Space Station

WORK PACKAGE 2
ADVANCED DEVELOPMENT

SSS87-0072

HIGH FIDELITY MOCKUP REPORT (FINAL)

PROJECT 30 MANNED SPACE SYSTEMS HABITABILITY

JANUARY 16, 1987

Prepared by: Project Engineering-Advanced Development/
Rockwell/Grumman.
For NASA Lyndon B. Johnson Space Center

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This document is submitted by the Rockwell Space Station Systems Division Advanced Development Project Office in compliance with the Advanced Development Plan (DR-05), Rockwell document No. SSS 85-0011, Revision 4, dated November 10, 1986.

The data contained in this document was generated as part of the project identified in the Space Station Advanced Development Plan as Project 30, Manned Space System Habitability. This corresponds to Grumman IR&D Project S143-301 under the direction of G. Harms. This data was identified and released to the Space Station Systems Division as Grumman document SS005-ATD-09.

ABSTRACT

The objective of Grumman's Manned Space Systems Habitability IR&D project was to develop guidelines and design criteria for Space Station habitat modules by focusing on three related functional disciplines: human factors, interior architecture, and crew support. Specific objectives for interior architecture study were:

- With the aid of scale models and existing mockups, select two or three of the most promising architecture candidates for continued evaluation
- Using full-scale mockups, evaluate the most promising candidates and select the preferred one
- Construct a high-fidelity mockup of the selected concept for in-depth evaluation.

This report presents results of evaluations of a combined habitat interior architecture developed from the "Symmetrical Four Standoff", or "Four Quad", cross-section currently favored by the space community for habitable modules. Descriptions are given of full-size mockups constructed to provide three-dimensional representations of key crew interfaces and accommodations, as well as to provide a realistic means of evaluating crew traffic flow and cargo transport operations.

CONTENTS

ILLUSTRATIONS

1 - INTRODUCTION

This is the final report for the Interior Architecture study conducted within Grumman's Manned Space Systems Habitability IR&D Project described in Reference 1.

The overall objective for the Manned Space Systems Habitability Project was to develop guidelines, design criteria, and concepts for Space Station habitats and habitability functions that will enhance the crew's living accommodations in space, and provide an environment for achieving a high productivity level. Human factors, interior architecture, and crew support disciplines play important, interrelative roles. This report focuses on the interior architecture contribution to this project.

1.1 STUDY OBJECTIVES

- The long-term objective was to select and refine preferred concepts, and to build high-fidelity mockups of the selected habitat configurations
- Develop multipurpose and combined habitat function modules to reflect the growing interest in such concepts
- Utilizing appropriate mockups, develop, demonstrate, and evaluate the following:
  - support structure interfaces for equipment and facilities
  - utilities interfaces
  - manufacturing techniques
  - coordination of work activities with work sites
  - crew use of all crew accommodations
  - common man/machine work station interfaces
  - housekeeping techniques
  - on-orbit maintenance and reconfiguration capabilities

- stowage concepts
- timelines, work duty cycles, and human productivity to the extent practicable at one-G.

2 - SUMMARY

This report focuses on studies performed to determine the feasibility of the combined habitat module concept providing an environment aboard the Space Station that is conducive to high crew performance and productivity, provides the functions necessary for crew health and safety, and incorporates facilities, accommodations, and amenities for crew rest, recreation, well-being, and general welfare.

The interior architecture used to develop the combined habitat arrangement was the "Four Quad" concept adopted by NASA for its Space Station habitable modules. This architecture features a longitudinal open center, square in cross-section, with 11 equipment package locations on each side. The structural mounting for the packages are identical; this allows a high degree of interchangeability and enhances maintenance operations.

A full-size mockup of a combined habitat module was constructed containing representations of functional sites of sufficient fidelity to conduct evaluations of crew work activities at work sites, volumetric sufficiency for crew tasks in enclosed areas (e.g., donning and doffing clothes in crew quarters), traffic flow, and cargo handling. In addition, a higher fidelity mockup

of the galley and wardroom was constructed at Grumman's Houston facility. Crew operations associated with meal preparation, meal serving, dining, and cleanup were evaluated to determine the most efficient arrangement of galley equipment.

The Multipurpose module is a habitable module containing mostly laboratory equipment and experiments, but also contains functions required for crew safety, Station maintenance, command and control, and personal hygiene. Since the Four Quad interior architecture was also used for this concept, no full-size module mockup was constructed because the results of the evaluations conducted in the habitat could be applied to similar operations in the multipurpose module. Moreover, no unique operations were identified to justify the construction for a full-size mockup.

A partial full-size mockup to study utilities and resources lines routing a privoting equipment rack was also constructed and the routing concept evaluated for accessibility and cable motion.

The overall assessment is that the Four Quad interior architecture is a viable concept for a crew living and working environment.

3 - COMBINED HABITAT CONCEPT EVALUATIONS

3.1 RATIONALE FOR COMBINED HABITAT STUDY

This concept was studied briefly in 1985 but was set aside to concentrate on the separate habitat module scenario then in vogue, i.e., "active" and "quiet". However, the space community has renewed its interest in the combined habitat concept for budgetary reasons, since a combined habitat contains all functions and amenities needed to support life aboard the Space Station. Indeed, the "combined" concept has supplanted the "separate" concept for Space Station applications. Moreover, NASA's decision to adopt the Four Quad concept for its module architecture prompted a change in the direction of the IR&D effort from continued development of the Loft interior architecture, preferred as a result of two in-house evaluations (Ref Interim Report SS005-ATD-05 dated 27 March 1986), to the development of the four standoff concept to best serve the interests of the Space Station program.

The combined habitat module concept has the added advantage of achieving permanent manned presence in space early in the build-up of a Space Station. It provides, in a single module, the functions necessary to support a crew for long durations in space, as long as a means for immediate crew return to earth is at hand in case of an emergency.

3.2 DESCRIPTION OF COMBINED HABITAT CONCEPT

The combined habitat incorporates into one module all functions necessary to sustain crew life aboard the Space Station for long duration missions. Living accommodations contain facilities for

eating, sleeping and privacy, recreation, personal hygiene, waste management, and housekeeping. Crew health is maintained by a Crew Health Care System (CHECS) comprising a diagnostic and treatment area, and a separate exercise area. A command and control station affords the means to manage and monitor the Station subsystem, conduct proximity operations, consult maintenance procedures, monitor logistical status, etc. Stowage containers and lockers are provided for general stowage, wardroom equipment, safe haven survival, miscellaneous supplies, and emergency gear. An Environmental Control and Life Support System (ECLSS) provides a constant supply of breathable air as well as potable and hygiene water for crew needs, and cooling water for equipment.

Figure 3-1 shows a typical cross-section of the Four Quad configuration with equipment packages on four sides.

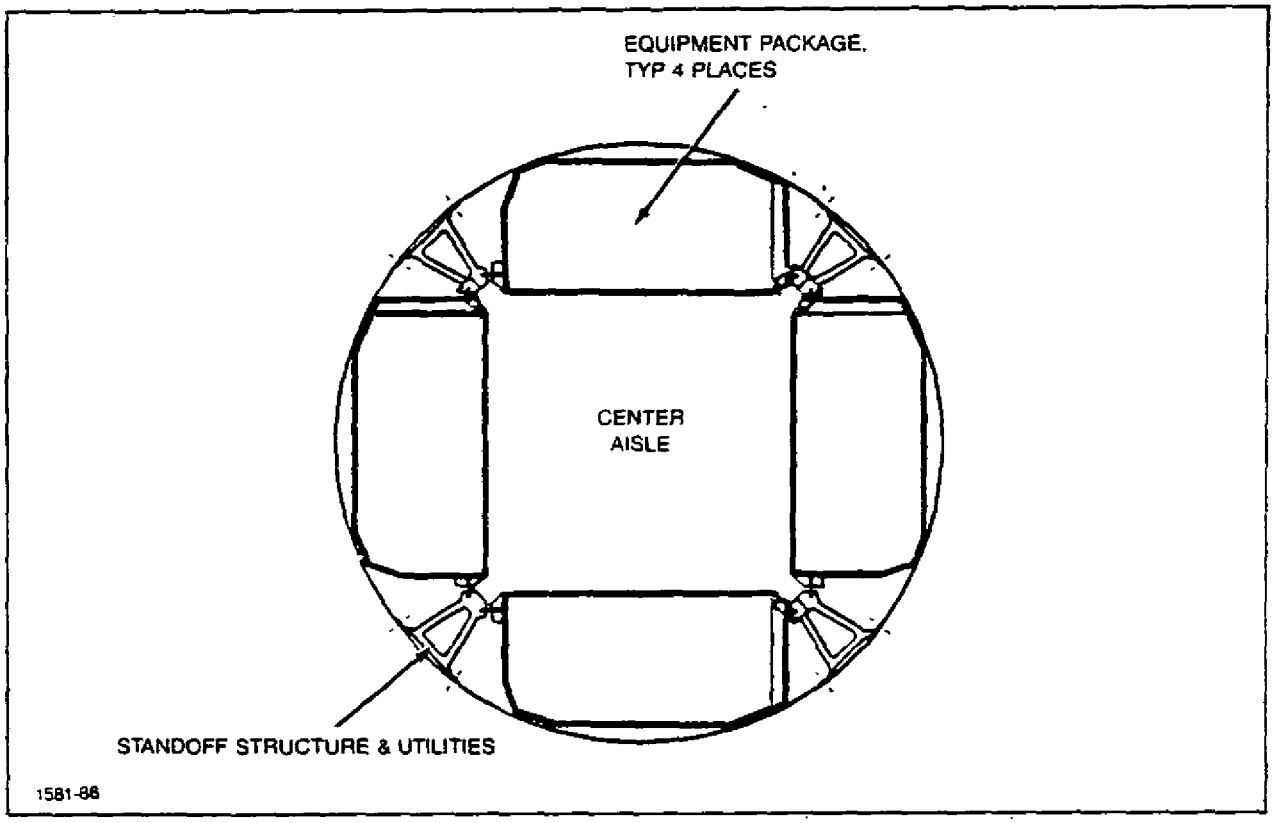

Fig. 3-1 Four Quadrant Concept, Typical Cross-Section

The module plain cylinder length of 11.79 m (38.67 ft) accommodates 11 packages on each of four sides, for a total of 44 package spaces available for habitat outfitting. A crew size of eight people, currently projected for a four module Space Station, served as the basis for this study. As reported previously, not all functions required to support a crew of eight and maximize productivity can be housed in one module of the size (44.5 ft long) currently contemplated for the Station. A maintenance work station and a duplicate personal hygiene and waste management facility must be located in an accompanying module (the multipurpose module in the current Station configuration) to minimize nonproductive time to perform necessary crew functions and provide the necessary functional redundancy.

A major concern of the crew is the ability to rest and sleep undisturbed by noise and vibration, since a good rest is essential to crew productivity, health, and morale. This concern was addressed by dividing the habitat module into essentially three zones, according to the noise level anticipated at the functional sites: quiet; intermittently active; and active. The forward end of the module (in the direction of flight) contains the sleeping quarters for the entire crew. Eight crew quarters are located in four pairs, one pair at each quadrant, to constitute the quiet zone where outside noise is minimal.

In the middle of the module, the CHECS medical facility and personal hygiene facilities are located. The medical facility is used mainly to monitor vital signs and perform blood tests, treat illnesses and injuries, and monitor the atmosphere and water. The noise level is relatively low and occurs infrequently. The personal hygiene facilities are used primarily during hours when the active crew is awake, and the waste management facility is used as needed and is completely enclosed for privacy and contamination control.

The aft portion of the module contains the galley, wardroom, and exercise area. The latter two are considered the most active and potentially the noisiest of all functional sites. As such, they are placed furthest from the crew quarters.

The top and bottom quadrants contain stowage and subsystems.

Figure 3-2 is a topographical map showing an unwrapped representation of the four quadrants and the arrangement of the various functional sites to achieve the three-zone module layout that achieves the goal of providing a pleasant, productive, and safe habitat.

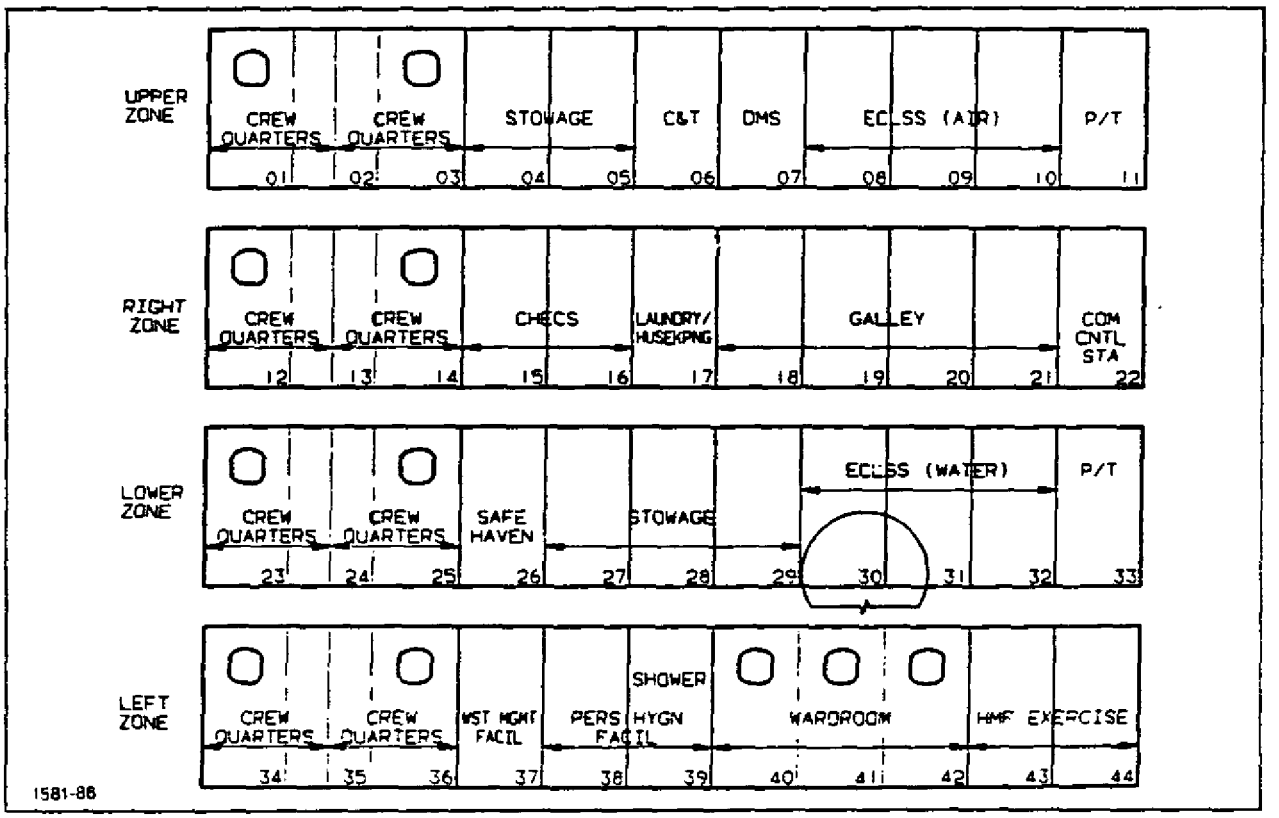

Fig. 3-2 Habitat Module, Topographical Representation

3.3 EVALUATION APPROACH

To evaluate the suitability of the combined habitat for crew living and working, crew operations and man/machine interfaces had to be duplicated with a level of fidelity sufficient to

conduct meaningful task simulations. These simulations were performed by test subjects according to operational scenarios and task timelines developed to simulate real-time activities in the Space Station. These simulations were designed to evaluate traffic flow, e.g., identify bottlenecks, chokepoints, busy traffic areas, emergency egress paths, etc; evaluate crew movement and motions necessary to perform task; evaluate the arrangement of equipment at a functional site from the standpoint of crew ability to perform the task; evaluate efficiency of layout to minimize unnecessary movement; check for unsafe conditions; forecast crew acceptance and effects on crew morale and productivity; and verify crew task timelines and operational scenarios. In addition to crew interfaces, other important considerations evaluated such as maintainability aspects, reconfigurability, access, cargo transport, lighting effects, and color effects.

In addition to full-scale representations, the architecture was also analyzed using models and drawings.

Live test subjects and evaluators consisted of former astronauts, human factors specialists, systems engineers, and design engineers. Comments were received and reviewed to determine the impact on design, operations, arrangement, and task timelines. Adherence to design guidelines was determined as well as recommendations to modify design guidelines to improve crew efficiency and productivity.

The result of this IR&D segment was to determine the viability of the combined habitat approach to arrive at a module design conducive to crew productivity, safety, health, and well-being.

3.4 EVALUATION AIDS USED

To provide the means to evaluate the architecture using line simulations, full-scale mockups were constructed. A full-size combined habitat mockup was constructed to conduct traffic evaluations, functional site relationship evaluations, functional site relationship evaluations, and equipment arrangement and volume evaluations within or at the various sites. Fidelity of the mockup fairly represented the equipment or facilities under evaluation. One equipment rack was capable of being deployed to study access to the module shell or to the back of the rack for maintenance. This rack was also used to demonstrate reconfigurability by its removal, transfer, and replacement in the module. Figures 3-3 through 3-8 are photos of the full-scale mockup at Grumman-Bethpage. Figures 3-9 and 3-10 are photos of the 1/24th size model that represents the combined habitat. The equipment packages are movable and detachable so that various architectural arrangements could be studied three-dimensionally. Fifth and ninety-fifth percentile mannequins also were employed in the full-scale mockup to add realism in certain operations.

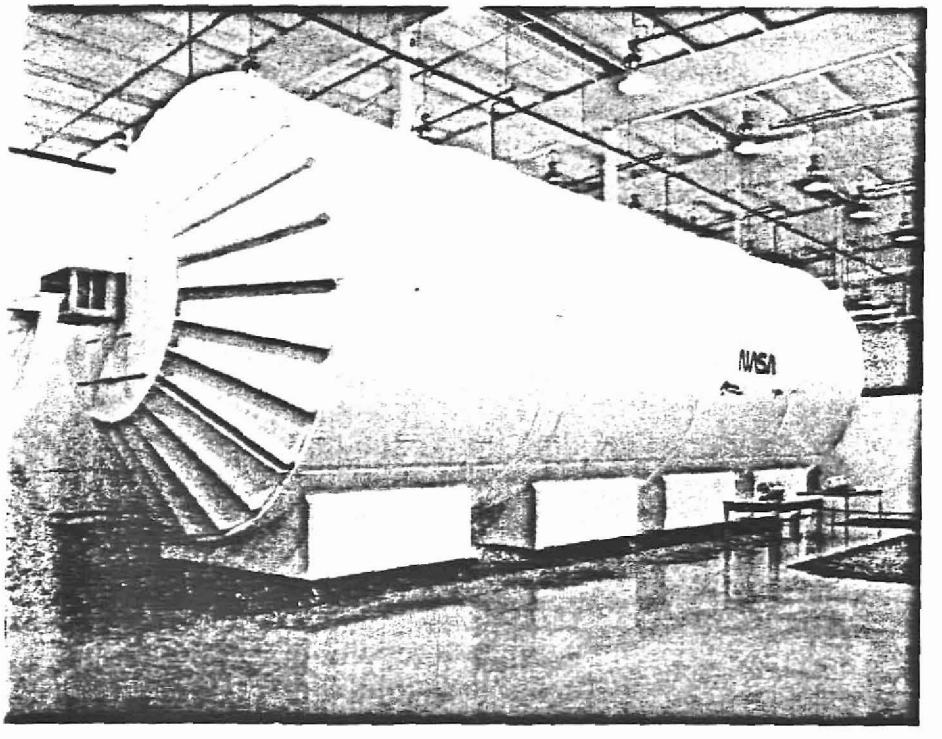

Fig. 3-3 Exterior View, Habitat Module Mockup

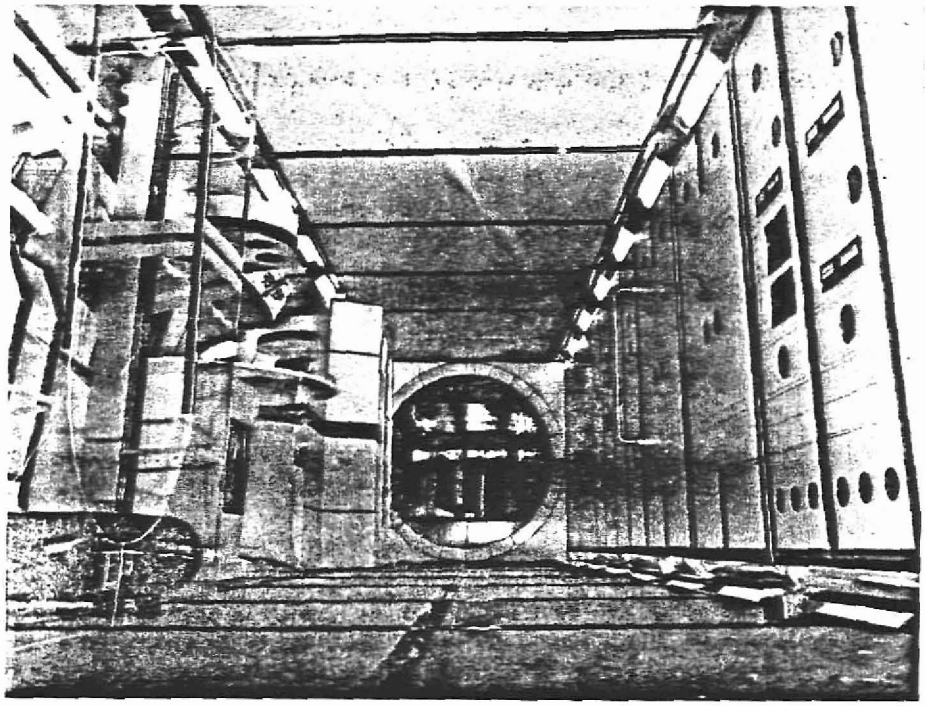

Fig. 3-4 Interior View, Habitat Module Mockup

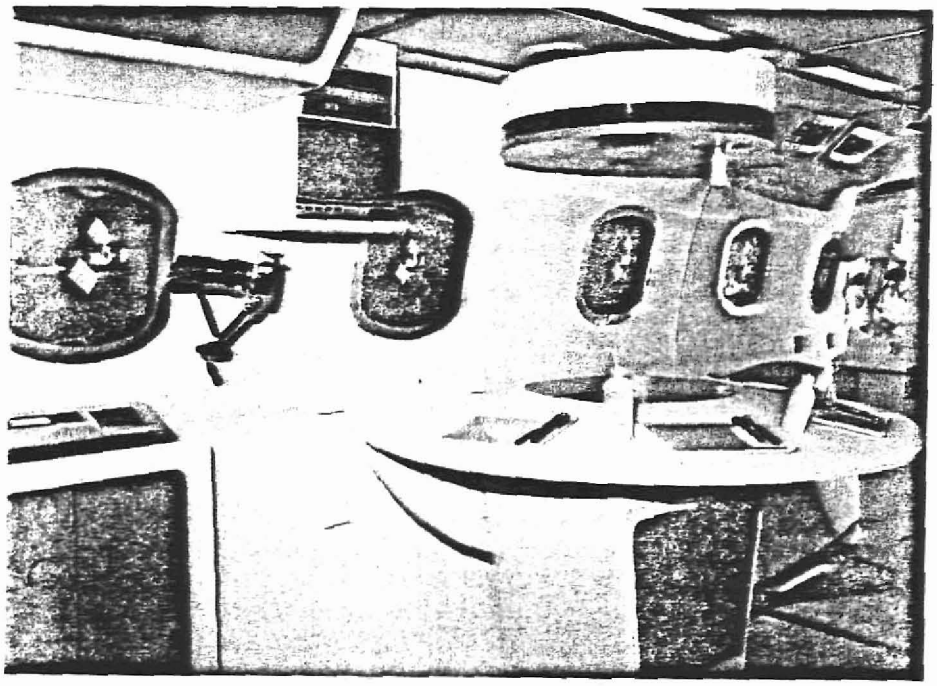

Fig. 3-5 Wardroom, Habitat Module Mockup

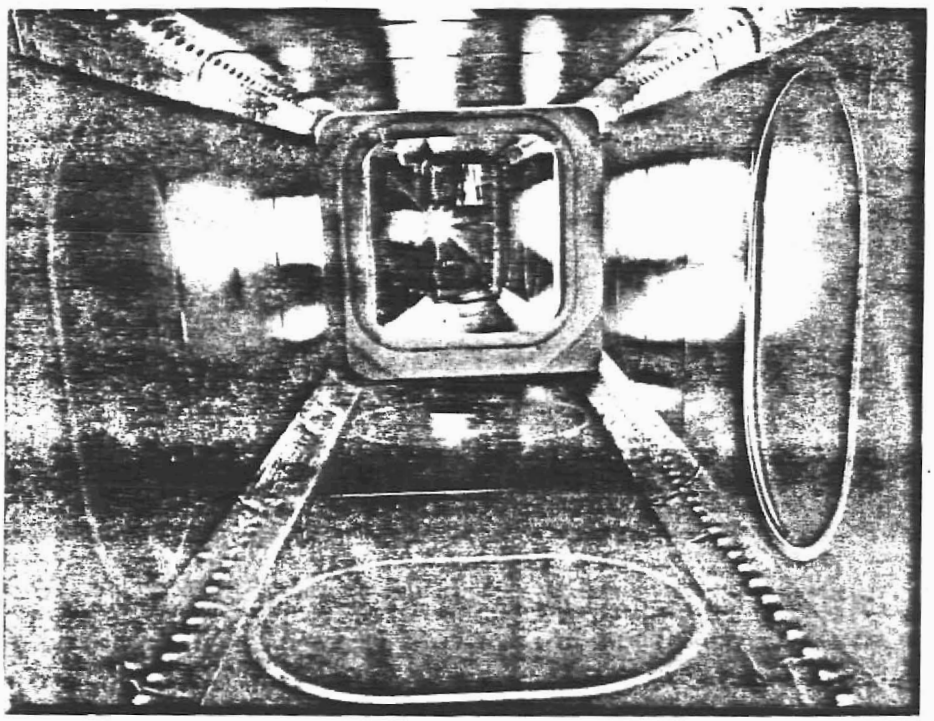

Fig. 3-6 Crew Quarters, Habitat Module Mockup

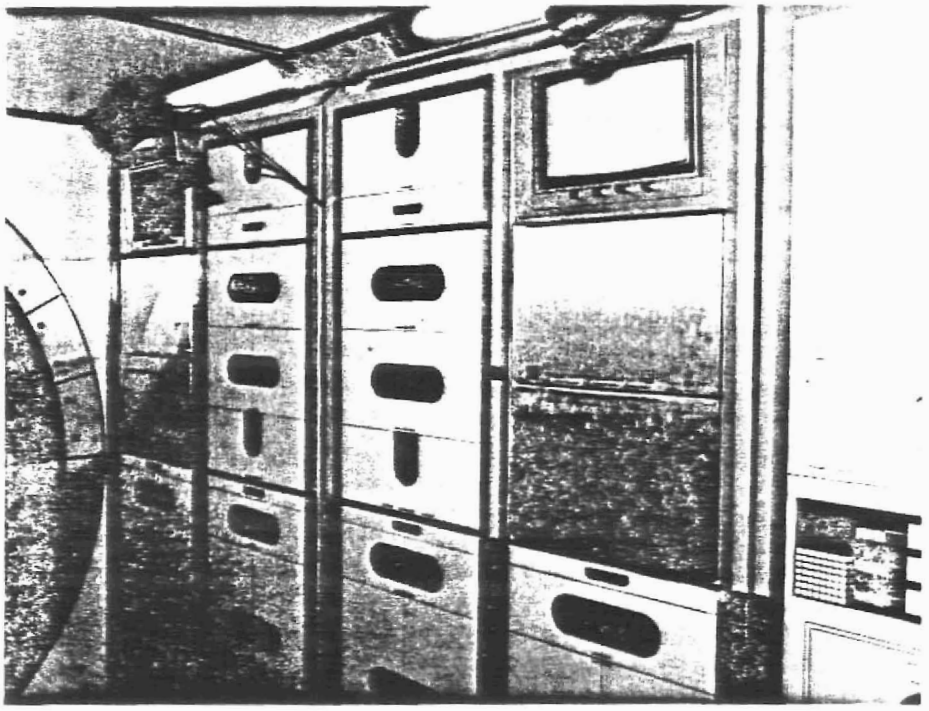

Fig. 3-7 CHECS Medical Facility, Habitat Module Mockup

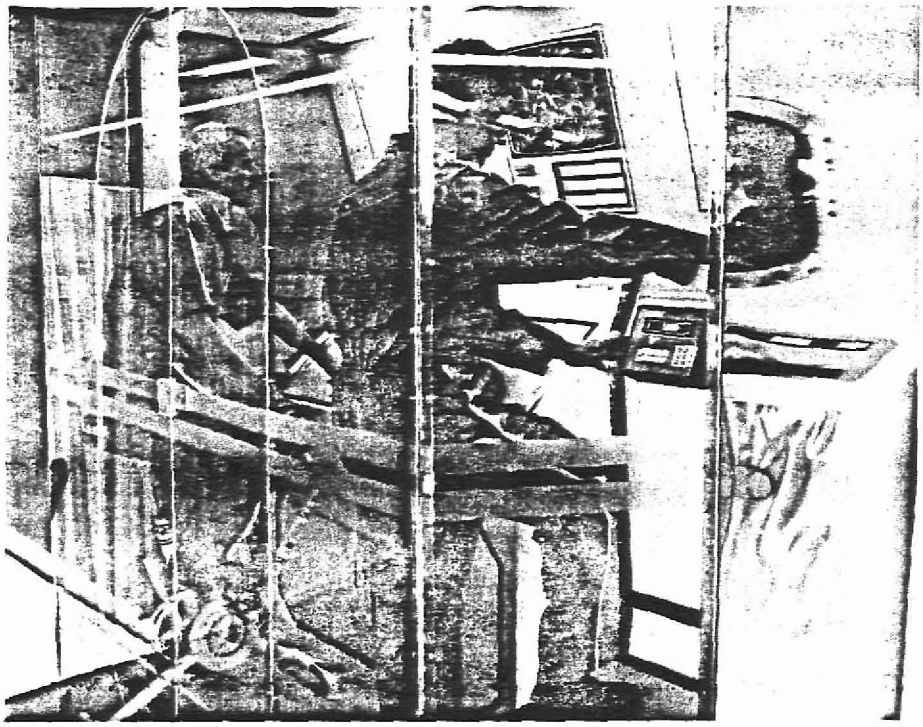

Fig. 3-8 CHECS Exercise Facility, Habitat Module Mockup

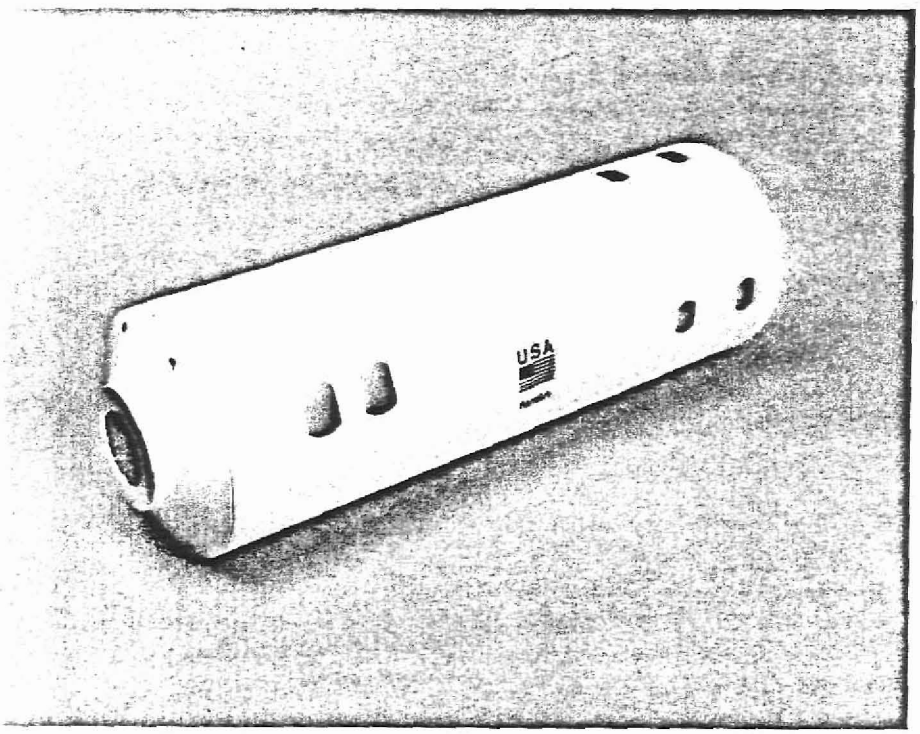

Fig. 3-9 Exterior View, 1/24th Scale Habitat Module

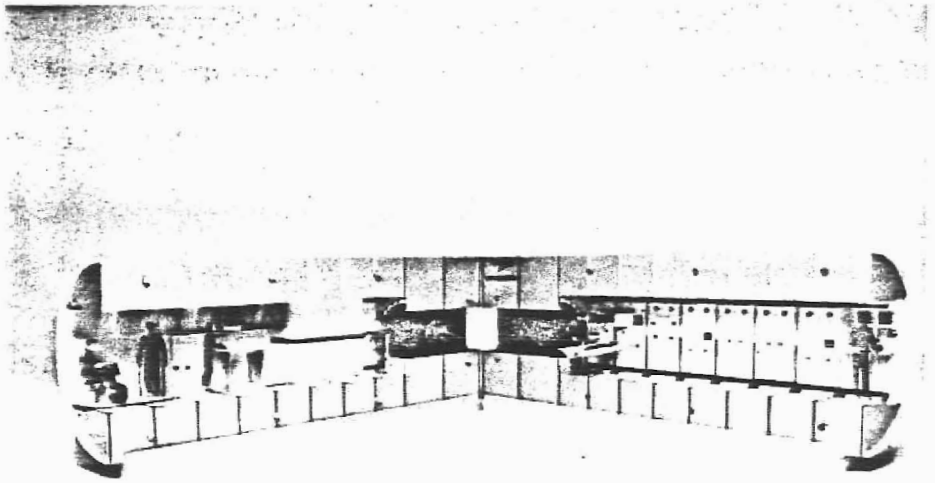

Fig. 3-10 Interior View, 1/24th Scale Habitat Module

A full-scale mockup of the galley and wardroom was constructed in Grumman-Houston to evaluate galley operations (Fig. 3-11).

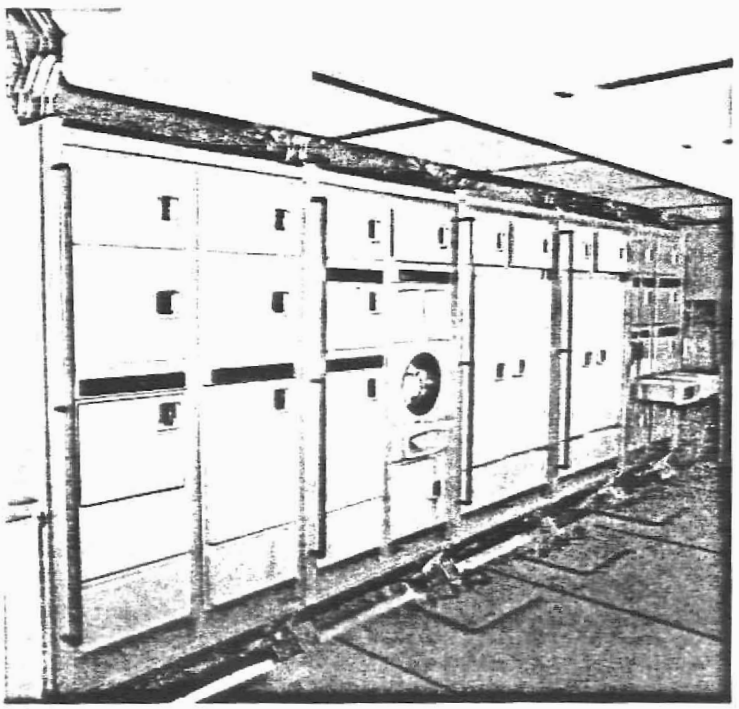

Fig. 3-11 Galley/Laundry Mockup

3.5 EVALUATION RESULTS

All functional elements of the habitat mockup were constructed and evaluated against known and assumed requirements. The overall assessment was that the quad truss cross-section provided an architectural concept that is excellent for installation of rack-mounted equipment and acceptable for crew-occupied facilities. The truss structure provides a unique matrix of mounting points whereby equipment racks can be readily installed in all 44 module locations.

Specific evaluations of each facility are delineated below.

3.5.1 Racks

Each equipment rack is configured to contain two hinge fittings on the bottom, which interface with the quad truss structure. The top portion of the rack contains a two-motion latch handle which activates linkages interfacing with the truss structure in the adjacent quadrant. Each rack can be folded down quickly and easily by activating the latch at the top of the rack. This interface exists at all 44 locations in the module, thereby allowing interchangeability of racks. The only limiting factors are the electrical, air, and piping interface provisions at each location.

The interior arrangement permits the racks to be moved from one module to the other.

3.5.2 Crew Enclosures

The cross-section established for the equipment racks is not adequate to house occupants with required equipment. It was determined that the inboard wall of the enclosure would have to be extended inboard 12.0 in. to provide the necessary volume for the occupant and associated equipment. This extended wall had

to be movable and capable of being displaced outboard when the adjacent upper and lower racks are to be rotated away from the module skin.

The crew enclosures are designed to pick up the same quad truss structure as the racks. Adaptor fittings added to the quad truss structure will provide the required interfaces to the enclosure structure.

3.5.3 Shell Access

The equipment racks will rotate out 90 degrees to provide access to the module shell skin. An astronaut can float behind the deployed rack and interface wiring to gain complete access to the skin and quad truss structure in the immediate vicinity. The rack wiring, piping, etc, can be serviced with the rack in the deployed position.

The enclosures are designed to house tailored equipment racks, which also pick up the quad truss structure via special adaptor fittings. These racks can be rotated clear of the skin to provide the necessary access. In the case of the crew quarters, all the equipment is located away from the skin. In one location, where the equipment is against the skin, the rack is designed to swing on a vertical hinge to provide the required skin access.

3.5.4 Windows

The habitat topography is configured to locate the wardroom on the nadir side of the module. Two large windows in the wardroom provide excellent views of earth. The window can be configured to accommodate work stations at the same time crewmembers are assembled about the dining/conference table.

A zenith window was provided on the other side of the module behind one of the equipment racks. Access to the window is achieved only by rotating the rack 90 degrees. This does not appear to be a good situation. The topography layout requires further work to provide access to a good zenith window without the need for moving equipment.

Each crew quarter is provided with a 10.0 in. viewing window. Views from the eight windows will vary according to the position on the Space Station.

3.5.5 Galley/Wardroom

This facility was installed in the full habitat mockup in Bethpage in low-fidelity, and in a higher fidelity partial mock-up in Houston. Both mockups reveal that five full racks are required to house all the appropriate galley/housekeeping facilities in the wardroom. The void created by the removal of three racks is sufficient for a dining table for four to six crewmembers, and is marginally acceptable for eight persons. Evaluation of various table sizes and shapes indicated that it should be designed for four to six persons with expansion capabilities built in to accommodate eight crewmembers. If the table could be stowed outboard when not in use, it would provide more freedom of movement for the crew. Timeline operations for food access, preparation, eating, clean-up and disposal were performed in the higher fidelity mockup. Through these tests, recommendations were submitted to engineering for the relocation and reconfiguration of some of the galley facilities. These items were taken under consideration and additional studies and layouts are being made to update the galley/wardroom.

No evaluations were made to ascertain the recreational aspects of the wardroom.

3.5.6 Exercise Facility

This facility is contained in an expanded enclosure compartment. The inboard wall is made of a transparent material to create a roomy feeling. This inner wall is capable of being folded outboard in the event that the adjacent upper and lower racks are to be rotated for skin access.

Two items of exercise equipment (ergometer and treadmill) are located within this facility and both units face outboard. An entertainment console/monitoring panel is located outboard of the exercise units so that the crewmembers may view the large TV screen and/or look out an adjacent window while exercising.

A single door is provided for access into this compartment.

Evaluation of this facility indicates it is sufficiently large for two occupants with a small treadmill and ergometer. If a rowing machine needs to be installed instead, then this facility may have to be enlarged.

3.5.7 Health Medical Facility

Two full-size double racks were provided for the on-board medical facility. This facility is configured to accept one patient and accommodate two attendants. Details of the rack equipment are vague. Discussions with New York Hospital personnel resulted in an innovative arrangement of the equipment to optimize diagnostic and treatment activities. Considerably more work has to be done in this area.

3.5.8 Waste Management/Personal Hygiene Facility (WM/PHF)

Original layouts depicted this facility occupying four rack widths (168 in.). Overall habitat volume requirements dictated that only three rack widths (126 in.) were available for this

facility. Numerous layouts were produced to see if this limited volume would meet all the requirements for the WM/PHF. As stated before, the crew enclosures were all expanded inboard to provide the necessary volume to house personnel. The triple width compartment was essentially divided into a shower facility, personal hygiene facility, and a waste management facility. The three facilities were subdivided in the middle with a folding curtain. In this manner, the shower and half of the PHF could be used by one occupant, while the other half of the PHF and waste collector system could be used by another person. The waste collection systems considered were the units proposed by Hamilton Standard and Whitmore. The shower unit used in the mockup was supplied by Bell & Trotti.

Evaluation of this facility revealed that it is large enough to house two persons simultaneously and yet afford privacy to each occupant. One input during the evaluation was that it might be advantageous to provide a handwash unit that is accessible from outside the compartment.

3.5.9 Crew Quarters

As stated at the beginning of this report, the crew quarters were located at one end of the module for noise isolation. In order to house eight crewmembers in the minimum module length, groups of two were located in a keystone fashion in all four quadrants. The crew quarters enclosure compartment in each quadrant is three rack widths long (126 in.) extending inboard to a point 25 in. from the axial center line. This enclosure provides approximately 300 cu. ft. of volume for two occupants and attendant stowage/facility accoutrements. The internal arrangement is configured to provide equal facilities for two crewmembers in equally divided subcompartments. However, if desired, the median divider can be folded back to create one large office-type enclosure for two people.

Evaluation of this arrangement indicates the gross volume per compartment is satisfied, as is the capability for rearrangement. Each compartment has a viewing window, adequate stowage facilities and a good entertainment/office center. The module skin is accessible for cleaning and inspection.

3.5.10 Command & Control Station

One rack width was allotted for a command and control station. The station is designed to accommodate one operator normally, but will allow two operators under certain conditions. This station is mounted to the quad truss structure in the same fashion as the equipment racks. No external viewing window is provided at this station. The latest NASA studies indicate that this work station might be relocated outside the HAB module to one of the nodes.

3.5.11 Equipment/Stowage Racks

The remainder of the modular racks in the module house the stowage hardware and subsystem equipment. Allocation for this is as follows:

- ECLSS - 6
- Power/Thermal - 2
- DMS - 1
- Comm & Track - 1
- Safe Haven - 1
- Stowage - 5

Little work has been done in this area to determine hardware installation into these facilities. Subsequent input indicates the ECLSS rack quantity has to be increased by one to seven. If so, this reduces the stowage racks by one, to four. Preliminary studies of known stowage hardware items indicate that four racks are insufficient to house all the stowage items.

One solution would be to relocate a large portion of the ECLSS and power/thermal equipment to the nodes. This would free at least six racks for other functions, such as stowage.

3.5.12 Hatches

The habitat layout described in the preceding paragraphs makes one basic assumption that is critical to the overall arrangement. The end hatch in the module, if used, must not infringe on the plain cylinder length of the module in order to clear the crew quarters.

4 - MULTIPURPOSE LABORATORY (MPL) MODULE CONCEPT

In addition to the habitat, a second identically sized module is installed in the Space Station complex. This module's main function is to provide laboratory facilities for the user communities and also contain some habitat functions such as waste management, personal hygiene, and stowage facilities. The architectural concept described for the habitat is the same for the MPL, thus permitting interchangeability of certain equipment racks between modules.

4.1 MPL MODULE DESCRIPTION

The extent of our MPL studies was limited to topography layouts to develop an arrangement best suited for laboratory operations (Fig. 3-12).

To optimize commonality, it is assumed that lab module structure with its quadrant truss structure is identical to that of the habitat. The same window locations are shown in the lab as in the hab. However, in the lab, ten of the windows are covered by equipment racks, limiting visibility.

The equipment racks that are assumed to be the same (or similar) to that in the habitat are:

- ECLSS - 6
- Power/Thermal - 2
- Comm & Track - 1
- DMS - 1
- Comm/Control Station - 1
- Safe Haven - 1

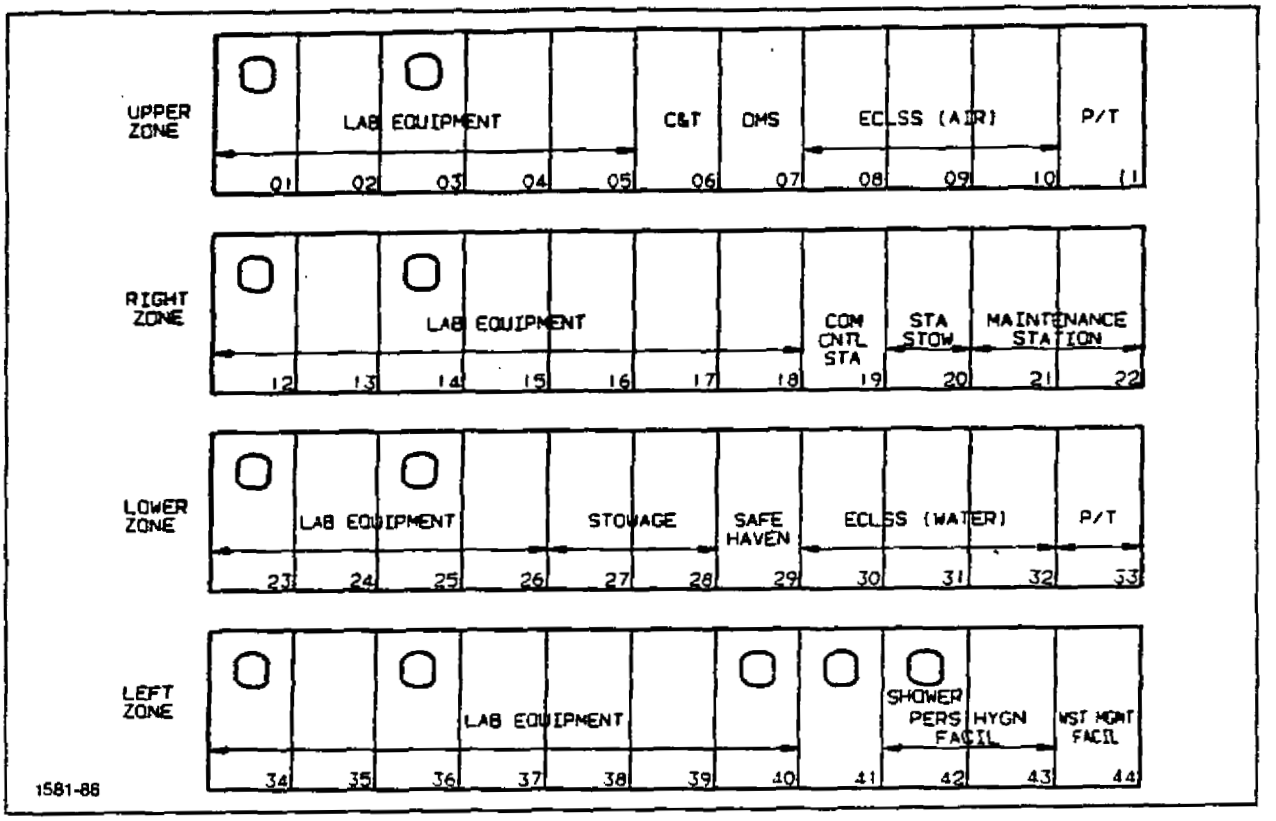

Fig. 3-12 Multipurpose Laboratory Module, Topographical Representation

The crew enclosures identical to those in the habitat are:

- Shower
- Personal Hygiene
- Waste Collection.

The remainder of the racks are dedicated to laboratory experiments.

4.2 EVALUATION RESULTS

As stated before, little work has been done on the MPL, except for topography layouts and maintenance station studies. Limited conclusions can be made from the study effort to date, but the following evaluations can be elicited:

- The module shell parameters should be the same as those for the habitat, including common window locations
- The quadrant truss structure concept is good for a laboratory-type installation

- The quadrant truss structure provides a good routing system for experiment rack services, i.e., wiring, plumbing, etc. However, providing multiple services for interchanging lab racks might prove to be a very difficult design task
- The lab interim arrangement takes advantage of the existing window locations.

5 - REFERENCES

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2. Internal Architecture Concept Study, "The Four Corner Modular Truss Concept," SS005/ATD-04, 22 October 1985.

3. Manned Space Systems Habitability Habitat Module Interior Architecture and Mockups Initial Report, SS005/ATD-02, 29 August 1985.

4. Manned Space Systems Habitability Interior Architecture & Mockups Interim Report, SS005-ATD-05, 27 March 1986.