

**The Reuse of Logistics Carriers
For the First Lunar Outpost
Alternative Habitat Study**

Final Report

NASA/ASEE Summer Faculty Fellowship Program--1992

Johnson Space Center

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NASA/JSC

Directorate: Engineering

Division: Systems Engineering

Branch: Systems Definition

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Date Submitted: August 20, 1992

Contract Number: NGT-44-005-803

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ABSTRACT

The Systems Definition Branch deals with preliminary concepts/designs of various projects currently in progress at NASA. One of these projects is called the First Lunar Outpost. The First Lunar Outpost (FLO) is a proposed permanent lunar base to be located on the moon. In order to better understand the Lunar Habitat, a detailed analysis of the lunar environment as well as conceptual studies of the physical living arrangements for the support crew is necessary.

The habitat will be inhabited for a period of 45 days followed by a six month dormant period. Requirements for the habitat include radiation protection, a safe haven for occasional solar flare storms, an airlock module and consumables to support a crew of 4 with a schedule of 34 extra vehicular activities. Consumables in order to sustain a crew of four for 45 days ranges from 430 kg of food to only 15 kg for personal hygiene items. These consumables must be brought to the moon with every mission. They are transported on logistics carriers. The logistics carrier must be pressurized in order to successfully transport the consumables. Refrigeration along with other types of thermal control and variation in pressure are defined by the list of necessary consumables.

The objective of the proposed work was to collaborate the Habitat Team with their study on Logistic Carriers as possible alternatives for additional habitable volume. Options for possible reuses was also determined. From this analysis, a recommended design is proposed.

INTRODUCTION

The logistics operations for the Lunar Base are concerned with the packaging, scheduling, distribution, and storage of equipment, spares and consumables to supply the lunar surface operations.

Since the Lunar Base will be developed after the Space Station has been operational for some years, the maintenance and logistics concepts for the Lunar Base should be compatible with the Space Station system. Compatibility issues such as commonality of LRU's (Line Replaceable Unit) and dimensional standards on storage containers to assure that they can be handled and secured properly during each phase of the delivery process from the Earth to the Moon should be considered. Commonality of LRU's is critical for the Lunar Base so that the same LRU will be able to support many different subsystems and subcomponents. By properly specifying common LRU's, the number of spares should be reduced and the reliability and production costs of the LRU improved.

Logistics for the Lunar Base involves three locations in a complex tracking and mass handling operation. First, the only source supplies during the first six years of lunar operations is the Earth. At a later date, oxygen supplies will be supplemented by lunar oxygen production from the pilot and production plants. The data bases which track the equipment availability, maintenance schedule, packaging, shipping and life time use will be based on the Earth and the Moon. The supplies are transported to the Space Station which serves several functions including:

- temporary holding point to prepare for final shipment to the Moon.
- minimal repackaging for shipment.
- equipment checkout and minimal refurbishment.
- source of supplies needed immediately when unavailable from the Earth.

PROBLEM STATEMENT

The purpose of the Alternative First Lunar Outpost Habitat Study is to investigate alternative habitat concepts from the base line SSF (Space Station Freedom) derived habitat. As part of this investigation, pressurized logistics modules have been identified as a possible solution to expand the habitable volume of the First Lunar Outpost.

This particular study looks at the use of logistic carriers for the purpose of expanding the pressurized volume of FLO. Included is how these logistic modules will be utilized and what functions they will support in order to use them as a habitable volume.

Some basic requirements were defined for the carrier. First of all, it is necessary to carry a resupply of consumables for a crew of four for a 45 day mission. Secondly, since 76% of the food for long duration missions is refrigerated or frozen, the carrier needs to provide refrigeration/freezer capabilities.

ASSUMPTIONS

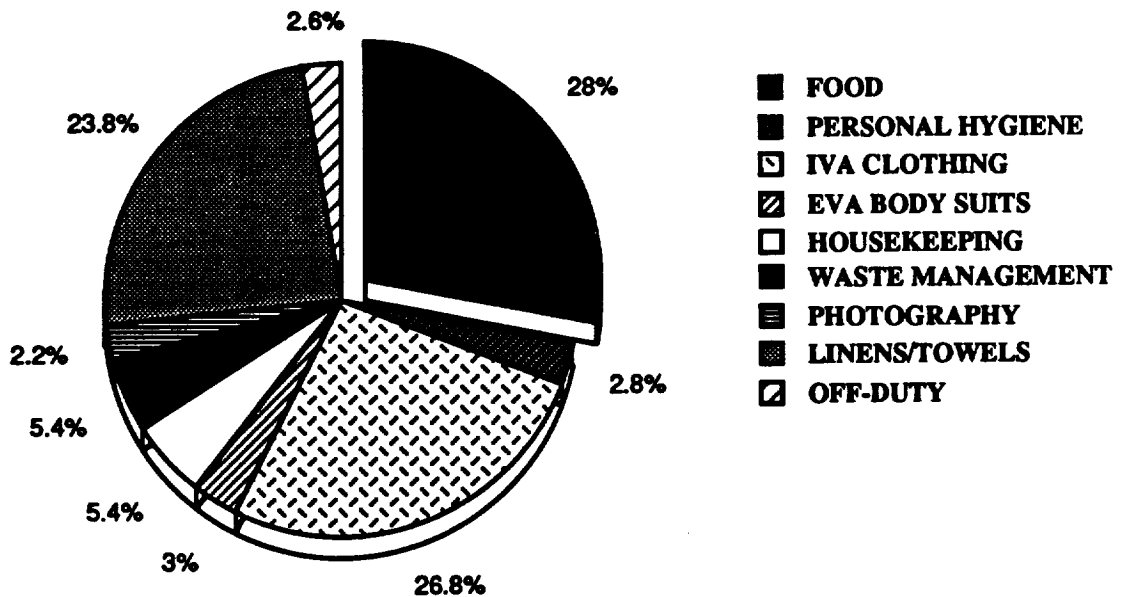
There are various assumptions that were needed to make in order to carry out the study. The habitat module is assumed to be on the ground. This assumption is necessary due to fact that the present Habitat Module is on top of the lander 50 feet above the ground. In order for the logistics carrier to be connected easily, the logistics carrier also needs to be on ground level. It is going to be transported from the landing site on a motorized undercarriage and brought to the habitat module for connection. Also, it was assumed that radiation shielding would be provided. Further analysis of radiation protection was not taken into account since it would require its own trade study.

DESIGN PROCESS

The first item that needed to be defined was the size (volume) and weight (mass) necessary in order to resupply the mission. Data was provided from the First Lunar Outpost Lunar Habitat Documentation and the Logistics Carrier Study for FLO done by Lockheed. Consumables consist of food, personal hygiene items (soap, wipes, tissues, dental care, hair grooming and body care items), IVA clothing (indoor clothing), EVA body suits, housekeeping items (dry and wet wipes, trash bags and vacuum cleaner bags), waste management (filters, fecal bags, and canisters), photography equipment, linens and towels and off-duty items (pens, pencils and other personals).

<u>Consumables</u>	<u>Mass (kg)</u>	<u>Volume (m³)</u>	<u>% Tot. vol.</u>
Food	439	1.29	28.0 %
Personal Hygiene	52	0.13	2.8 %
IVA Clothing	190	1.24	26.8 %
EVA Body Suits	25	0.14	3.0 %
Housekeeping	79	0.25	5.4 %
Waste Management	34	0.25	5.4 %
Photography	19	0.10	2.2 %
Linens/Towels	142	1.10	23.8 %
Off- Duty	63	0.12	2.6 %
TOTALS:	1043	4.62	100 %

This is a chart of the breakdown of the consumables in order to determine which consumes the most space. Food is the major component while IVA Clothing and Linens/Towels rank as the second highest consumers of module space. This is due to the fact there is no clothes washer on board and the crew members will need to use fresh items regularly.



Analysis of Design Requirements:

Design Issues:

When considering the use of the present logistic modules for possible expansion of the lunar habitat module, certain design issues must be taken into consideration. Since the habitat does not have fixed dimensions, a fair degree of flexibility concerning the design of the logistics module is adequate.

Alternate materials such as inflatables could be studied to see which material provides the optimal results and is the most advantageous. A needs analysis of pressurized vs. unpressurized requirements should be prepared in order to further define which equipment and consumables need to be under which atmospheric condition. Information on air and thermal control extensions to be connected to the proposed logistic modules could be looked at. Other minor issues such as how much trash is generated by the habitat module in order to determine the size of the waste container can add to the determining of what function will the logistic module/carrier serve.

Functions of Habitat Module:

While trying to make use of existing hardware and minimizing new technology developments, the SSF (Space Station Freedom) was chosen as the most applicable because of similar design requirements. The basic SSF module structure provides equipment that is included in the module for the LEO (lower earth orbit) application. For the lunar outpost application, some additional equipment (both internal and external to the module) is required to support the habitat and crew.

These are the different habitat segments and each of its corresponding functions:

- » **Communications and Data Management System (CDMS):** requires extensive communications equipment capable of receiving signals which are transmitted over extremely long distances as well as the capability of sending back messages; adequate space must be allotted for the ingress of one or more crew members at a time. The CDMS is designed to provide various services such as data acquisition, data processing, data storage, subsystem control, and communications. The CDMS must support human interaction while crew is present and must be capable of operating autonomously for periods when a crew is not present (Lunar Habitat Documentation, 5/92).
- » **Power Distribution:** provides the necessary power lines within the scarring with possible extensions for adjoining compartments.

The basic power system of the Lunar Habitat Module consists of (1) photovoltaic arrays, and (2) regenerative fuel cells. The concept is to use photovoltaic arrays for daytime energy needs and fuel cells for power during lunar nights (LHD, 5/92).

- » **ECLSS (Environmental Control Life Support System):** recovers materials essential for crew survival, such as water or oxygen, from crew metabolic wastes such as carbon dioxide, waste hygiene water, or urine. The option selected for the lunar habitat ECLSS is the closed water loop design. This includes water processing hardware used to reclaim potable and hygiene water from crew waste water and requires only a minimum of resupply of water (91 kg) per 45 day mission (LHD, 5/92).

- » **Thermal Control System:** provides temperature control to the habitat, inhabitants, and subsystems (internal and external to the module). this is done by systems which transport heat from the location in which it is produced to a location it can be rejected to the environment. The SSF internal Thermal Control System is applicable to the lunar habitat with a few minor changes. New external heat rejection system is required (due to the solar array temperature high of ~ 380°K during midday): a horizontal radiator with no heat pump chosen for simplicity and low power requirement (LHD, 5/92)

- » **EVA/Airlock:** one or two independent airlock modules to support EVA operations, transfer the crew from lander to habitat, store EVA suits, as well as provide an EVA dust removal system. One of the airlocks can provide hyperbaric capabilities. Both airlocks will be able to function as safe haven for the habitat. Each airlock can accommodate two EVA crew members simultaneously during normal operations and four during contingency operations (LHD, 5/92).

- » **Structural Support:** consists of the necessary equipment to withstand the launch loads as well as being able to hold up the Lunar Habitat once on the moon. The loads on the Lunar Habitat that result from random vibration and rotational acceleration during launching are quite large due to the greater distance of the module from the center of gravity of the Heavy Lift Launch Vehicle (HLLV). The external structures needed additionally compared with the SSF are: solar array masts, radiator supports, an antenna mast, the habitat support structure, the habitat and lander interface, and the regenerative fuel cell tank supports (LHD, 5/92).

"Living" Volumes of Habitat

- » **Wardroom:** consists of crew gathering, eating, entertainment, and other community functions. As the focal point of the crew's environment, it serves the same purpose as a conventional living and dining room. Seating and table arrangements are flexible in order to provide possible reconfiguration according to the crew's needs. Additionally, monitors, displays, controls for both information and entertainment could be incorporated within the surrounding equipment (Initial Mars Habitat Study, 1/92).
- » **Galley:** a food preparation facility which includes food heating/cooking equipment, short-term food storage, food preparation area, dedicated stowage for servicing equipment and utensils, clean-up facilities, handwashing facilities, drink dispenser and trash receptacles. Connections to the habitat's fresh and waste-water supply are necessary. Special task lighting will also be provided (MHS, 1/92).
- » **Crew Quarters:** consists of private/semi-private accommodations like sleeping stations, wardrobe area, personal stowage, a shared entertainment center and work area, with a passageway to the hygiene compartment. Each sleep station can have an adjustable bunk which can be reconfigured to allow a sit-up position. Additional stowage either above or below the sleeping stations is also a consideration (IHMS, 1/92).
- » **Hygiene Facility:** includes two habitat facilities integrated into a common area - personal hygiene and body waste management. Although both functions are addressed within the same enclosed volume, each should be independent subsystems which could be accessed simultaneously in private. The hygiene facility will include provisions for whole and partial body cleansing, handwashing, and personal grooming (IMHS, 1/92).
- » **Exercise/Health Facility:** dedicated region within the module which serves both routine crew exercise and health care needs as well as emergency medical situations. In emergency situations, certain surrounding portions could be removed in order to provide easier ingress. When health care treatment is not required, practically the entire region could accommodate exercise activity. The equipment and electronics volumes could be located overhead to maximize volume (IMHS, 1/92).
- » **Trash Management Facility:** it incorporates trash collection and compaction functions while providing an easy transfer of the compacted trash to a more permanent storage location. Other receptacles for trash collection may be located in the crew quarters as well as the hygiene facility for intermediate collection

until transferred to this facility for compaction. Perhaps some sort of energy source could be derived from the elimination of this trash (IMHS, 1/92).

- » Food/Consumables Stowage: adjacent to the galley and food preparation area are subsystems of palletized food packages further divided into individual portions of food items in long-term stowage. Certain food items may be transferred in a short-term containment facility or refrigerator within the galley for more convenient access (IMHS, 1/92).
- » Laundry Facility: cleaning of personal clothing, bedding, and towels will be performed here. The needed equipment includes a washer/dryer, intermediate stowage of launderable items, consumables used in the process, and a suitable surface for organization and folding of the laundry. Collection points within the habitat will transfer to this facility for laundering (IMHS, 1/92).
- » Additional Stowage: provides extra room for equipment, supplies, personal items, and/or cleaning utensils. Goods from the logistics carriers could be temporarily stored here.

From all of these habitable volumes, it is clearer which functions could be retrofitted for the Logistics Carrier. Yet, certain sizing dimensions still need to be addressed.

SPACE STATION DATA

Boeing Aerospace Company provided Marshall Space Flight Center with a document which defines the known configuration of the Logistics System required to support the Space Station program. This report provides both mass and volume requirements necessary for a resupply to Space Station. From this data, an analysis of the ratios of its components to the total volume allows the determination of the total necessary volume needed for FLO.

This is the overall breakdown:

Total Internal Volume:	85 m³	% of Total
Consumables	43.5	51.2
Access Space	30.5	35.9
Subsystems	11.0	12.9

CALCULATION OF TOTAL VOLUME

These ratios provided a basis upon which to calculate the volume necessary for the determined volume of consumables. Each value determines the approximate volume taken up by each category. This information was necessary in order to determine the total volume for both resupply and habitation purposes.

As stated previously, the total consumables required for a crew of four for a 45 day mission is 4.62 m³. Adding a factor of 20% for a packaging void, an additional 0.924 m³ is added to the current amount in order to allow for unaccounted space. The total comes out to 5.54 m³. This total is then divided by the ratio of consumables for the Space Station module. The volume for the consumables, 5.54 m³ divided by 51.2 % (SSF's consumables ratio) gives a grand total of 10.8 m³. From the total, the following breakdown was developed.

Volume Requirements:

Consumables (+ 20% packaging void)	5.54 m ³
Subsystems Volume	1.40 m ³
Access Space	3.86 m ³

SHAPE STUDY

Of the shapes to be considered in order to decide on the geometry of the carrier, three main shapes were identified: a sphere, a rectangle, and a cylinder. The sphere did not work well with any rack system since consumables usually took on some sort of rectangular shape. The rectangular shape does not work well with a pressurized environment. A cylinder, either vertical or horizontal provided the most positive feedback.

In considering the feasible solutions between a horizontal or vertical cylinder, various items were considered. The volume space of both configurations differs in usability. The horizontal orientation provides 5.5 m³ rack space for the consumables. While the vertical orientation only provides 3.4 m³ of available rack space due to the gaps of unaccessible space. Circulation space in the horizontal mode works better for reconfiguration than the vertical mode.

DESIGN REQUIREMENTS

Once the horizontal configuration was chosen to be the determined shape, a few basic design requirements were needed to be made. The height was determined based on data from Skylab. Their vehicle was six and a half feet high in zero gravity. Allowing for some additional space due to the 1/6th g, a height of seven feet six inches was decided to be adequate. The access width was defined by physical dimensions of a man in an EVA suit. The maximum breadth for a 95%ile male is 34 inches. That is the exact width of the proposed design. Since the carrier needs to be pressurized in order carry the consumables, the shape must be in accordance. Lastly, when the logistics carrier is no longer self-sufficient, it must have the capability to be dependent on the habitat. For figures of proposed design see appendix.

ADDITIONAL REUSES

Possibilities for reuse were considered only of the functions which would not cause too much of an additional load on the habitat's present systems. Crew quarters is a strong possibility due to the fact that little additional power was needed to reconfigure the carrier. Science laboratories is also an option since there is refrigeration and freezer capabilities already on board. EVA storage and maintenance could be applied in the carrier and leave that much more extra space on the habitat module. Last but not least, it could be used as equipment stowage.

CONCLUSIONS

From this study, certain objectives were attained. Information on the details of the logistics operations was provided to the Alternative Habitat Team. The insight on possible reuses helps to determine the real possibilities of the logistics carriers reusability. Since a logistics carrier is needed regardless if it is reused or not, it would be more volume efficient to use its space once its original functions have been accomplished. Also, added space helps to improve the psychological and social attitudes between each crew member. The flexible configurations such as being able to remove the racks enhances the suitability for each mission. As a long term goal, it opens the door for longer duration missions with the possibility of permanent residence on the moon.

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Lunar Habitat Documentation. Marshall Space Flight Center. Huntsville, Alabama. May 1992.

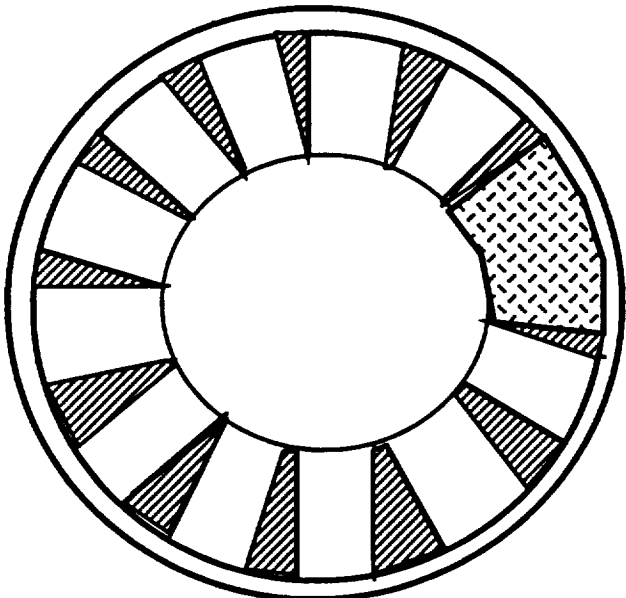
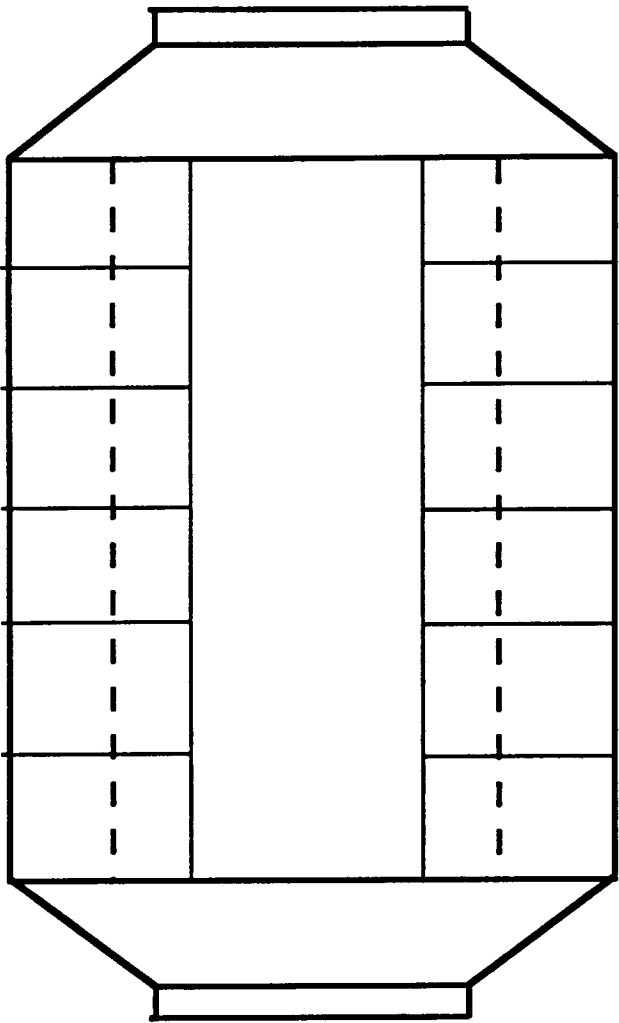
Lunar Base Maintenance and Supply Options. Advanced Space Transportation Support Contract. No. NAS9-17878.

Proposed Concepts

Horizontal

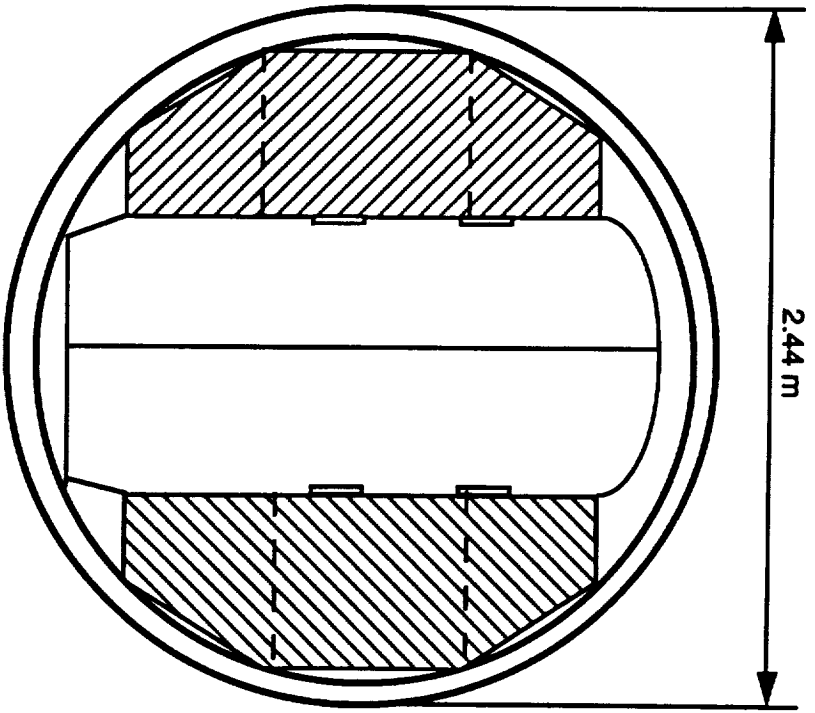
vs.

Vertical

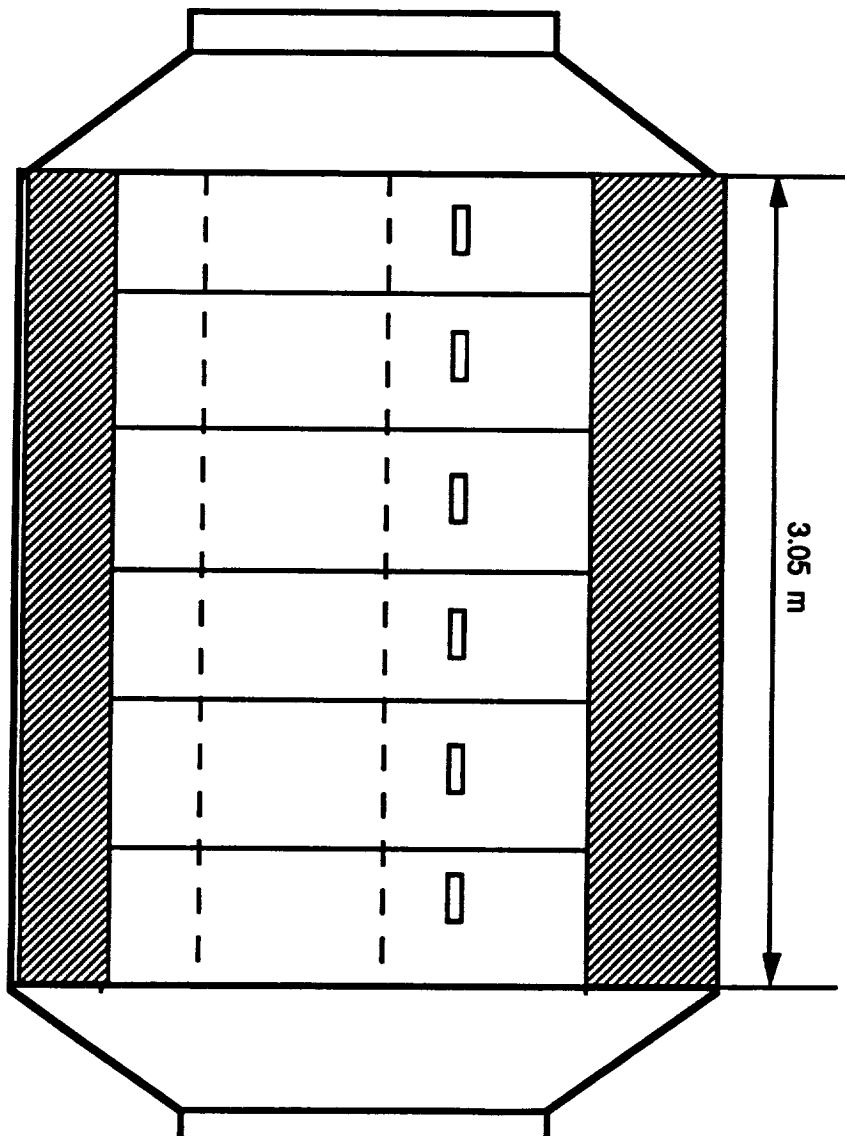


PLAN VIEW

Recommended Design



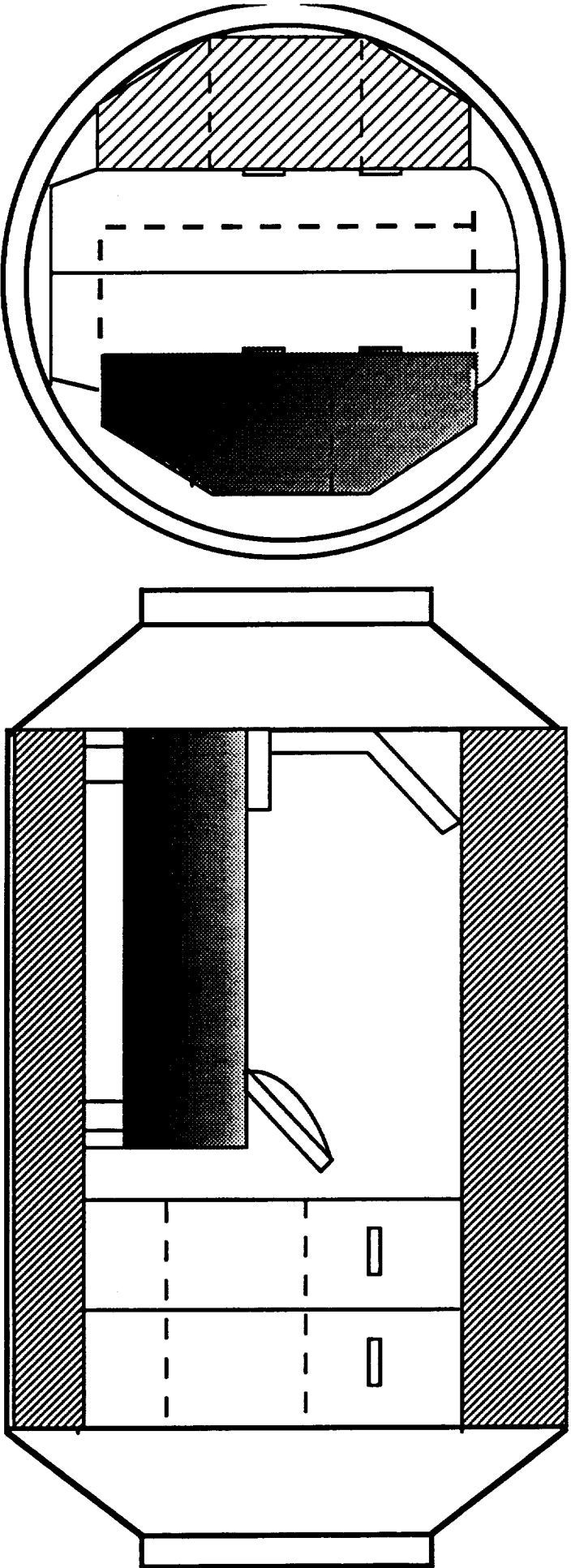
Front View



Side View

Reuse Options

- Racks removed to provide crew quarters



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE December 1992	3. REPORT TYPE AND DATES COVERED Contractor Report	
4. TITLE AND SUBTITLE National Aeronautics and Space Administration (NASA)/American Society for Engineering Education (ASEE) Summer Faculty Fellowship Program-1992 Volume 2			5. FUNDING NUMBERS NGT 44-005-803	
6. AUTHOR(S) Richard B. Bannerot and Stanley H. Goldstein, Editors				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Houston Houston, Texas			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) University Programs Office Lyndon B. Johnson Space Center Houston, Texas			10. SPONSORING / MONITORING AGENCY REPORT NUMBER NASA CR 188242	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Unclassified/Unlimited Star Category 99			12b. DISTRIBUTION CODE	
<p>13. ABSTRACT (<i>Maximum 200 words</i>) The 1992 Johnson Space Center (JSC) National Aeronautics and Space Administration (NASA)/American Society for Engineering Education (ASEE) Summer Faculty Fellowship Program was conducted by the University of Houston and JSC. The program at JSC, as well as the programs at other NASA Centers, was funded by the Office of University Affairs, NASA Headquarters Washington, D.C. The objectives of the program, which began nationally in 1964 and at JSC in 1965, are (1) to further the professional knowledge of qualified engineering and science faculty members; (2) to stimulate an exchange of ideas between participants and NASA; (3) to enrich and refresh the research and teaching activities of participants' institutions; and (4) to contribute to the research objective of the NASA Centers.</p> <p>Each faculty fellow spent at least 10 weeks at JSC engaged in a research project in collaboration with a NASA JSC colleague. This document is a compilation of the final reports on the research projects performed by the faculty fellows during the summer of 1992. Volume 1 contains reports 1 through 12, and Volume 2 contains reports 13 through 24.</p>				
14. SUBJECT TERMS			15. NUMBER OF PAGES	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

