SPACEPORT AURORA: AN ORBITING TRANSPORTATION NODE

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With recent announcements of the development of permanently staffed facilities on the Moon and Mars, the national space plan is in need of an infrastructure system for transportation and maintenance. A project team at the University of Houston: College of Architecture and the Sasakawa International Center for Space Architecture, recently examined components for a low Earth orbit (LEO) transportation node that supports a lunar build-up scenario. Areas of investigation included: identifying transportation node functions, identifying existing space systems and subsystems, analyzing variable orbits, determining logistics strategies for maintenance, and investigating assured crew return systems. The information resulted in a requirements definition document, from which the team then addressed conceptual designs for a LEO transportation node. The primary design drivers included: orbital stability, maximizing human performance and safety, vehicle maintainability, and modularity within existing space infrastructure. For orbital stability, the "power tower" configuration provides a gravity gradient stabilized facility and serves as the backbone for the various facility components. To maximize human performance, human comfort is stressed through zoning of living and working activities, maintaining a consistent local vertical orientation, providing crew interaction and viewing areas and providing crew return vehicles. Vehicle maintainability is accomplished through dual hangars, dual work cupolas, work modules, telerobotics and a fuel depot. Modularity is incorporated using Space Station *Freedom* module diameter, Space Station *Freedom* "standard" racks, and interchangeable interior partitions. It is intended that the final design be flexible and adaptable to provide a facility prototype that can service multiple mission profiles using modular space systems.

INTRODUCTION

Background

President Bush has stated the goals for the United States space program. This national plan includes establishing permanently staffed facilities on the Moon and Mars. These facilities will provide the foundation for extensive research on human response to longterm missions and the observation of our evolving solar system through astronomical instruments.

The first phase of the nation's space plan is Space Station *Freedom*, which is a scientific facility conducting experiments in microgravity. It does not, however, encompass the functions necessary to assist and maintain a lunar base in the near future. Phase two of the national space plan is a permanently staffed lunar facility within the first decade of the twenty-first century.

Research at the University of Houston College of Architecture and the Sasakawa International Center for Space Architecture has been in progress to develop a facility that can provide mission support for lunar and Mars initiatives. Because lunar and Mars support missions differ, the project team concentrated on a transportation node that could support a lunar base. It is intended that the final design be flexible and expandable to provide a facility prototype that can service single and/or multiple mission profiles using modular space systems and subsystems.

Problem Statement and Options

An orbiting facility is necessary for the construction and support of a lunar base. This facility will serve as a stepping stone for space exploration and advancement.

First option. S. S. *Freedom* should be redesigned and re-evaluated as a transportation node. This is costly, time consuming and alters its present function as a microgravity research facility[1].

Second option. Phase in S. S. *Freedom* as a transportation node. This modification would delay projected phases of the national space plan (e.g. lunar facility)[1].

Third option. A separate transportation node is designed and developed to advance space initiatives. This option does not interfere with S. S. *Freedom* and provides a concentrated effort in the second era of space travel.

Options and Choice

The project team weighed all three options and chose to design a separate transportation node. The project team agreed that to redesign S. S. *Freedom* as a transportation node would be in conflict with its present international research mission. Therefore, it was decided to design a second facility that would complement S. S. *Freedom* and support a lunar base. The project was given the name Spaceport *Aurora*, which signifies a new dawn, a new beginning in space exploration.

Assumptions

- S. S. *Freedom* will remain a pure scientific experimental facility.
- All facility components limited to orbiter payload bay size and mass capabilities.
- Shuttle and Orbital Maneuvering Vehicle (OMV) required for transportation and construction of spaceport.
- Heavy Lift Launch Vehicle (HLLV) not required.
- Low Earth Orbit (LEO) facility; orbital altitude within proximity to S. S. *Freedom*.

- Crew Size:

Permanent Crew	Lunar Transfer Crew
Commander	Commander
Pilot	Pilot
Flight Surgeon; FS	Crew Medical Officer; CMO
Crew Medical Officer; CMO	Lunar Specialist - 3
Intra vehicular activity; IVA - 2	
Extra vehicular activity; EVA - 4	
Technician Specialist - 2	
Subtotal: 12	Subtotal: 6
Total: 18	

- International crew
- Two split six-hour work shifts, six crewmembers per shift, six-day work week.
- Crew rotation every six months.
- "Dirty" microgravity environment.

Phases of Spaceport Aurora Configuration

Phase I: Initial configuration. The initial configuration for Spaceport *Aurora* begins with the launch and deployment of the "power tower" truss, power beam truss, fuel depot truss, and docking ring. Once this is completed, truss hardware is added (power lines, communication lines, fuel lines, solar arrays, solar dynamics, radiators, antennas, remote manipulator system (RMS), mobile transporter, and reaction control modules (RCM)).

After the structure is assembled, initial pressurized modules (with partial racks) are launched. They include one habitation and one common module along with interconnecting nodes. Once the modules and nodes are connected and attached to the structure, a logistics module (with supplies) is transported. The modules are completed with the installation of the remaining racks. The final step is occupation of the facility by the initial crew (4) (see Fig. 1).

Phase II: Assembly configuration. The assembly configuration consists of the launch and deployment of two rigidized inflatable hangars with door hardware and two rotating fixtures. Two work modules are launched along with a command module, control module, cupolas, two hyperbaric/airlocks and interconnecting nodes.

Once the assembly area is completed the remaining modules (with partial racks) are launched and connected. They include: a second habitation module, hotel (crew transfer) module, and the health maintenance facility (HMF)/experimental plant growth module. The modules are attached to interconnecting nodes and completed with the installation of the remaining racks. The final step is the launch of two assured crew return vehicles (ACRV) each capable of supporting a crew of 8. At the completion of this phase the facility has a permanent crew of 10 (see Fig. 2).

Phase III: Lunar mission configuration. The lunar mission configuration consists of the launch and installation of the fuel depot (8 propellant tanks, propellant management device and micrometeoroid protection) that will store and transfer fuel for the lunar vehicles. Once the fuel depot is completed the third and final ACRV is launched to accommodate a permanent crew of 18.

The final step is the launch of lunar vehicle components for assembly. This will be a gradual process that coincides with the development of the lunar facility. As lunar initiative activity increases so will the assembly of vehicles aboard Spaceport *Aurora* (see Fig. 3).

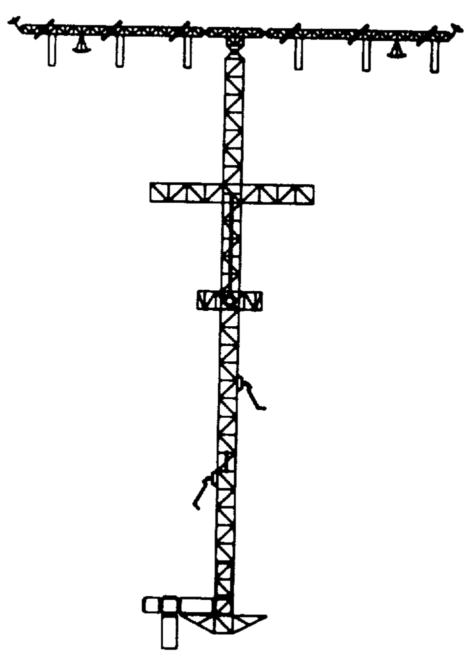

Fig. 1. Initial Configuration

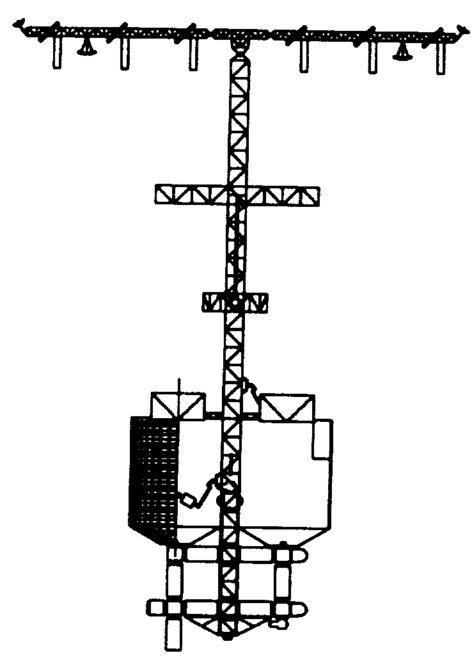

Fig. 2. Assembly Configuration

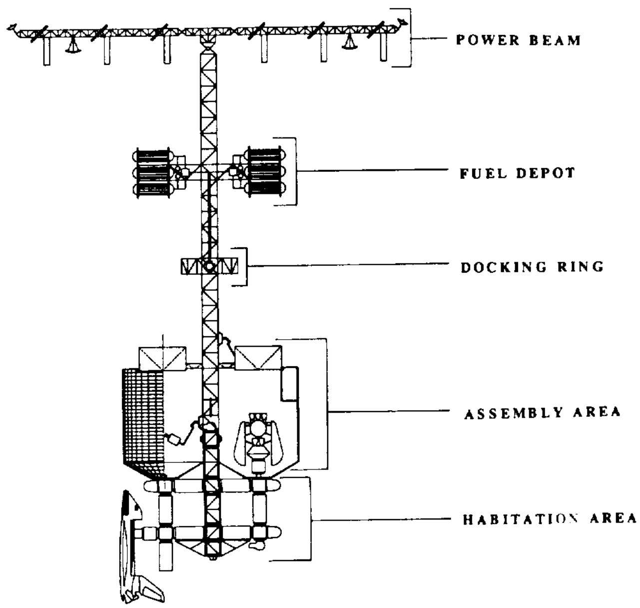

Fig. 3. Lunar Mission Configuration

Refer to Fig. 4 for total mass transported and total shuttle flights required per completion of phase.

DESIGN

The research on individual components provided a guideline for the overall configuration of the spaceport as well as the components themselves.

Facility Configuration

Goals. Spaceport *Aurora* is an orbiting transportation node with a hands-on environment involving routine and risk. With such operations occurring on a continuous level certain goals become apparent:

- Provide a productive working and living environment
- Provide redundant systems for safety and maintainability
- Provide for servicing of vehicles
- Provide a configuration that reduces orbital surface drag
- Provide for modularity within existing space infrastructure

Concepts. To provide a productive working and living environment a separation of the two activities is necessary. Both activities (working and living) require zoning of spaces as private or public.

To reduce orbital drag the components with the largest frontal surface area should be positioned parallel with the orbital path (x-axis)[2]. To reduce fuel consumption the mass of the spaceport should be balanced along the z-axis, creating a gravity gradient stabilized facility[3].

Design solution. The "power tower" configuration is chosen because it provides a gravity gradient stabilized facility (which will assist in the transfer of propellant) with minimal orbital surface drag. The power tower provides an efficient structure using a modular construction system that will accommodate components of the existing space infrastructure. The power tower truss measures 560′ (170.7 m) in length using a 17′6″ (5.3 m) by 17′6″ (5.3 m) bay module and the power beam measures 400′ (121.9 m) in length using an 8′ (2.4 m) by 8′ (2.4 m) bay module . The power tower serves as the spine supporting the various facility components of Spaceport *Aurora*

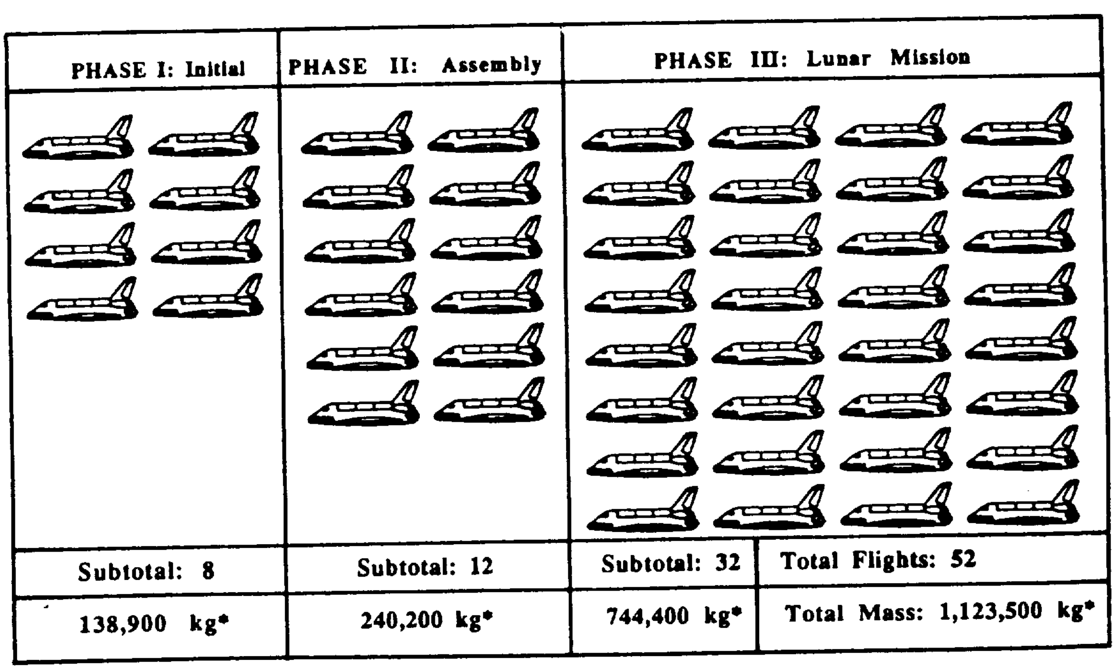

Fig. 4. Spaceport Aurora Configuration; Shuttle Flights and Mass

Assembly

Goals. Because of hazardous working surroundings and continuous monitoring, the assembly area must be a productive environment. The following goals are essential:

- Provide a safe working area in space
- Provide service and assembly capabilities
- Provide expedient construction
- Minimize EVA

Concepts. To ensure crew safety and minimize EVA time, redundant automated systems and telerobotics are necessary. In order to maintain EVA productivity during vehicle assembly, the hangar should be completely enclosed. Another safety factor within the hangar is protection from micrometeoroids. A double-insulated skin made of aluminum and Kevlar is necessary to keep meteoroid penetration at a minimum(4).

A clear unobtrusive viewing area for EVA and telerobotic observation is required. This IVA station should be in close proximity to the vehicles serviced. Communication and monitoring throughout the facility is accomplished through audio/visual equipment.

Design solution. Rigidized inflatable hangars are incorporated to reduce shuttle flights, construction time and EVA time. The hangars are compact and placed within the orbiter cargo bay. Two hangars 85′ (25.9 m) in diameter by 120′ (36.6 m) in length are incorporated rather than one to increase the number of vehicles repaired and to reduce turnaround time. The control module 14′6″ (4.4 m) in diameter by 25′ (7.6 m) in length is located perpendicular to the two hangars providing dual, separate work cupolas on opposite sides for telerobotics supervision and observation. The assembly cupolas are located 10′ (3 m) from the vehicle which is under repair within the hangar, providing a clear unobstructed view for IVA personnel. The command module, adjacent to the control module, 14′6″ (4.4 m) in diameter by 34′ (10.4 m) in length is the control center for the entire facility. The command module monitors facility communications, navigation, energy levels, environmental systems and propellant supplies. The command module also provides a (EVA repair) viewing area within the hangars. The work modules 14′6″ (4.4 m) in diameter by 34′ (10.4 m) provide IVA repair of components which are too small and/or tedious for EVA within the hangars (see Fig. 5).

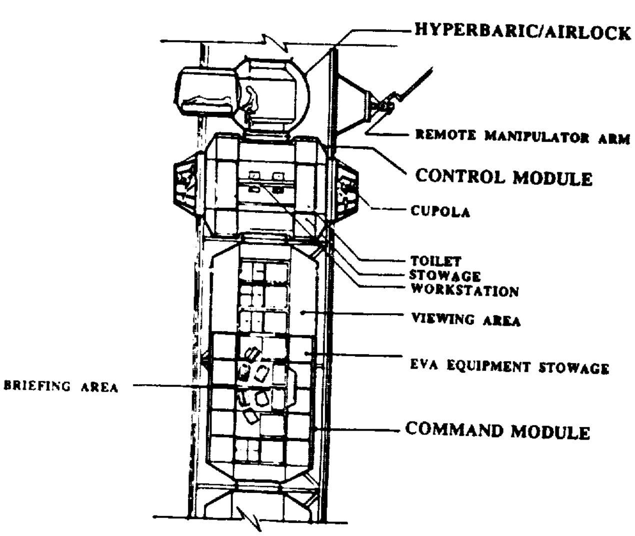

Fig. 5. Command Module, Control Module and Hyperbaric Airlock

EVA access to the hangars is accomplished through the rotating drums or through the hyperbaric airlock. This provides direct access for EVA personnel into the hangars (an enclosed volume) reducing safety risks.

Both pressurized and unpressurized docking is needed. A docking ring 60′ (18.3 m) in diameter with a hard dock is used for transfer of propellant and replacement parts. A pressurized docking node is used for transfer of lunar and spaceport crews. Thus, the cargo delivery does not disturb the habitation modules.

Habitation

Goals. The habitation area is the central meeting place for group interaction. Positive psychological and physiological environments are desirable. The habitation goals are:

- To increase productivity
- To utilize space efficiently
- To provide a safe environment

Concepts. The habitation area supports various functions which are inter-related yet different. Activities within the habitation modules include:

Sleeping	Personal Hygiene
Recreation	Eating
Drinking	Meetings
Studying	Personal Stowage
Relaxation	Training
Meal Clean-Up	Communications
Private Conferences	Clothing Maintenance
Dressing	

Separation of the habitation activities is important. Zoning from private to public is necessary.

To utilize space efficiently, interchangeable partitions for accommodating transfer crews provide flexible interiors. The permanent crew has sleeping quarters 28 ft^2 (8.5 m^2) which are larger than the transfer crew 14 ft^2 (4.3 m^2) who are on board for a shorter period of time (5).

A consistent local orientation throughout the facility is an important factor to consider (6). This will assist the permanent crew in performing daily activities, provide the transfer crew in adapting more quickly to their surroundings and, therefore, increasing productivity.

Design solution. All pressurized modules within the facility are 14′6″ (4.4 m) in diameter by 34′ (10.4 m) in length. This length is based on: (1) minimizing visibility distance from assembly cupola to vehicle in hangar; (2) configuration of modules within the power truss bays 17′6″ (5.3 m); and (3) modularity for maintenance. Although the modules are shorter than standard S. S. *Freedom*, their length is consistent throughout the facility (for flexibility) and they are transported with partial racks preassembled.

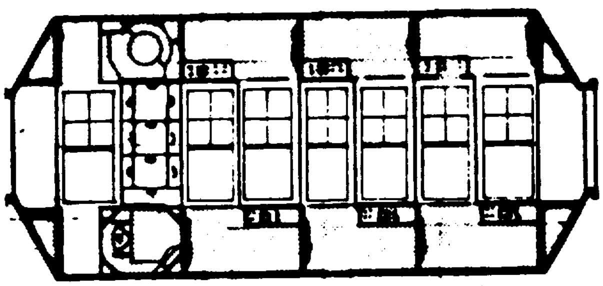

Fig. 6. Habitation Module (Permanent Crew)

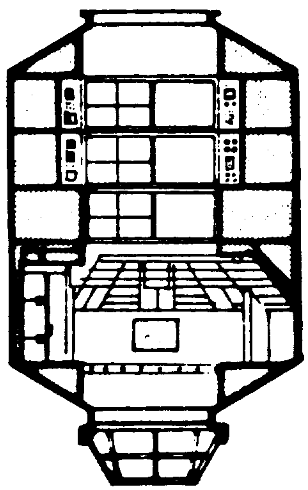

Fig. 7. Earth Viewing Wardroom Cupola

Because of split work shifts, dual habitation modules for crew sleeping quarters provide privacy and redundancy. Each module has a separate hygiene facility that serves as a backup (and improves maintainability) in case of malfunction (see Fig. 6).

A common module is centrally located to accommodate crew activity such as dining, housekeeping, recreation, etc. A hotel module accommodates transfer crews (lunar and spaceport) and serves as a backup for common module housekeeping activities (cooking, laundry, dining, etc.).

A consistent orientation is maintained throughout the facility except when entering the Earth viewing wardroom cupola and the control module. Both the Earth viewing cupola and control module are unique spaces that require a change in orientation for maximum viewing capabilities. The Earth cupola is an area where "sharing a unique experience can relieve some of the stress of a confined environment"[7] (see Fig. 7).

Health Maintenance Facility (HMF)

Goals. The HMF provides the crew with physiological and psychological treatment. When compared to S. S. *Freedom*, the following goals for Spaceport *Aurora* HMF are:

- Assured crew safety and health
- Increased function of airlocks
- Increased privacy
- Improved patient care

Concepts. The HMF requires a large separate facility because of the large crew and the split work shifts. The flight surgeon is trained for preventive care, diagnostic care and therapeutic care[8]. The flight surgeon will monitor and record crew behavior, which will serve as a data bank for future long term missions (lunar and Mars). Because of the diverse medical functions, the health facility is zoned according to

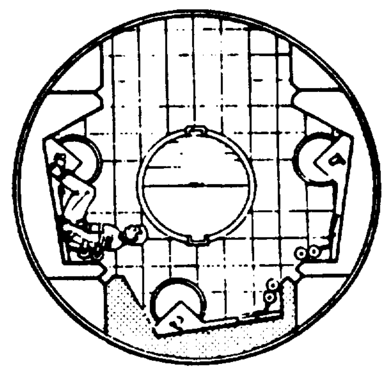

Fig. 8. Exercise Area

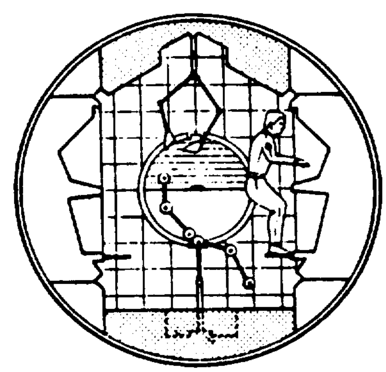

Fig. 9. Medical Area

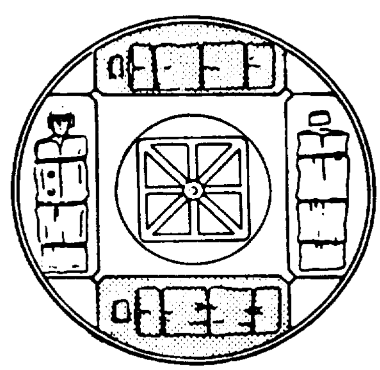

Fig. 10. Quarantine/Recovery Area

activity level to provide improved individual patient care and increased privacy.

Design solution. The HMF is a separate module shared with the experimental testbed. The HMF occupies 65% of a habitation module 14′6″ (4.4 m) in diameter by 22′ (6.7 m) in length. It is located adjacent to an assured crew return vehicle (ACRV) for expedient patient evacuation.

The HMF facility is zoned according to activity function: (1) exercise adjacent to the entrance of the module (most active); (2) medical and health monitoring located at center of the module (moderately active); and (3) recovery and/or quarantine adjacent to testbed (inactive) (see Figs. 8, 9, and 10).

Exercise as preventive care is particularly stressed. The bicycle ergometer and treadmill are cited as the most efficient devices. The exam table is redesigned as a restraining apparatus for improved patient comfort in microgravity. The airlock adjacent to the HMF also serves as a hyperbaric chamber in case of EVA decompression.

Because of the dangers of a hands-on environment in space, a fatality may occur. Preparation for such an event is neither pleasant nor predictable. In order to maintain crew safety, a rack system in the recovery area is designed as a temporary morgue using refrigeration techniques (to preserve the deceased crewmember and contain the spread of disease) until the body is transferred to Earth.

Assured Crew Return Vehicle (ACRV)

Goals. The goals for ACRV are to provide a simple, reliable vehicle that requires minimum crew training. The vehicle should be volume efficient, provide buoyancy (for water landing), reasonable loiter time (return trip time), and minimal *g*-stress upon reentry (for a deconditioned or injured crewmember).

Concepts.

- Apollo
- Station crew return alternative module (SCRAM)
- Reference configuration, Discoverer shaped
- Langley lifting body (see Figs. 11-14).

Design solution. Based on ACRV comparisons the "Reference" Discoverer design is chosen. It is 13′6″ (4.1 m) in diameter by 11′6″ (3.5 m) in length based on passenger capacity (6) with injured crewmember (8) uninjured crewmembers, 24-hour loiter time, single flotation point for buoyancy, minimal *g*-stress upon reentry and minimal crew interface[11]. A total of three vehicles are necessary for complete evacuation of facility personnel (see Figs. 15 and 16).

Power Systems

Goals. The power systems' goals are to provide high output, reliability, efficiency, low weight and volume, and regulation of heat build up.

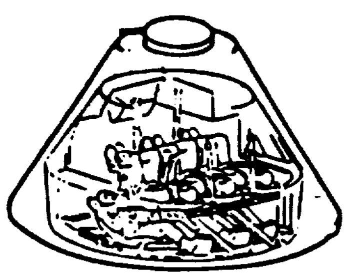

Fig. 11. Apollo-derived Vehicle[9]

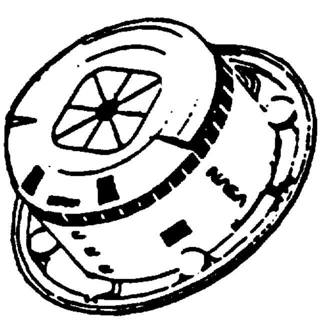

Fig. 12. SCRAM Vehicle[9]

Fig. 13. Reference/Discoverer-Shaped[9]

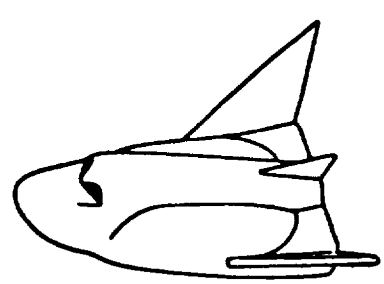

Fig. 14. Langley Lifting Body[9]

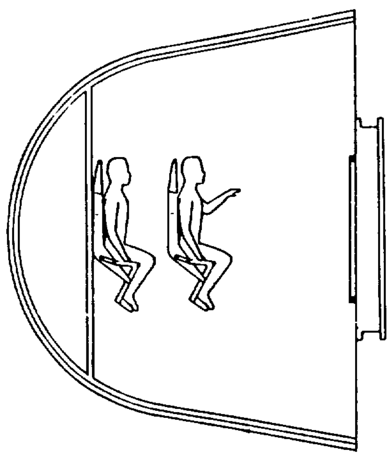

Fig. 15. Discoverer Longitudinal Section[10]

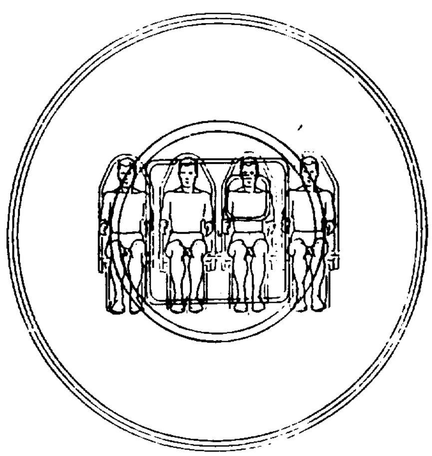

Fig. 16. Discoverer Cross-Section[10]

Concepts.

- Photovoltaics: (a) silicon cells (b) gallium arsenide cells
- Solar dynamic
- Electrochemical storage: (a) nickel cadmium batteries (b) nickel-hydrogen batteries
- Fuel cells
- Power management and distribution (PMAD): a system converting power from the solar arrays and distributing it to specific jobs.

Design solution. Spaceport *Aurora* requires a hybrid power system to ensure safe and efficient operation. Photovoltaic arrays (6 power modules; 20′ (6.1 m) in width by 95′ (29 m) in length) are used as a primary source of power with solar dynamics, 50′ (15.24 m) in diameter, as the secondary system[13]. Nickel-hydrogen battery packs provide the backup system low mass and weight requirements[14]. A power management and distribution (PMAD) unit is required to control and distribute incoming power. Radiators are required to eliminate excess heat and are located near solar arrays and habitation area (see Figs. 17 and 18).

Fuel Depot

Goals. The fuel depot goals are to provide safe, efficient, stowage and transfer of propellant, while using minimal EVA and maximum telerobotic operation. The fuel depot is an important component for mission success, yet dangerous to crew safety. The immediate environment adjacent to the depot is prone to pollution from transfer of propellant and boiloff gases. Safety, therefore, is an important goal. The fuel depot should be remote from the habitation modules, yet easily accessible from the assembly area.

Concepts:.

- Attached fuel depot
- Tethered fuel platform
- Co-orbiting fuel platform

Design solution. Based on a comparison of the three concepts, an attached fuel depot is chosen to reduce propellant transfer time. The depot is located opposite the habitation area to reduce risk of pollution (from fuel spill) and to provide a gravity gradient stabilized facility. The fuel depot

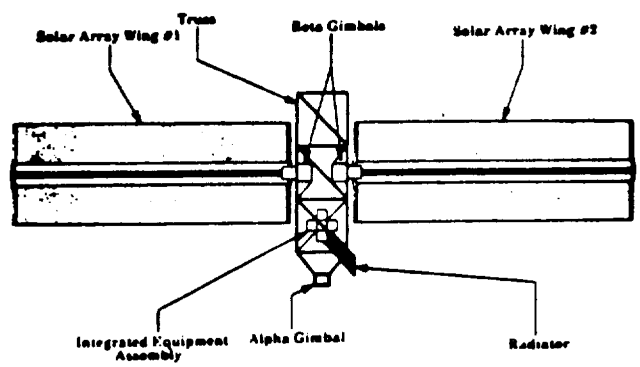

Fig. 17. Photovoltaic Module[12]

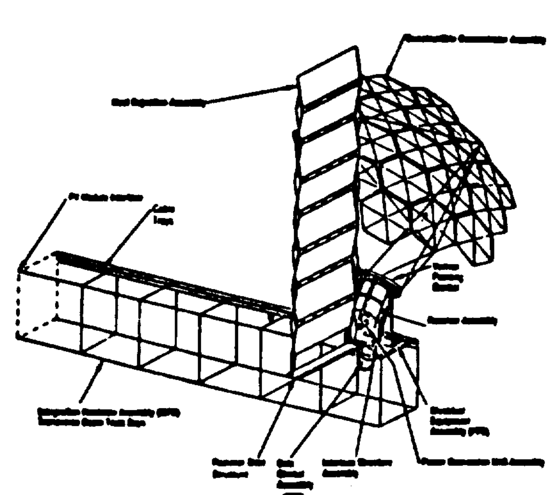

Fig. 18. Solar Dynamic System[12]

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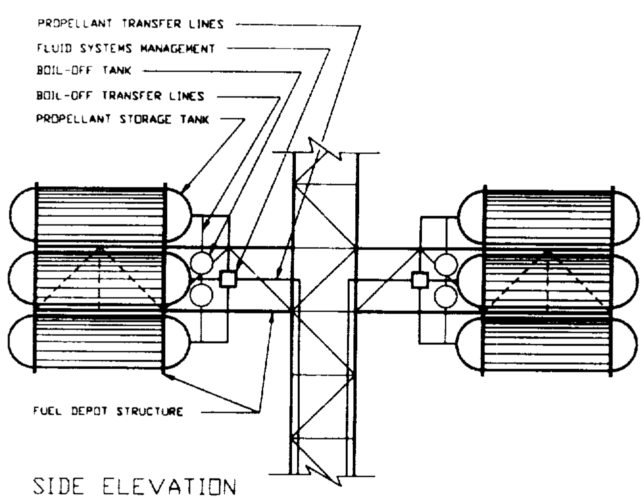

Fig. 19. Fuel Depot

consists of 8 propellant tanks (each containing an oxygen and hydrogen tank) 14′6″ (4.4 m) in diameter by 44′ (13.4 m) in length each containing 100,000 lb of propellant. The depot also contains a propellant management device (on either side of the truss), fluid transfer lines (refrigeration and heat lines), and is enclosed with a Kevlar micrometeoroid double skin(4) (see Fig. 19).

The propellant tanks will be partially filled for the initial launch, since the orbiter's maximum cargo capacity is limited to 55,000 lb. Once connected to the fuel depot structure, each propellant tank will require two shuttle trips for maximum stowage capability (100,000 lb). The orbiter will transport a reusable transfer propellant tank to LEO, where the shuttle will rendezvous with Spaceport *Aurora*. Once the shuttle is attached to the docking ring, transfer of propellant to the fuel depot occurs through transfer lines which connect to the transfer propellant tank. This operation is automated and monitored by a fuel specialist from within the command module; there is no need for EVA supervision for this activity. After the process is complete, the orbiter returns the transfer tank to Earth where it will be inspected and replenished with propellant.

Refueling of vehicles occurs after the vehicle has been serviced and repaired in the hangar. Vehicles within the hangars will contain no fuel to reduce risks to EVA personnel and to reduce pollution to nearby viewing cupolas. The RMS transports the vehicle toward the docking ring, where it is connected to a hard dock with propellant transfer lines. Once the vehicle is fueled, it is deployed with an attached OMV (acting as a space tug) and launched within the vicinity of Spaceport *Aurora*.

Experimental Plant Growth Facility

Goals. The primary goal of the plant growth facility is to gather data on the effects of microgravity on plants. A second goal is to provide an Earth-like environment to serve as a morale booster.

Concepts.

- Hydroponics: root is grown in nutrient solution(15)
- Aeroponics: root is grown in air(16)

Design solution. The plant growth facility is adjacent to the HMF occupying 35% of a habitation module 14′6″ (4.4 m) in diameter by 12′ (3.7 m) in length. Two standard racks are incorporated for growing plants using the aeroponic method. The aeroponic method consists of a nutrient solution line that sprays the plant root area within an enclosed membrane. A nutrient solution collector and return line

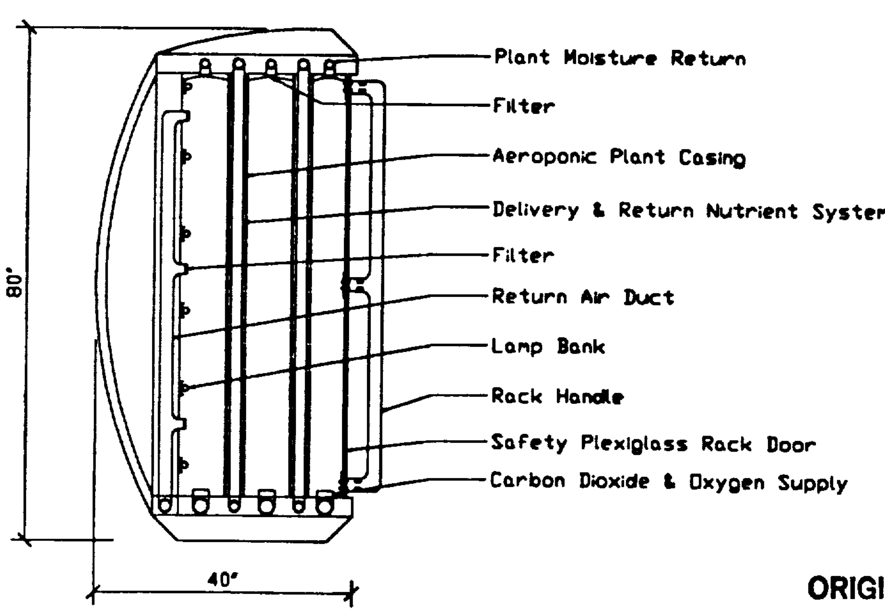

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Fig. 20. Plant Growth Rack: Aeroponic Method

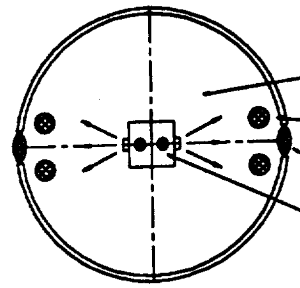

Fig. 21. Aeroponic Membrane Section

transfer the remaining solution to the storage tanks using pumps[17]. The plants within the racks will be grown in continuous artificial light cycles. A major concern is the heat that the lights generate. To reduce heat buildup, fiber optics are incorporated that provide the same light intensity and maintain low heat levels within the racks and module (see Figs. 20 and 21).

Along with the hardware above, management devices to monitor and operate the plants are necessary: (1) Atmosphere management: air revitalization, atmosphere pressure, module temperature and humidity control; (2) Water and waste management: water reclamation, water quality monitoring and solid waste management; (3) Food management: record edible biomass, food preparation and reclamation of inedible biomass[18].

CONCLUSION

Spaceport *Aurora* is a low Earth orbit (LEO) gravity gradient stabilized transportation node, which provides support missions for the construction and maintenance of a lunar facility. All spaceport components are constructed and supported through the orbiter and OMV. Deployable truss systems and rigidized inflatable hangars are used to minimize EVA and expedite construction. Modularity and flexibility is enforced using existing space systems and subsystems (standard racks, airlocks, environmental controls, etc.) used in S. S. *Freedom*. Dual hangars, habitation modules and hyperbaric chambers serve as a backup in case of malfunction, which provides redundancy.

A total of 52 shuttle flights is necessary for full configuration of Spaceport *Aurora*. Estimating shuttle operation at peak capacity (10 flights per year), the time frame for full configuration is estimated at five years and six months. Total orbiter flights is calculated using mass of components transported, and an additional two flights (per phase of configuration) in case of unexpected logistics problems. Total mass transported at completion date of configuration will be 1,123,500 kg.

Safety, through enclosed hangars, evacuation vehicles (ACRV) and a remote fuel depot reduces risk to crewmembers. A productive environment is accomplished through zoning of the two different activities: working and living. Human comfort is achieved through the use of large crew quarters, private spaces, and Earth viewing cupolas, which improve living conditions within a confined environment.

The configuration for Spaceport *Aurora* is based on a defined mission profile: to support a lunar facility and its space transfer vehicles. It is intended that the design for *Aurora* can be modified and adapted depending on the mission profile. Using existing space systems and subsystems, Spaceport *Aurora* can vary in configuration to accommodate different profile scenarios as space activity increases and a need for maintenance arises.

In conclusion, Spaceport *Aurora* will provide a convenient service route to the Moon. It is not intended as an end in itself but as a milestone along this journey. The spaceport is the logical rest stop to change the modes of space transportation. Much like an aircraft carrier the spaceport will act as a mobile landing strip to many space vehicles.

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