corporation contacts and from information gathered at two professional conferences. This DRL number T-784, line item 1 was submitted in August, 1972.

C. MONTHLY PROGRESS REPORT, MCR-72-205

In addition to other reports, a monthly progress report of all work performed during each month of the contract has been submitted. The reports are in narrative form, brief, and informative in content. These reports provide a month by month account of the contracts progress. They include a program summary, significant progress achieved, planned progress for the following month, status on the progress against initially - developed milestones, and a summary of the manhours and dollars spent by month and cumulative through the program. This DRL number T-784, line item 3 was submitted monthly.

D. PERFORMANCE TEST PLAN, MCR-72-246

The performance test plan describes the tests that were performed and the detailed test procedures for testing the Shuttle Orbiter Crew Compartment and flight deck. The test plan was prepared in three separate procedures, Horizontal one-g, Vertical one-g, and Neutral Buoyancy to cover the modes of Shuttle operation. This DRL number T-784 line item 13 was approved by Mr. Gordon Rysavy, technical monitor in September, 1972.

E. A/E HANDBOOK, SUPPLEMENT NO. 2, MSC-01530

The design criteria developed as a result of this contract was presented as Supplement II to the "Architectural/Environmental Handbook for Extraterrestrial Design", MSC-03909. The supplement included data applicable to such Shuttle Orbiter crew compartment design as mobility and restraint systems, the effects of dual one/zero-gravity on design, criteria for furniture and equipment placement and design, accessibility requirements, and other design parameters. This DRL T-784, line item 7 was submitted in May, 1973.

F. A/E RATIONALE HANDBOOK, SUPPLEMENT NO. 2, MSC-01532

This report contained the recommended design rationale in support of the design criteria used to update the A/E Handbook. This rationale was Supplement II to MSC document MSC-01532. This DRL T-784, line item 8 was submitted in May, 1973.

G. TEST FILM AND PHOTOGRAPHS

During the neutral buoyancy testing, significant results are recorded on 16 mm movie film, video tape, and still photographs. For all the tests conducted, approximately feet of movie film, feet of video tape, and still photographs were taken and submitted to NASA-JSC. The film and photographs were submitted to NASA-JSC in May, 1973 as DRL T-784, line item 9.

H. SUMMARY REPORT, MSC-03774, ADDENDUM I

The summary report is submitted in conjunction with the final report and does not exceed 10 pages. The report contains an introduction, study scope and objectives, relationship to other NASA efforts, method of approach and principal assumptions, basic data generated and significant results, study limitations, implications for research, and suggested additional effort. This report was submitted in May, 1973, as DRL-T-784, line item 5.

VI. SUMMARY OF A/E DESIGN FOR ONE AND ZERO GRAVITY

This section is included to present a summary of the applicability to shuttle-type vehicles and the effects of dual gravity upon architectural/environmental design as determined by this contract. It will also include a summary of the man model for zero gravity and the data generated during the course of the contract. The Architectural and Environmental Handbook Supplement 2, NASA-JSC Document 01530, is considered a part of this section as specific criteria for dual gravity.

A. APPLICABILITY TO SHUTTLE - TYPE VEHICLES

During the performance of this contract, the Shuttle contractor and the NASA have been assessing the various crew compartment configurations. This section attempts to correlate the contract test results with the latest Shuttle configuration.

Table VI-1 illustrates these differences by direct comparison of the tested Shuttle areas to the current Shuttle design considerations. A number of conclusions may be drawn from this comparison and an overview of the total Shuttle Orbiter - habitability is being sacrificed for the basic vehicle subsystems, i.e. power, weight, volume, equipment, etc. This condition was anticipated as the design progressed. Other systsms will not allow habitability to compromise their design. This then poses the question of how best to apply what was learned from the study effort to today's configuration problem. The answer which emerges if that the habitability aspects must reduce accordingly to the space available and then embellish to provide what human needs may be satisfied. This application would dictate a mini-couch, shared access volume (passageway need for galley, personal hygiene unit, etc., and other such reductions which could be made and still provide the basic habitability items originally defined.

A possible design layout applying this philosophy is illustrated in Figure VI-1, -2, & -3. This layout is based on current design concepts and inputs from the NASA and the Shuttle prime contractor. The only real question which appears to grossly effect the layout at this point in Shuttle development is exactly how many personnel will be accomodated within the orbiter. We have assumed at least eight personnel based on an analysis of defined payload experiments. For a minimum volume impact, it is also assumed that two of these personnel will occupy the flight deck rather than the crew compartment area, except for eating, body functions and general crew activities (they would sleep on the flight deck).

Table VI-1 Shuttle Compartment Comparison

Area	Test Parameters vs	Current Shuttle Design Parameters	Applicable Test Data for Criteria Implications
Galley	Horseshoe shaped module with Skylab type preparation and serving system.	Flat walled shaped, built into equipment bay with Apollo type preparation, possibly Skylab type if selected.	Foot Restraint in front of galley area, handholds for stability, use of hinged doors above knee height only, should have fold down or pull out food preparation table top.
Personal Hygiene Unit	Square enclosure providing fecal/urine collector, handwasher, mirror and personal grooming area. Door closed for privacy.	Unit located in access passageway from external service hatch to interior. Provides fecal/urine collector, handwasher and privacy curtain.	Foot Restraints in front of collector and handwasher, handholds for stability, seat angles and head/leg height dimensions, tanbour doors for privacy and access. Should consider clothes hangers and mirrors for personal grooming.
Couches	Rectangular shaped with space for six full sized couches plus passageway area.	No full size crew couches, crew (4 only) will occupy seats on flight deck for launch and reentry and sleep in bays hung from crew area walls (head to feet). Possibly provide passengers with seats, Apollo couches or mini-couches.	Arrangement, orientation and mobility/restraint aids applicable if passengers were placed in lower crew area compartment. If mini couch used, the design mechanism may be directly applicable.
Crew Area/Passageway	Open area for direct access to all habitability and system functions/equipment.	Small area formed as passageway to gain access to equipment bays and provided habitability functional areas. Crew area limited to access space only.	Mobility and restraint aids for access to each area particularly where the three operational modes if the Shuttle are involved.
Flight Deck	Three station area with direct access from crew area below.	Four station area with access through airlock to other vehicle areas.	Mobility and restraint aids for crew access to various stations, reach envelopes for zero gravity conditions, and locomotion data between flight deck and crew area.
Airlock	Cylindrical Unit with two hatch openings.	Cylindrical Unit with three hatch openings.	Direct comparison with almost all data for personnel functions applicable.
Equipment Bay and Storage	Equipment located to sides of crew compartment.	Equipment takes up large portion of nose section and side areas.	Restraints for equipment access.

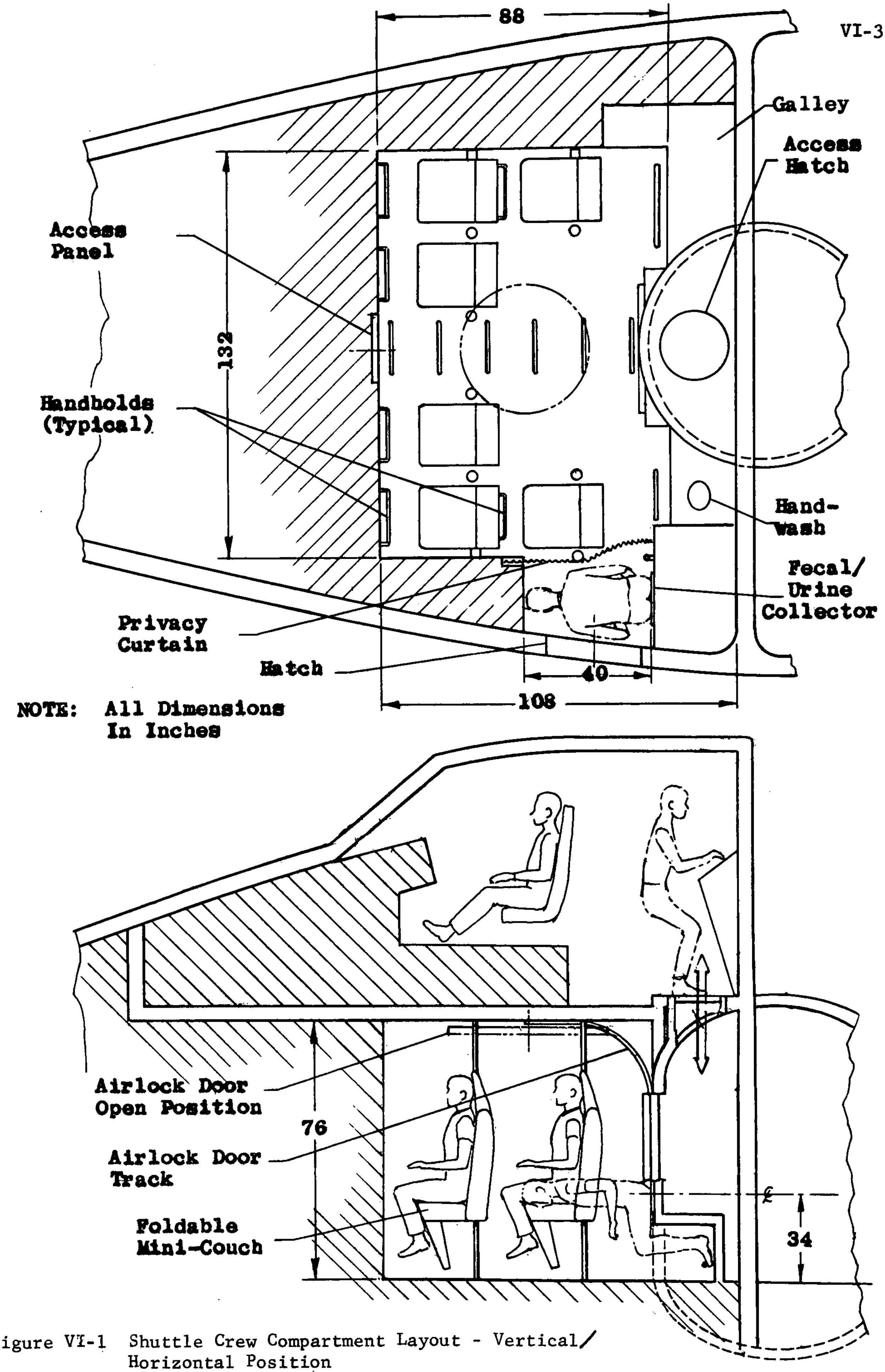


Figure VI-1 Shuttle Crew Compartment Layout - Vertical/
Horizontal Position

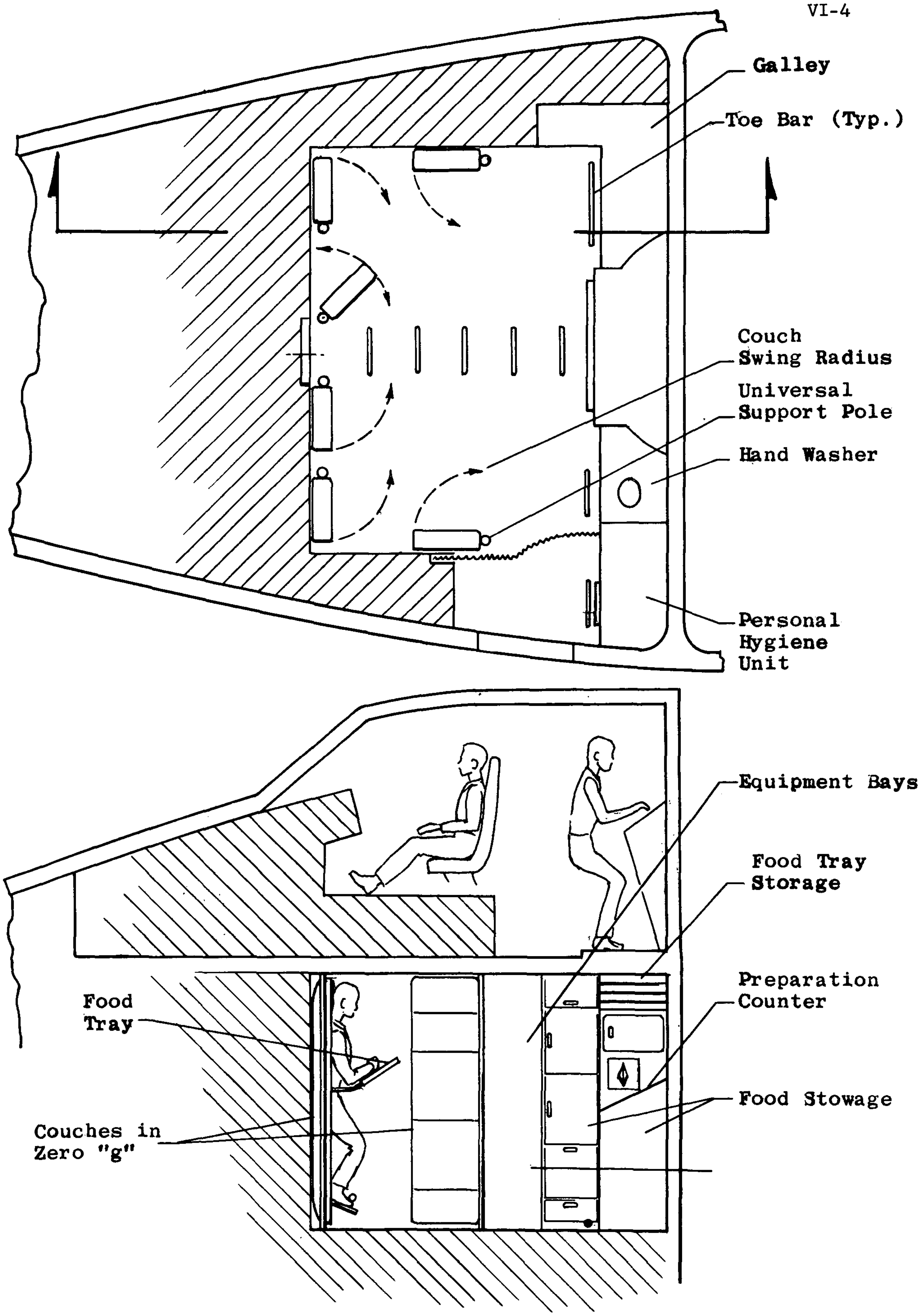


Figure VI-2 Shuttle Crew Compartment Layout - Zero Gravity

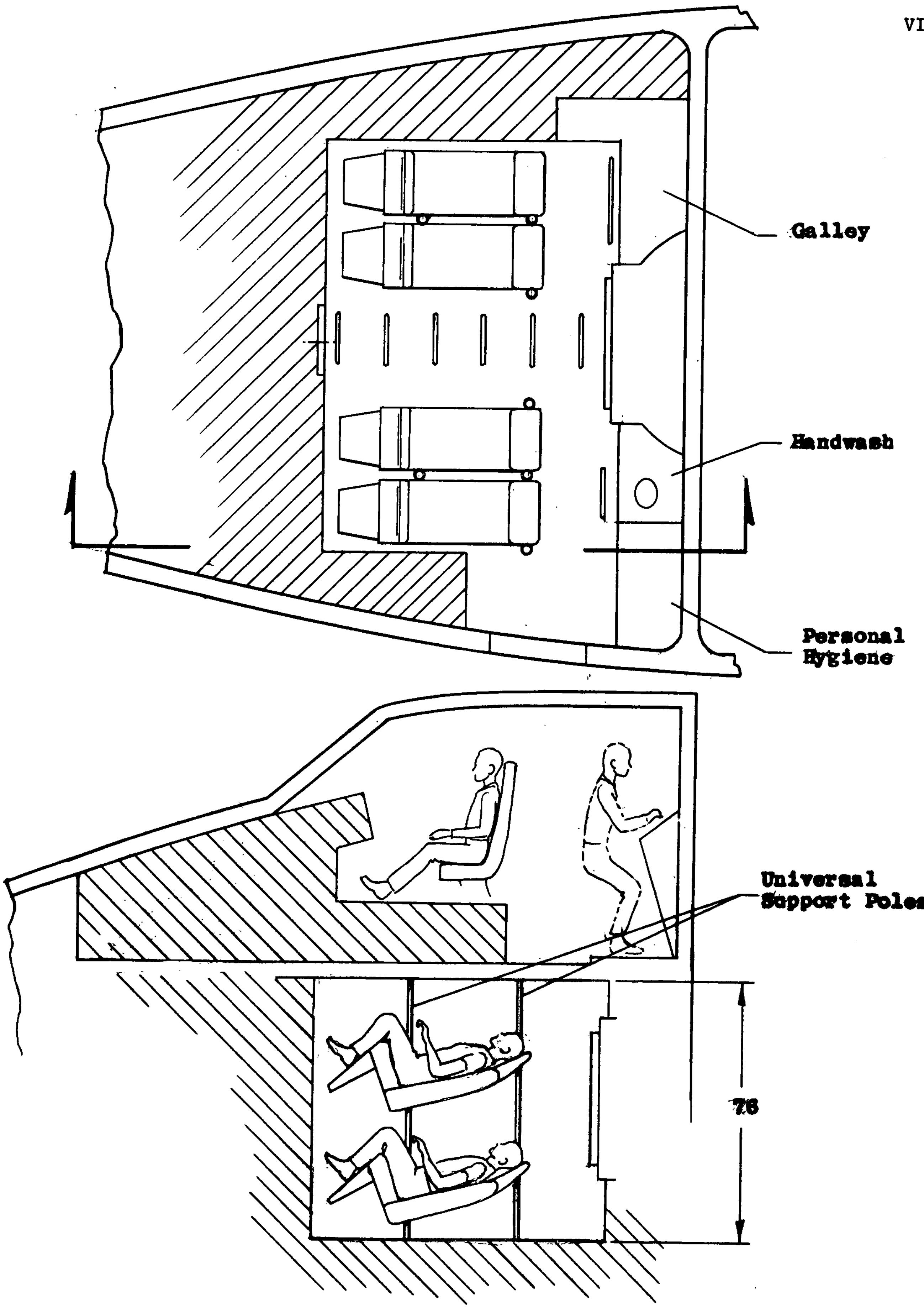


Figure VI-3 Shuttle Crew Compartment Layout - Reentry Flight Mode

The layouts for the three operational modes shown in Figures VI-1, 2 and 3 provides a good sound compromise with the Shuttle crew compartment volume. The design features provide a satisfactory habitat as well as a clean structural design. As recognized from the layout, the key to optimum volume utilization here is a mini-couch capable of being easily relocated for each functional mode. The mini-couches are used in conjunction with seven (7) - universal support poles which attach to the vehicle structure with extendable fixtures and to various attach points on each couch with quick disconnects. These poles provide support and also act as pivot points for the couches to facilitate access to equipment bays behind the couches (zero gravity). The couches themself would be somewhat austere compared to the full size couches previously considered, but the essential features would be retained - multiposition seat, personal storage, sleep restraint, arm rest with tray attach points, and clerical tray and trash/wipe receptacle. The mini-couch would not pivot about its longitudinal axis (since it repositions in total and launch position is also valid for emergency abort and landing); it would not contain any electrical systems - lights, fan or stereo. These electrical systems would be provided within the crew area structure. The fan would not be necessary since no privacy curtain would be incorporated. Of course, all of these features could be retained, if volume, weight and power constraints allowed for them.

This layout also took into account all of the design problems encountered during each series of test conducted during the study. The following list details the benefits of this design over that configuration tested:

- Accommodate up to 8 personnel (2 on Flight Deck) with 7 feet - 4 inches x 11 feet (Rockwell allows 7 feet x 7 feet with no couch provisions). The 11 feet could go to 10 feet if access is reduced.

- Eliminates excessive access heights to any point
- Allows use of personal hygiene unit on pad with no tilt requirement for equipment
- Allows use of fecal/urine collector with handwasher free for other crewmen
- Gives direct access to crew compartment
- Mini-galley is still efficiently arranged
- Mini-couches may be easily reoriented for launch, zero gravity or horizontal one gravity flights
- The galley could be serviceable in all operating modes.
- There is good access to all equipment

- Access to the crew couches is good in all modes (corner position is tight, but acceptable)
- Opens up nice volume for zero gravity
- The work area is separated from the living area (the payload specialist is on the flight deck)
- Occupants in the couches when in zero gravity have no trouble with visual contact since they are facing each other
- The walk areas on consoles and equipment is minimized considerably
- The passengers/crew do not have to carry packages up vertical heights (maximum height - 7 feet - 4 inches)
- The smaller space provides excellent mobility conditions
- The volume is utilized better through space sharing, e.g. the personal hygiene unit access is also a passageway
- The traffic patterns from Galley to couch is a direct line in zero gravity with no interference

There are several disadvantages of course to this design layout which are recognized as follows:

- The hatch into the airlock door would track up to the ceiling when open (this reduces ceiling height, but not a significant problem)
- The couches would require positioning in the crew compartment after most checkout is completed in the equipment bays surrounding the crew area
- The corner couch occupants would have to climb over the inboard couches
- Ladders in the "floor" would still require caution
- Only the urinal could be used in the horizontal flight mode

Despite these disadvantages, it appears that the layout shown integrates the study results into the current Shuttle design concepts in an acceptable manner.

B. EFFECTS OF DUAL, ONE/ZERO GRAVITY, ON A/E DESIGN

Several areas exist where specific design criteria for a vehicle which must operate in two orientations of one-gravity and zero-gravity environments have been identified. Those criteria are presented in the following paragraphs with a brief discussion of each area.

1. Locomotion - Movement from one point to another in a vehicle that operates in the dual environments of one-and zero-growth will be dictated primarily by the one-gravity mode. Another major consideration is the two orientations of a vehicle in the one-gravity mode. This factor requires special aids in access to various areas and the design of hatchways and furnishings to facilitate operation in the two orientations. The designs for the transfer of personnel and equipment when the vehicle is in a verticle position is deemed to require the more extensive aids. None of these aids should hinder the operation in either the other one-gravity orientation or zero-gravity.

The following design criteria applies:

- Strategically placed ladders and hand holds to gain access to work platforms and to furnishings. An aid is required if the height to be negotiated is above 20 inches.
- Structures with built-in foot/hand holds.
- Platforms where required for walkways, to service equipment, and to protect equipment that due to orientation becomes susceptible to being stepped on or otherwise damaged.
- All furnishings shall be designed to provide hand holds or stepping locations.

2. Door/Hatchway Design - The design of doors and hatchways for one/zero-gravity dual usage is again dictated primarily by the requirements of the one-gravity environment as the minimum sized doors/hatchways for one gravity are more than adequate for the zero-gravity environment. However, the technique employed in opening or closing a door/hatchway is directly affected by the design and the required access volume to a room, module, or area. Sliding type doors require the least amount of volume for access to a particular area, provides stabilization aid, and are easily operable in both one and zero gravity. Specialized requirements, such as the airlock which must maintain pressurization, will dictate a different type of doorway and would require some type of hinged doorway. For these specialized requirements where hinged doors must be used, the positioning of the door is important to take advantage of existing volume. As in a module like the airlock, where the hatchway to the exterior should open into the volume, it is desirable to position the hatch so that it

opens on the same side as the hatchway to the interior of the vehicle to provide maximum clear area for equipment and restraints. A typical hatch would operate by coming straight off the seal a short distance and then swing to the side.

Normal aircraft or shipboard size doorways would be suitable for zero/one-gravity vehicles exterior doors and the sliding or tambour door for access to interior areas that require privacy. The hatchway to the flight deck could serve a multiple of uses beside a positive separation between the two occupied areas. The other uses include a platform to protect equipment during on-pad operation, a platform to gain access to the pilot/copilot seats, and as a platform to operate other stations on the flight deck.

3. Furniture Design - The design of specific furniture items for one/zero-gravity dual is dictated primarily by the functional requirements of one gravity and the greater than one-gravity loads imposed by launch, reentry, landing, and crash conditions such as the seat/couch support. All other items must be structurally designed for the greater than one gravity to maintain structural integrity of the vehicle. Therefore, the furnishings will be designed to accommodate the anthropometric dimensions of the crew/passengers and the functional requirements. This will include safety devices incorporated into the design of door openings to equipment and for items stored within compartments to withstand all anticipated "G" loads.

4. Related Design Factors - The following design criteria, although not directly applicable in any of the above areas, are presented as meaningful extensions of the data developed.

- Nominal arrangements will primarily be dependent upon vehicle configuration and the requirements that are imposed by the actual missions. The next probable design constraints will be the one/zero-gravity operations in providing safe and efficient work areas.

- Emergency egress for a vehicle that could have as many as 10 crewmen/passengers must receive special considerations as to escape routes and devices.

- Airlock hatches operating latches must be of sufficient size to allow operation by a crewman in a pressure suit. In conjunction with these handles, hand holds or foot rails should be located to facilitate opening the hatches.

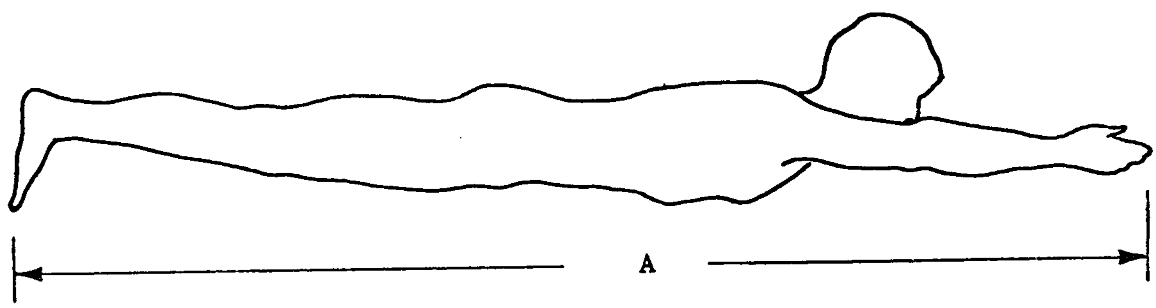
- Crew/passenger couches when in position to take greater than one-gravity loads in one gravity are not compatible for some habitability tasks such as eating due to the angle the tray is with respect to the normal gravity vector.

- Shared access volume can be utilized to a great extent in the area occupied by the six couches as tasks are unrelated and seldom will two occupants be performing the same task that requires sharing of access at the same time.

C. MAN MODEL FOR ZERO GRAVITY

The following data further defines the characteristics of a man in a zero-gravity environment. This definition is provided to make the designer aware of man's actions in this environment which could effect the man-machine interface design.

a. Translation in Large Volume - During translation along a path greater than the body stature length, the subject usually pushes off with his feet, soars approximately parallel to the defined path with his head tilted back such that his eyes are also parallel to the path. The arms and hands are extended parallel to the path which in effect lengthens the body envelope dimensions. This is illustrated in Figure VI-4.



A=81.5 inches for 5 Percentile
A=92.4 inches for 95 Percentile

Figure VI-4 5 and 95 Percentile Length During Zero-Gravity Soaring

b. Translation in Small Volume - Zero-gravity maneuvering in a small volume, such as a personal hygiene module is usually accomplished with the body orientated to the task to be accomplished. The hands and arms are used extensively during the maneuvers with the feet utilized only for restraint and stabilization.

c. Degrees of Motion - Five degrees of body motion are primarily utilized in the locomotion process. These are translation in X, Y and Z planes, pitch about x-axis and yaw about the z-axis. Roll about the y-axis is seldom utilized. See Figure VI-5.

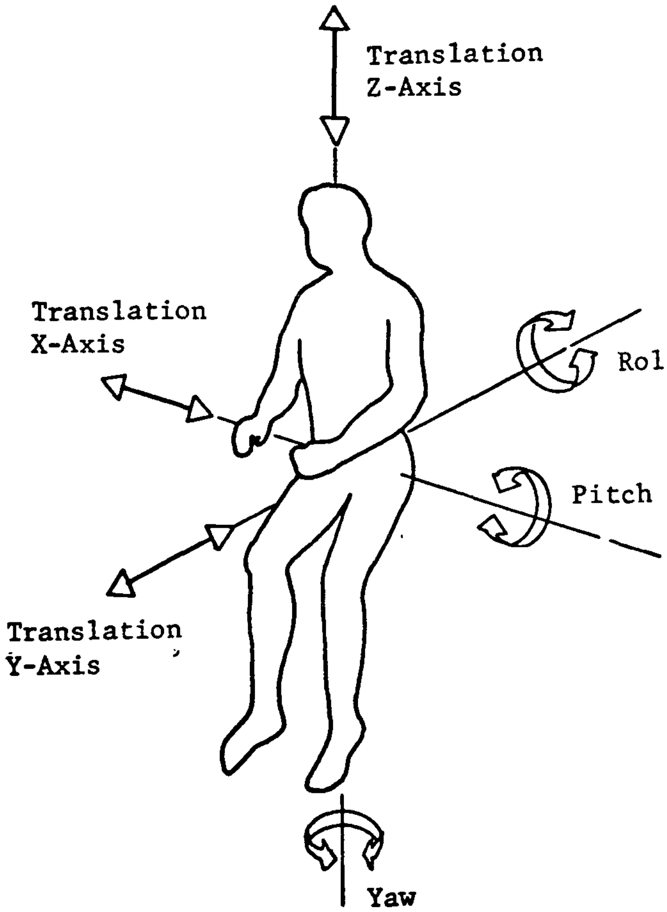


Figure VI-5 Degrees of Motion Possibilities

d. Mobility/Restraint - In a zero-gravity environment, the hands and arms are utilized to a greater extent during locomotion than in one gravity. The feet are normally utilized as mobility aids for propelling, whereas the hands are utilized for guidance.

e. One-Gravity Versus Zero-Gravity Usage of Limbs - In one gravity, the heels and ball of the feet are utilized during the locomotion and stabilization process. In zero gravity, the heels of the feet are utilized less and the ball of the foot and the toes are utilized more. During zero-gravity stabilization, the leg muscles are utilized much more than in one gravity standing. The calf and upper leg muscles are primarily affected.

f. Increase Stature Height - In the absence of gravity, actual body measurements of the stature height is increased. Neutrally buoyant conditions increase the stature height as much as 5/8 of an inch. In true zero gravity, this stature height may be increased even more. See Figure VI-6.

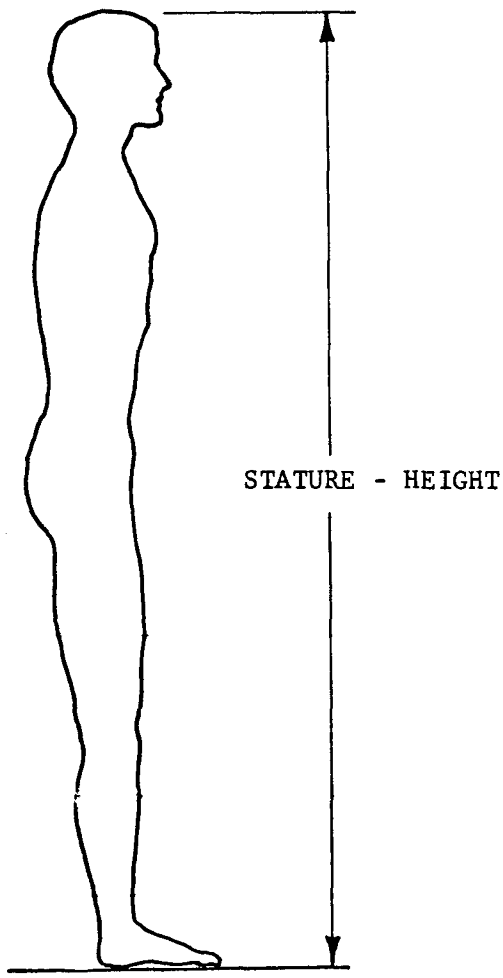


Figure VI-6 Stature Height Increases as Much as 5/8 of an Inch During Neutrally Buoyant Conditions

D. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The data generated during this contract was design criteria and considerations applicable to a manned vehicle in a dual gravity environment. This criteria was published as a second supplement to the "Architectural and Environmental Handbook", NASA-JSC Document 03909. This criteria included development of concepts for a shuttle galley, personal hygiene facility, crew/passenger couch area, airlock, system station and flight deck access. The criteria was based on results obtained from the testing phase of the contract and is presented in the following paragraphs by applicability to the mode as tested.

1. Horizontal One Gravity Mode

With the vehicle in the horizontal attitude in one gravity, several design considerations were determined. The following significant items should be considered under the condition of horizontal one-gravity operations:

a. Personal Hygiene Unit - The seat angle must not exceed 30° from the horizontal and should be less than 10° for assured comfort. At a seat angle of 30°, a lap belt restraint is required. Operations of controls become difficult and the wipe up procedures require the man to stand up and away from the seat. This also requires the equipment to operate at a tilt. If the seat angle exceeds 30°, it becomes almost impossible to use the collector remit. This condition of seat angle is a definite nuisance. A solution to this would be to rotate the seat from horizontal to vertical when changing shuttle operational modes; however, this would entail a considerable design change in the personal hygiene collection unit, and very poor volume utilization. The more practical solution would be to orient the seat for either vertical or horizontal one gravity useage, ruling out one or the other or orient the seat for optimum collection unit efficiency in one mode of one-gravity while maintaining volume utilization considering zero-gravity operation.

b. Crew/Passenger Couches - Access to the upper crew couches was noted as a real problem. There was not enough space to easily obtain entry and also exit especially under emergency conditions. If the couches had been lower this problem would have been alleviated, but then the space envelope of the lower couch would have been violated. This lowering would also produce other problems in the vertical launch mode. If the problem is to be eliminated, either the ceiling height must be raised or the upper couches must be capable of assuming two positions - an upper for vertical operations, a lower for horizontal operations. The upper couches also suffer from poor servicing and convenience conditions too. The same solutions would also relieve these problems. In conjunction with the couches, an associated problem also exists with the passageway space from forward to aft. If adequate walkway space is provided, valuable equipment bay space is lost. If on the otherhand such passage is not provided, a safety hazard would then exist. It must be for the NASA to decide rather the nuisance of climbing over crew couches is acceptable for the horizontal position or if passageway space must be allotted. It appears from the testing that for the short duration of horizontal operations, the nuisance could certainly be tolerated if the safety aspects do not override this condition. All couch activities could be performed efficiently except eating due to the requirement to either hold the food tray or sit it on the stomach which is very awkward. Fluids would be very difficult to handle.

c. Flight Deck - Another nuisance factor which became obvious during testing was the ceiling height within the flight deck (64 inches). This condition will require considerable safety features in all equipment and controls placed in the ceiling. This is especially true for ingress/egress from the pilot and copilot seats. The center console further reduces the usable head height during such movements and acts as an effective obstruction. The seats should be moveable forward and back to assist in this area. If the tested head height is maintained, the operations in the horizontal mode will probably be noted as a real "headache" literally.

d. Mobility Aids - Ladders may become nuisance or safety hazards under the horizontal mode of operation. For instance, the ladder rungs attached to the "wall" during the on-pad launch mode are located on the "floor" during horizontal orientation. These represent safety hazards and would require special markings to avoid tripping. Ladders up the walk also produce protrusions from the wall which may intefere with passage or mobility. The ladder used between the crew area and the flight deck must be removable if entry is to be made, into the payload bay. This would provide a nuisance for horizontal servicing if the ladder must be frequently moved.

e. Walls vs Floors - Walls used as flooring in the vertical position will require special grid or walk areas, any controls, cabinets, equipment, etc. located on these walls must be sufficiently protected to prevent damage from shoes or the full weight of a 95th percentile man. These problems are interchangeable between the two one-gravity modes.

2. Vertical One Gravity Mode

When the vehicle mockup is in the vertical, on-pad, attitude there are several significant design considerations. The following areas were noted as being significant in the design of man-machine interface criteria.

a. Ladders and Packages - The test results proved that the climb up to the upper couches was greatly hampered when attempting to carry packages. This held true for both male and female test subjects. The problem stems from the limitation of one hand to climb with when the other hand is holding an object. This is, therefore, a real safety hazard as well as a nuisance. It is obvious too, that if a Shuttle passenger enters in a suited conditions, he will have difficulty in the same manner. One solution to this problem may be the addition of transfer devices, but this would add weight and take valuable space. Another answer which would have the least impact on the Shuttle, would be to provide special GSE Platforms capable of being removed by launch technicians after the passengers are fully situated and prior to closing the hatch. Any attempt to provide stairs in place of the ladder would only prove completely unsatisfactory from the spacecraft systems requirements.

b. Ladders and Handholds - A brief review of Table IV-6 in regard to access, servicing, locomotion ease and convenience will fully illustrate the inadequacy of ladders and handholds throughout the Shuttle Nose when in the vertical position. This condition is created by the increase in height for access above the aft bulkhead. The most logical solution to this inadequacy is to provide additional ladders and handholds in the form of GSE for complete vertical mode servicing. This solution is a valid one in that after all equipment has been checked out, there is no need for extensive equipment access. The crew compartment would only need provisions for access to the various launch seats or couches. Also, after launch, any added ladders or handholds would become superfluous in zero gravity or the horizontal flight mode.

c. Walls vs Floors - The multiple use of wall or floor surfaces must be considered, especially where such surfaces certain contact consoles or equipment bays. These surfaces should provide safe walking paths and all controls or protrusions must be well protected. This, of course, must be accounted for in zero gravity design also since all surfaces may be contacted by a crewman. However, this is more critical in the one-gravity operational modes because of the increased loads. This is a structural problem which may be easily solved by proper surface design, but the designers must be aware of the conditions.

d. Hygiene Unit - Because of the design of the hygiene facilities equipment and the physical orientation to one condition (horizontal), only the fecal/urine collector is usable in the vertical position. Even this piece of equipment becomes quite a nuisance factor if the seat is at an angle (this requiring equipment rotation). Using the configuration tested, if the seat was rotated to a comfortable position there would be interference with the head and opposite wall if the facility was used on the pad. The other equipment is totally unuseable since it is 90° out of plane for normal service. There are only two possible solutions to these conditions - eliminate any use of the hygiene unit while in the vertical position, or make the necessary operable equipment rotate and provide sufficient head and leg room for proper functioning. Access to the hygiene unit is also an associate problem since it too was 90° out of place. This was minor and could be allieviated by a proper door design and entry mobility aids.

e. Galley - The galley was simply not designed for vertical on pad usage. Since no crew usage is anticipated in the mode of operation, it represents no real problem to them. However, it does strongly suggest that all galley servicing be concluded when the Shuttle is in the horizontal position prior to mating with the booster.

f. Equipment Bay Access - This problem is directly related to items 1) and 2). The soltuions are also the same - provide as much servicing to the equipment bay prior to placing the Shuttle in the vertical position, and using GSE to gain access while on the pad.

g. Couch Access - The problem with access to the upper (forward) couches is more than just the ladders. The test subjects had to reach over to the couch and swing or crawl over to position themselves in the couch. This is quite hazardous from heights up to 16 feet. It appeared that additional handholds would have helped, but a relocation of the ladders would have helped even more. One possible solution would have been to have had a ladder capable of being located in an optium location for the vertical position and relocated after orbit insertion. Locating the ladder in the center of the couch rather than the end position would aid considerably in gaining access. The ladder should also be 90° to the rotational axis of the couch. Another possible solution would be to have access platforms at each couch level.

3. Simulated Zero Gravity - Neutral Buoyancy

The neutral buoyance test verified that orientation does not adversely affect the performance of habitability tasks. There are some areas, however, such as transfer procedures which is unique to a zero gravity environment. The following is a brief summary of the neutral buoyancy testing:

a. Couch Area

- Couch mounting orientation was not dictated by zero g and was useable in either the y-axis or z-axis mounting.
- All couch belt restraints could be operated in zero g, however, the lap belt in conjunction with the foot rail was all that was required to provide complete body stabilization and control.
- The couches provided good mobility aids in the couch area, such as hand holds, kick-off places, etc.

b. Galley

- The foot rail and hand rail in front of counter provided adequate restraint and mobility aids.
- The galley operations were accomplished with no problems in stabilization, orientation or accessibility to all areas of the galley.

c. Personal Hygiene Unit

- The 54.7 cubic feet of usable volume of the unit was sufficient for all tasks performed in the area.
- Donning and doffing of clothes depended somewhat on individual techniques, but foot rails and hand holds are necessary.
- More positive body control when operating the hand washer control valve could be achieved with a valve that was actuated by lifting the toes of one foot in lieu of pressing down and thereby keeping the heel stationary.
- Temporary clothing storage areas were required to hold a minimum of one change of clothing.
- Toilet seat angle for defecation can be at any angle that provides a minimum of 40 inches of open space normal to and above the toilet seat.

- A lap belt was required to maintain body contact with the toilet seat with both hands free.
- Urination collection device for males should be flexible in design to allow for the height of the 5 to 95 percentile males.

d. Flight Deck

- The ladder required in one gravity provided a very good mobility aid to the zero-g simulation.

e. Work Station

- A work station will require a sitting restraint with freedom to move the upper torso considerably to permit full operation of a large console.

f. Mobility Aids/Restraints

- Some specific mobility aids such as hand holds, were required to supplement the aids incorporated into the equipment design.
- Handholds must be designed to permit a torque to be applied by the hand.
- All surfaces within the volume must be able to withstand an impact force of the crewman and/or the force of the crewman pushing off from the surface.

g. Traffic Patterns

- Traffic patterns were dictated by equipment location and orientation in conjunction with the tasks to be performed.
- Body positions could be readily changed during translation to be properly oriented to the area that was being approached.

4. <u>General Design Considerations</u>

Throughout the test phase, there were some aspects that were not strictly related to any particular orientation of vehicle mode of operation. These items are presented here as general Architectural/ Environmental design considerations as follows:

- Storage areas below knee level (22 inches) should be pull-out drawer for better accessibility and visibility of contents.

- Storage areas above 54 inches from the floor should be swing-out doors for access

- Storage areas between 22 inches and 54 inches from the floor can be of any type access (swing - out, sliding, or pull-out drawer)

- High useage areas and equipment should be placed between 30 inches and 54 inches from the floor.

- Counter space in the galley was adequate and height (40 inches above floor) was satisfactory for all test subjects.

- Food trays in the galley were centrally stowed and at a height (66 inches to 78 inches) that was acceptable for all test subjects.

- Waste disposer in the galley was located 2 inches above and on the right side of the work counter which was easily accessible with either hand. Controls were located between the disposer and oven.

- Cleaning wipes in the galley were located on the left side of the work counter and easily accessible with either hand.

- Traffic patterns in the vertical mode are hindered by the orientation of all the equipment to the horizontal mode.

- When the vehicle is in the vertical position considerable effort is required to move from one area to another as one must climb up or down ladders, duck under objects, walk stooped over, and/or crawl on the hands and knees.

- There is no direct path between any two areas when the vehicle is in the vertical, on-pad, attitude.

- In a multiple orientation vehicle with the volume of the Shuttle Orbiter, the requirement for mobility aids is almost doubled. Specific mobility aids can be significantly reduced by designing the interior where walls in one orientation can be used to walk on in another orientations.

- In a zero-gravity environment and traffic patterns dictate a change in direction, a requirement for a mobility aid/restraint exists. The mobility aid/restraint can be a specific handhold or designed into the equipment/structure.

- Since handholds are used to provide a torquing motion as well as direct push-pull forces in a zero gravity-environment, the design of the handhold must account for the torque action.

- All surfaces within the volume of the vehicle must be able to withstand an impact force of the crewman and/or the force of the crewman pushing off from the surface.

5. Time Lines

Time required for various tasks was obtained during the various phases of testing and are provided in Table VI-2. It is significant to note that generally times required to perform the same task in a simulated zero-gravity environment were longer than when performed in the one-gravity sequence. The exception was during locomotion from the exist hatch to the flight deck and egressing from the work station to the top couch in the vertical one-gravity mockup mode. In both cases, the subjects had to climb ladders in the one-gravity mode whereas in the simulated zero-gravity mode the subjects could use the ladders as mobility aids. Times were generally higher for the vertical one-gravity mode when compared with the horizontal one-gravity mode due to climbing over objects and up ladders. The exception to this was when the subjects egress from the lower couch to the exit hatch. During the vertical one-gravity mode, the subjects simply swing from the lower couch onto the work station wall and exited through the hatch.

Table VI-2 Times Versus Tasks

TASK	TEST PHASE OF MOCKUP		
	HORIZONTAL ONE-GRAVITY (Seconds)	VERTICAL ONE-GRAVITY (Seconds)	SIMULATE ZERO-GRAVITY (N.B.) (Seconds)
A. Locomotion:			
1. Exit Hatch to:			
a. Payload Station	8	10	--
b. Flight Deck	20	55	23
c. Lower Couch	15	17	--
d. Upper Couch	--	11	--
2. Exit Hatch From:			
a. Flight Deck	7	20	27
b. Lower Couch	15	6	--
c. Upper Couch	--	13	--
B. Couch Functions			
1. Sitting to Sleeping	9	9	20
2. Egress Obtain Food Tray	11	--	25
3. Ingress From Galley	13	--	18
C. Galley Functions			
1. Scullary	48	--	70
D. Personal Hygiene			
1. Ingress Thru Door	3	7	13
2. Close Door	2	--	4
E. Airlock			
1. Ingress			
a. One Man	--	--	27
b. Two Men	--	--	45
2. Donning Pressure Suit	--	--	99
F. Work Station			
1. Egress to Top Couch	--	11	10

6. Man-Machine Interface Criteria

a. Male Urinal Height Location - The male-urinal interface becomes a critical man-machine problem since free droplets of urine can create bacteria and machine problems. Therefore, it is necessary that the penale height correspond to the urinal opening. The vertical distance from the floor to the upper edge of the juncture of the penis with the abdomen varies from 31.6 inches to 37.4 inches for the 5 to 95 percentile males. Males can increase this height by 1.6 inches by raising up on their toes or they can decrease this height by bending the knees forward. When bending the knees forward to lower the penale height vertically one inch, the knees must move forward approximately three inches on the horizontal as shown in Figure VI-7.

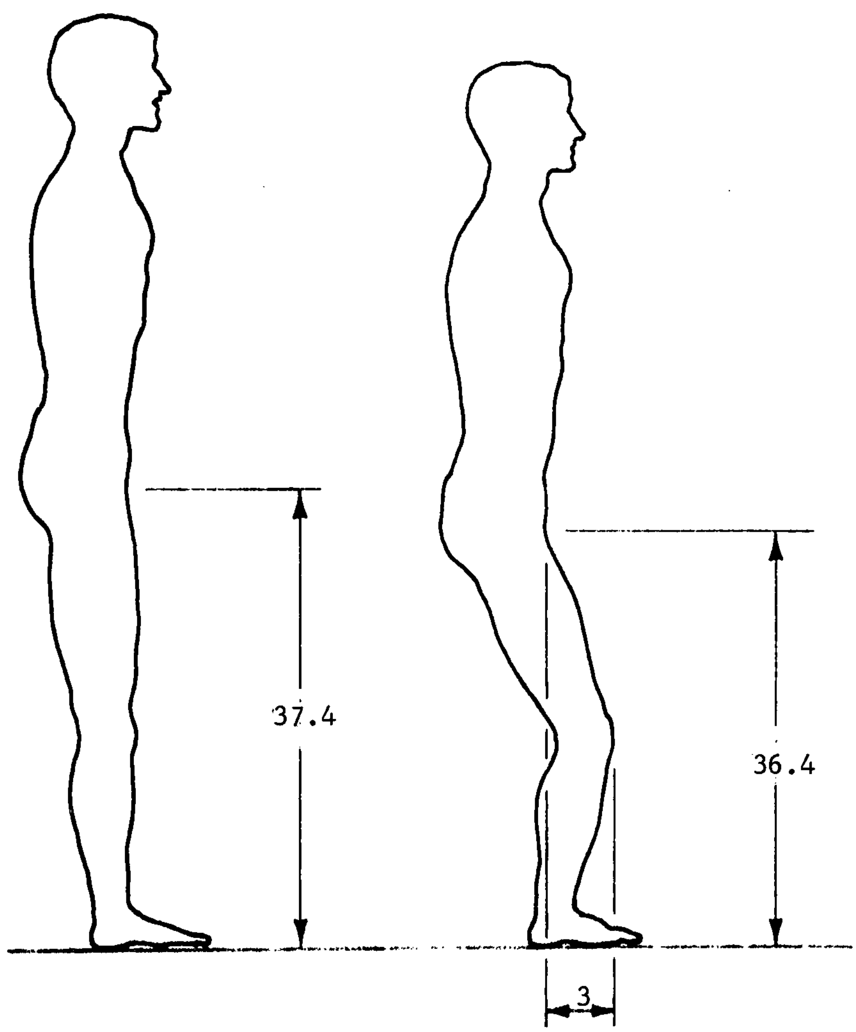


Figure VI-7 Knees Must Move Forward Three Inches for Vertical Drop of One Inch

b. Male Urinal Hand Restraint

When a male micturates, a specific three point restraint is necessary to assure that the man-machine interface is properly aligned. Proper alignment can be achieved by placing both feet under a toe bar and by placing one handhold directly behind and on the urinal opening centerline as shown in Figure VI-10. This restraint arrangement prevents torquing the body away from the urinal opening such as would be the case when utilizing a hand restraint on the side of the urinal.

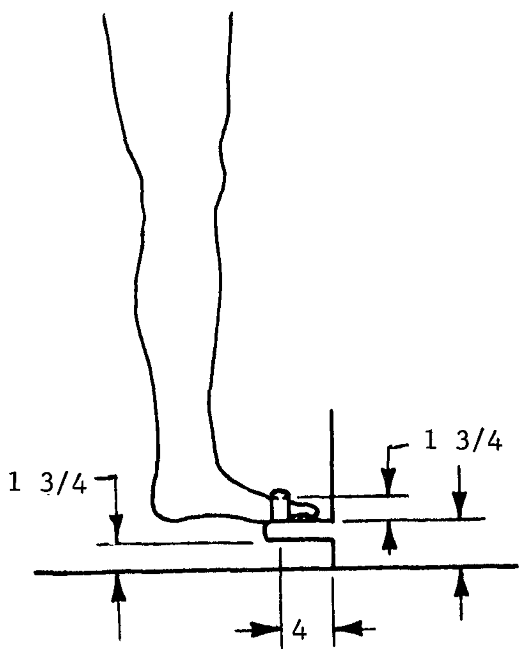


Figure VI-8 Two Step Foot Restraint to Allow Constant Urinal Height for 5 to 95 Percentile Males.

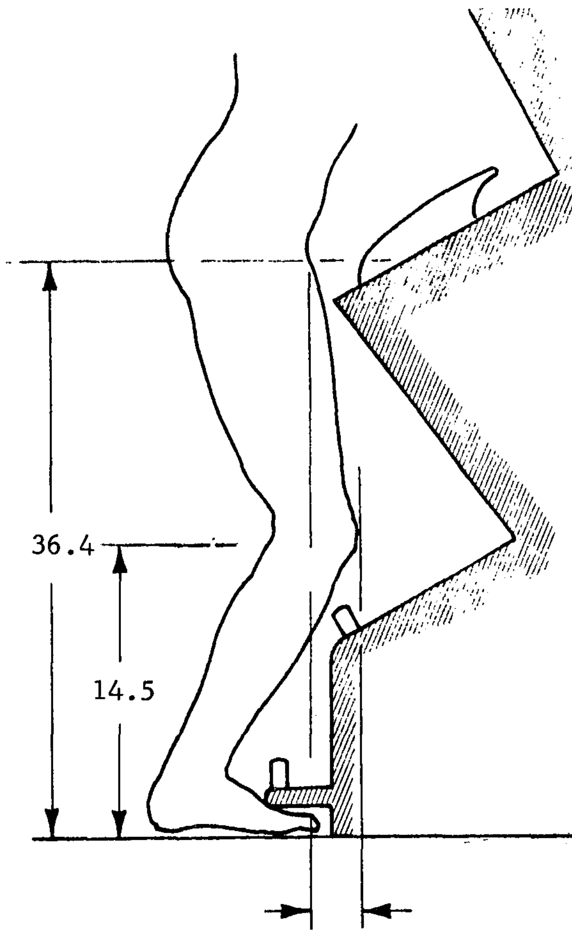


Figure VI-9 Slope & Recess Required Below Urinal Opening to Accommodate Lowering the Penale Height One Inch

b. Male Urinal Hand Restraint

When a male micturates, a specific three point restraint is necessary to assure that the man-machine interface is properly aligned. Proper alignment can be achieved by placing both feet under a toe bar and by placing one hand on a handhold directly behind and on the urinal opening centerline as shown in Figure VI-10. This restraint arrangement prevents torquing the body away from the urinal opening such as would be the case when utilizing a hand restraint on the side of the urinal.

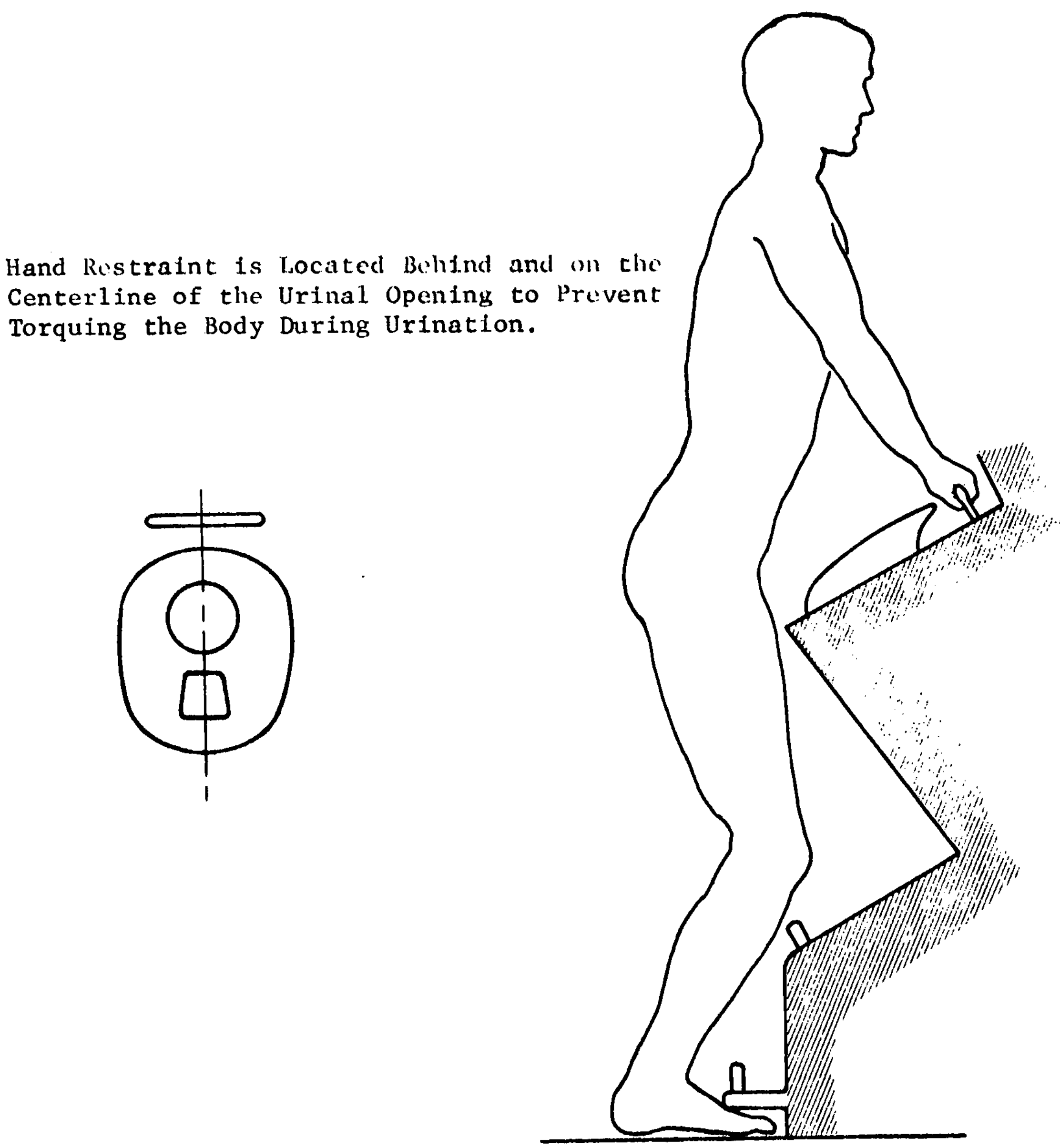


Figure VI-10 Urinal Hand Restraint

c. Foot Operated Levers

In a zero-gravity environment, it is desirable to utilize foot operated levers for activation of systems so that the hands can be free to perform tasks. It must be realized that the feet are also utilized in restraint to stabilize the body. If the lever is activated by pushing down, the foot is being directed away from the foot restraint bar and the return spring action of the lever will torque the body away and around the opposite foot. This may be corrected by lifting the toes up to activate the lever. This allows the foot to remain in contact with the foot restraint and maintains body stability. See Figure VI-11.

NOTE: ALL DIMENSIONS IN INCHES

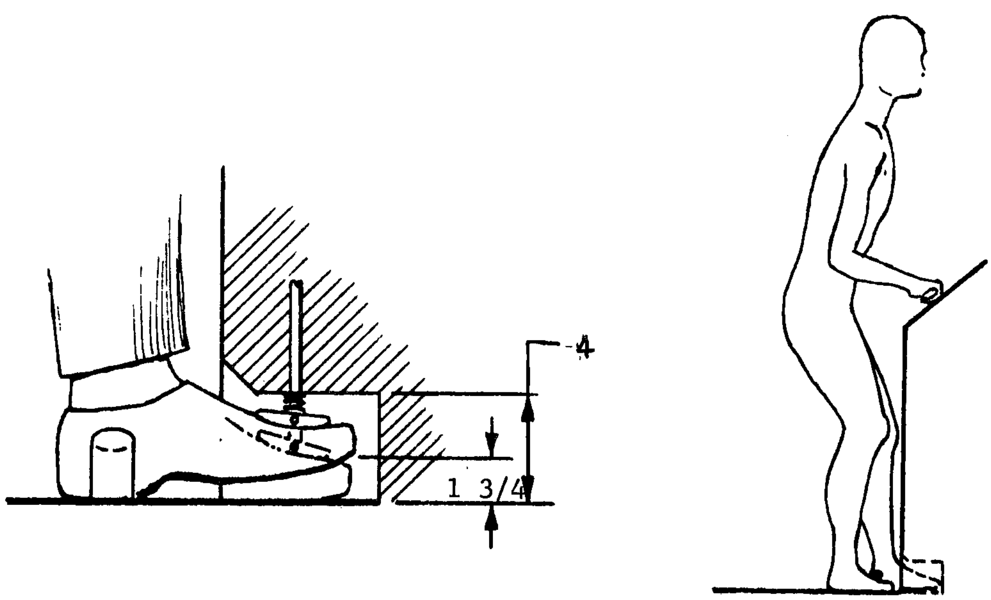


Figure VI-11 Foot Operated Lever is Activated by Lifting Up With Toe thus Keeping the Foot in Contact With the Toe Bar for Body Stability.

d. Stowage and Work Area Accessibility/Visibility Requirements

When utilizing toe rails accessability and visibility of contents in cabinets located below the knee level (22 inches) should be provided by pull-out drawers when the crewman is restrainted by a toe bar. This is illustrated in Figure IV-6.

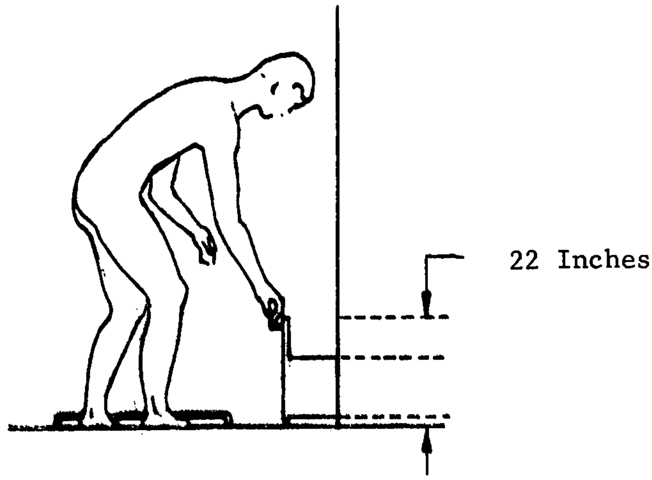


Figure VI-12 Utilize Pull-Out Drawers Below Knee Level for Better Accessability and Visibility of Contents When in Restraints Position.

Accessability and visibility for storage areas above 54 inches should be provided by swing-out doors as shown in Figure VI-13.

NOTE: ALL DIMENSIONS IN INCHES

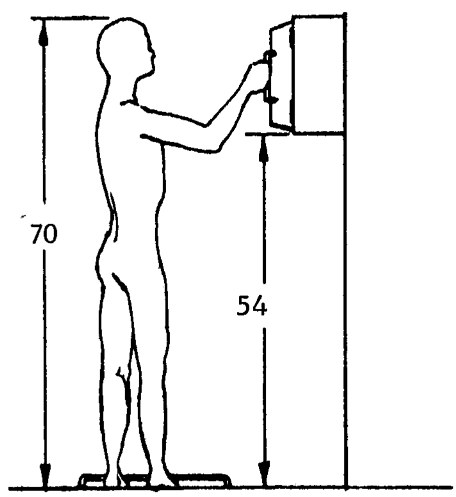


Figure VI-13 Utilize Swing-Out Doors above 54 Inches

Doors that are required to swing-out, such as refrigerators and freezers, should be located above the knee level (22 inches) so that the feet do not have to be repositioned. This point is illustrated in Figure VI-14.

NOTE: ALL DIMENSIONS
IN INCHES

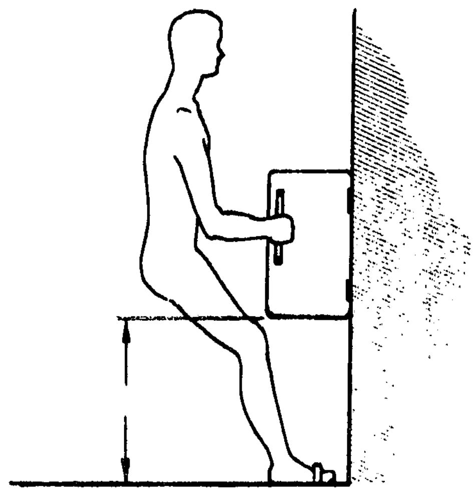


Figure VI-14 Swing-Out Doors Should be Located 22 Inches Above Floor to Avoid Contact With Knees of Restrained Personnel.

For efficient accessability and visibility high usage areas and equipment should be placed between 30 and 54 inches from the floor and counter space should be located 40 inches above the floor. These points are illustrated in Figure VI-15.

NOTE: ALL DIMENSIONS
IN INCHES

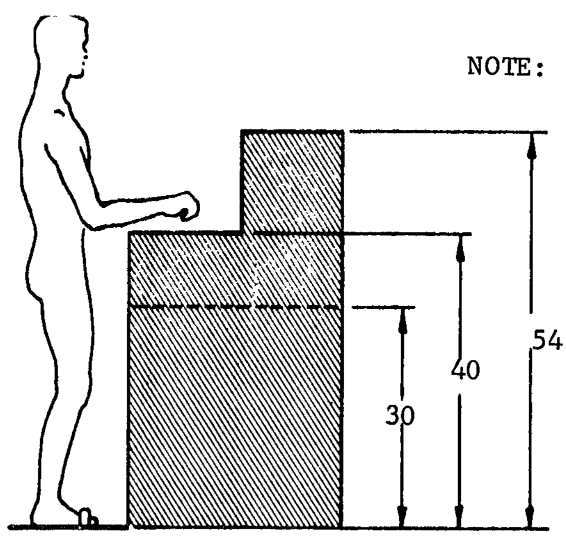


Figure VI-15 Dimensions for Counter and High Usage Equipment.

e. Doors

Doors such as a personal hygiene privacy door, should be designed to incorporate mobility/restraint aids to allow ingress/egress through the opening without separate aids. This could be accomplished by utilizing a split door that allows each half to slide laterally opposite the other half. Each half of the door should contain a hand restraint on both sides of the half door as defined in III-A. This will permit a crewman to open the door, ingress/egress through the opening and then close the door. This complete sequence is accomplished by utilizing the hands only. The split doors (tanbour) provide the crewman with equal opposing forces thus aiding in stabilization. See Figure VI-16.

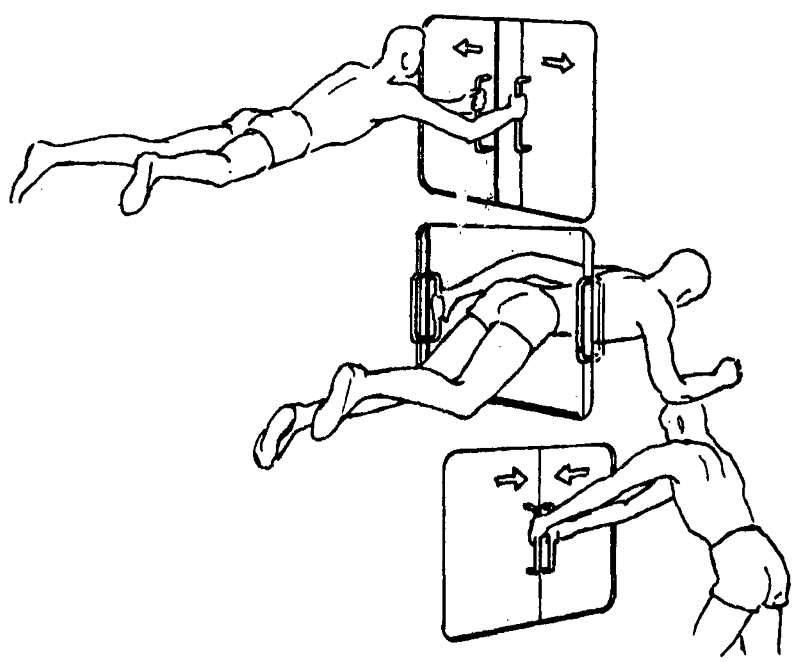


Figure VI-16 Crewman Ingressing Private Area Utilizing Split Door with Hand Restraints on Both Sides of Each Half.