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Final Design Report

An Earth Orbiting Satellite Service and Repair Facility

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The Raptor Corporation

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The Raptor Corporation was formed in the Fall of 1989 at The University of Texas at Austin as part of the Universities Space Research Association. Raptor was formed to design an earth-orbiting satellite service and repair station.

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Abstract

To exploit the burgeoning satellite telecommunications industry, estimated to be growing at a rate of $9 billion annually by the year 2000, the Raptor Corporation has taken on the task of designing an orbital facility capable of repairing and servicing satellites in geosynchronous orbit. This effort has produced a conceptual design for the Geosynchronous Satellite Servicing Platform (GSSP). The GSSP is a man-tended platform, which consists of a habitation module, operations module, service bay and truss assembly. This design review includes an analysis of life support systems, thermal and power requirements, robotic and automated systems, control methods and navigation, and communications systems. The GSSP will utilize existing technology available at the time of construction, focusing mainly on modifying and integrating existing systems. The entire facility, along with two satellite retrieval vehicles (SRV), will be placed in geosynchronous orbit by the Advanced Launch System. The SRV will be used to ferry satellites to and from the GSSP. Technicians will be transferred from Earth to the GSSP and back, in an Apollo-derived Crew Transfer Capsule (CTC). These missions will use advanced telerobotic equipment to inspect and service satellites. Raptor has tentatively scheduled four of these missions per year. At this rate, the GSSP will service over 650 satellites during the projected 25 year lifespan,. With the GSSP, Raptor will strengthen its leadership position in satellite servicing and the industrialization of space.

Table of Contents

Appendices

List of Figures

List of Tables

List of Acronyms

AI - Artificial Intelligence
ALS - Advanced Launch System
CDR - Combination Deploy and Retrieve
CTC -Crew Transfer Capsule
CTS - Communications and Tracking System
ECLSS - Environmental Control and Life Support Systems
ELV - Expendable Launch Vehicle
EVA - Extravehicular Activity
GBTCC - Ground Based Telerobotic Command Center
GCR - Galactic Cosmic Radiation
GEO - Geosynchronous Earth Orbit
GNC - Guidance Navigation and Control
GPS - Global Positioning System
GSSP - Geosynchronous Satellite Servicing Platform
IOC - Initial Operational Capability
IVA - Intravehicular Activity
LEO - Low Earth Orbit
MED - Momentum Exchange Device
MRMS - Main Remote Manipulator System
NASA - National Aeronautics and Space Administration
OMV - Orbital Maneuvering Vehicle
RCS - Reaction Control System
REM - Reontgen Equivalent Man
RFC - Reversible Fuel Cells
RTG - Radioisotope Thermal Generators
SEP - Solar Energetic Particles
SPE - Solar Particle Event
SRV - Satellite Retrieval Vehicle
SS - Space Station
STV - Space Transfer Vehicle
TDRSS- Tracking and Data Relay Satellite System
USRA - Universities Space Research Association
UT - The University of Texas

Executive Summary

The Raptor Corporation was formed in September 1989, to design and develop a commercial facility for the repair and servicing of satellites in geosynchronous Earth orbit. The product of that effort is a conceptual design for the Geosynchronous Satellite Servicing Platform (GSSP). Upon completion in 2010, the GSSP will be capable of telerobotically servicing a wide array of telecommunication satellites.

The Market

By the year 2000, telecommunication satellites will generate over $9 billion in revenues for the nations and corporations dependent upon their services. The current average lifespan of a satellite in geosynchronous orbit is 7 years; after 13 years in orbit, the failure rate is 98%. While continuing advances in technology may extend the lifetime of satellites in the future, the cost of constructing, insuring and launching a satellite will remain formidable. The GSSP will help lower these costs by extending the useful life of satellites with its servicing capabilities. The Raptor Corporation will also provide a low-cost alternative to companies and countries desiring satellite ownership by selling refurbished satellites at a cost well below that of a new satellite. Through servicing and sales, the GSSP will generate over $750 million annually. Tables 2.2 and 2.3 detail the projected cost, price and revenue structure for the GSSP.

The Task

Servicing of active and inactive satellites will entail component replacement, component repair, component refueling, or any combination thereof. Servicing tasks will be performed telerobotically from either the GSSP operations module or a ground based telerobotic command center.

Component replacement comprises the main service task identified by the Raptor Corporation -- 75% of satellite failure is due to component failure. Component replacement also provides another market opportunity; the GSSP can upgrade and enhance satellites as technologies improve.

Component repair will performed when the failed component is readily repairable. If repair cannot be effected robotically, the component will be placed in the operations module airlock, and servicing will be performed by technicians.

Refueling will be performed on-orbit at satellite location by the SRV via modular changeout of satellite fuel cells.

The Mission

A typical mission scenario is depicted in Figure 1.1. A satellite targeted for service is captured and transferred to the GSSP by a Satellite Retrieval Vehicle (SRV). The SRV is a modified Orbital Maneuvering Vehicle (OMV), which is scheduled to enter service during the initial stages of Space Station operations. After four satellites are berthed at the GSSP by SRV's, two Raptor technicians in a Crew Transfer Capsule (CTC) will travel to the GSSP using a Titan IV launch system. The CTC, an Apollo derived crew capsule, will rendezvous and dock with the GSSP, remaining there throughout the two week mission duration. The technicians will telerobotically repair the satellites, which are transferred in and out of the service bay using the Main Remote Manipulator System (MRMS). If repairs cannot be completed telerobotically, the technicians will repair the component in the operations module. If the component is too large to fit though the airlock between the service bay and the operations module, one of the technicians will enter the service bay, using an EVA suit and repair the satellite. Upon completion of repairs, the SRV's will redeploy the satellites to their original position, and the technicians will return to earth in the CTC.

The Facility

Designed for a 25 year lifespan, the GSSP will consist of a habitation module, an operations module, a service bay and a truss assembly. Two SRV's will be stationed at the GSSP.

The habitation module is 34 feet long and 14 feet in diameter, with 3,000 cubic feet of living area pressurized to 10.2 psi. Part of the habitation module serves as a safe haven during solar flares. The operations module is based on the Space Station Freedom resource node structure, and measures 17 feet long and 14 feet in diameter. The operations module contains all communication, telerobotic and computational equipment. A two chamber airlock located in the operations module serves for EVA preparation and as access to the service bay.

The service bay is an enclosed octagonal structure with dimensions 30 x 30 x 40 feet and constructed of an aluminum space frame enclosed with monocoque sheets of Kevlar.

The truss assembly is a dual purpose structure providing a construction foundation for the GSSP and acting as a track system for the main remote manipulator system. Additionally, the truss removes solar panels and thermal radiators from the proximity area of the service bay.

Construction of the facility requires four stages to completion, as depicted in Table 7.1, with all work performed in GEO. The first three stages will be constructed telerobotically from ground control. The final stage of construction, along with initial satellite servicing, wil be performed telerobotically by technicians at the GSSP.

Subsystems for the GSSP were chosen with both safety and cost effectiveness as prime considerations. With a planned two week, two crew member mission scenario as a baseline, an open looped environmental control and life support system was chosen. Cabin pressure will be maintained at 10.2 psi, ensuring safety and reducing prebreathing time when EVA activities are necessary. The composition of the cabin atmosphere is shown in Table 9.1 Consumables are resupplied for each mission, and waste material is filtered, stabilized, stored and disposed of. Tables 9.2 and 9.3 list consumables and waste requirements.

A system of photovoltaic solar cells in a planar array will provide the GSSP's power needs. The system generates 35 KW continuous power, is 850 square meters and weighs 2,500 kg. While not the most efficient system, the solar array meets the two main design criterion -- safety and cost effectiveness. Ammonia heat pipe radiators will be used for thermal heat rejection. A decision matrix for power systems can be found in Table 10.2 and thermal system comparisons in Table 11.1

The GSSP will be located in geostationary orbit at 255° East longitude. This position is advantageous because it allows for direct communications to U. S. ground stations, and is located near U. S. satellites, which will be the largest market for GSSP services. The 255° East GEO position is also desired for simplified stationkeeping purposes.

In geosynchronous orbit, the guidance, navigation and control systems are designed primarily for orbit maintenance. An inertial guidance system has been chosen for the GSSP. This system will provide the SRV, which uses a relative navigation scheme, with an inertial frame of reference. The inertial reference point will be at the GSSP.

This will provide superior SRV navigation during proximity operations. Stationkeeping for the GSSP will be performed by electrothermal hydrazine thrusters. Catalytic hydrazine thrusters will be used for the attitude control propulsion system. These two systems are advantageous because they require approximately the same supply pressure; therefor, a common propellant feed system can be used.

The GSSP will use a direct communication link with a ground station. The tracking and data relay satellite system (TDRSS), will be used to communicate with the Space Station and to track the SRV and the CTC.

Automation is the key to both safety, and an economically feasible design. Telerobotic hardware aboard the GSSP includes a space arm manipulator system, a flight telerobotic servicer and servicing robots for use inside and outside the service bay.

The main remote manipulator system is a 7 degree of freedom robotic arm, operated from the ground station or the GSSP. The MRMS will be used to construct the GSSP and to grapple and maneuver payloads around the GSSP.

The flight telerobotic servicer (FTS), is an advanced system used to perform high dexterity operations. The FTS employs an advanced vision system for control, and will be mounted on the SRV's and the MRMS. The FTS and MRMS will also be used for GSSP inspection, repair and maintenance.

A set of specialized arms, situated in the service bay, will use changeable end effectors to provide a flexible array of satellite servicing capabilities.

1.0 Introduction

The Raptor Corporation was formed in the Fall of 1989 to construct, design and maintain a commercial facility for the repair and servicing of geosynchronous satellites. This facility will provide services to countries and corporations with satellites in Geosynchronous Earth Orbit (GEO). Raptor's design of a Geosynchronous Satellite Servicing Platform (GSSP) is capable of robotic and manned servicing of a wide spectrum of satellites. The GSSP consists of a habitation module, an operations module and a service bay. It will be placed into GEO with four launches via the Advanced Launch System (ALS).

A typical mission scenario is graphically depicted in Figure 1.1 The mission begins with a modified Orbital Maneuvering Vehicle (OMV), based at the GSSP, called a Satellite Retrieval Vehicle (SRV), retrieving a satellite using Hohmann trajectories. When four satellites have been retrieved and are stored at the GSSP, technicians will be sent to the GSSP. They will travel in a Crew Transfer Capsule (CTC), which is based on a reusable Apollo-derived command module. The CTC will be delivered to GEO by a Titan IV or other man-rated vehicle of similar payload capability.

The technicians will perform necessary servicing or contracted upgrading of the satellites. At the completion of the servicing tasks, the SRV will redeploy the satellites to their original GEO positions and the technicians will return to Earth using the CTC .

With an average of four missions per year, and an estimated 25 year lifespan for the GSSP, Raptor will service over 600 satellites. From these scenarios, a market analysis can be formulated.

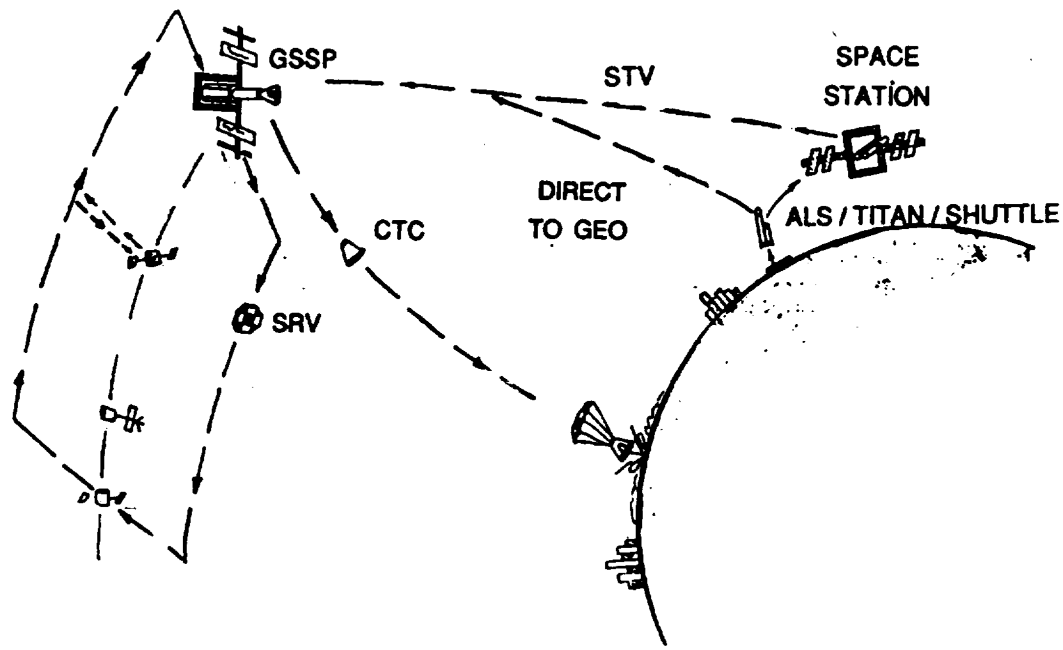

Figure 1.1 Typical Mission Scenario.

2.0 Market Analysis

The number of satellites in GEO, coupled with their significant cost, provide Raptor with a substantial market opportunity.

According to the TRW Space Log [1], there were 120 active and 310 inactive satellites in GEO in 1988. The number of GEO satellites has increased by 18% per year over the last decade, and this growth rate is expected to remain constant through the turn of the century [2]. This projects to over 1500 satellites in GEO by the year 2000. Based on a 98% probability of failure, the average lifespan of satellites is 7 years, with a maximum life time of 13 years [3].

The 120 active satellites generate $3 billion annually for countries and corporations dependent upon their services. A projected yearly growth rate of 20% places annual revenues at $9 billion by the year 2000 [4].

The average construction cost of satellites is $40 million, with insurance costs upwards of $10 million [5]. The average weight of a GEO satellite is 2000 kg [6] with launch costs ranging from $33,000/kg for Ariane to $75,000/kg for the Titan 34D/IUS [7], and thus, the cost of launching a typical satellite costs about $150 million.

The ability to extend the lifetime of satellites through regular repair and maintenance will be the main source of revenue for Raptor. Based upon straight line costs, the average satellite can depreciate at a rate of $21 million per year, as shown in Table 2.1. One service visit may be able to double the lifespan of a satellite; therefore, Raptor will impart significant savings to its customers. Although it is reasonable to believe that satellite reliability will increase in coming years, the sheer number of satellites in GEO should provide continued market opportunities.

Table 2.1 Satellite Depreciation.

Description		Cost (millions)
Construction		$50
Insurance		10
Launch (Space Shuttle)		87
	Total	$147
Annual Depreciation over the 7 year life span of the satellite		$21

As shown in Tables 2.2 and 2.3, Raptor will generate $500 million from scheduled repair and maintenance. This figure is based on one service visit per satellite every seven years, a projection of 16 satellites serviced per year (4 missions at 4 satellites per mission), and price of $31.2 million per service call.

Table 2.2 Raptor Cost Analysis

Initial costs: (millions of dollars)		
Construction		$1,000
Insurance		200
Deployment (4 ALS launches)		4,500
	Total	$5,700

Annual costs: (4 missions annually)		
Launch (Titan IV)		$177 [6]
Tracking		18 [7]
CTC: Recovery		18 [7]
Repair and refurbishment		18 [7]
	Total	$231

Table 2.3 Raptor Pricing Structure

Satellite Servicing:		
Annual cost		$231
Initial cost ($5,700/25 yrs)		228
Repair cost		10
	Total	$469
Cost per satellite ($469/16)		$29.3
10% profit		2.9
	Service price	$31.2

Satellite Repair and Resale:		
Purchase cost (4 annually)		$58.8
Repair cost		40.0
Redeployment cost		40.0
	Total cost	$138.8
	Sale price	$300.0

Revenue generated annually = $261.2 million.

Refurbishment and resale of inactive satellites is another potential GSSP market. Nations desiring the benefits of satellite ownership, but lacking developmental capital are prospective customers. Based on a purchase cost of ten cents on the dollar, the sale of 4 reconditioned satellites (one per service mission) will generate an annual income of $261.2 million, as shown in Table 2.3.

Although market conditions are subject to change; Raptor strongly believes that it will realize substantial profit from its satellite servicing and refurbishing capabilities.

References: Market Analysis

1. "TRW Space Log",TRW Incorporated, August 1989.

2. White, R.L. and White, H. M. Jr., The Law and Regulation of International Space Communication, Artech House: Boston, Mass., 1988, p.10.

3. Morgan, W. and Gordon, G. ,Communications Satellite Handbook, John Wiley & Sons: N.Y, N.Y.,1989, p.760-761.

4. Osbourne, D. , "Business in Space", The Atlantic, 25:5, May 1988.

5. Webster, S., "TOS: Commercial Launch Vehicles for the 80's", Satellite Communications, Sept. 1983, p.44-50.

6. McCuskoe, T. and Pinon, E., Personal Communication, The Large Scale Programs Institute, Austin, Texas 12/11/89.

7. Mandel, H. C., Personal Communication, Johnson Space Center, Houston, Texas 12/11/89.

3.0 Design Assumptions

The Raptor design for the GSSP is dependent on the following assumptions:

1. 15 to 20 years until Initial Operational Capability (IOC),
2. Advanced telerobotic capability,
3. Satellite Retrieval Vehicle (SRV),
4. Crew Transfer Capsule (CTC) availability,
5. Advance Launch System (ALS), and
6. Increased modularity in satellite design.

The servicing of geosynchronous satellites will require technologies and equipment not currently available. The GSSP does, however, utilize designs and prototypes that are scheduled to be available by the time of IOC. NASA, in a 20 year forecast compiled by the Consortium of Texas Research Universities, has assigned highest priority to the advancement of telerobotic capability. Advancement in telerobotics is crucial to successful GSSP operations. Both the SRV and the ALS are projected to be operational by the year 2000. The CTC is not currently in production; however, it is derived from a previous design that could easily be produced.

To be commercially viable, the Raptor Corporation must keep design and development costs of the GSSP to a minimum. Therefore, the 15 to 20 year time frame must be adhered to, to allow development of equipment and technologies mentioned above.

The refinement of advanced telerobotics will enable the Raptor Corporation to service satellites and maintain the GSSP operations from ground stations. This would reduce costs by minimizing missions requiring technicians.

The ALS will assist the Raptor Corporation in achieving its goal of Space Station/Space Shuttle independence. Dependable, competitively priced Heavy Lift Launch vehicles, capable of placing payloads in GEO, are desirable for economic savings.

An SRV, a modified version of the Orbital Maneuvering Vehicle designed for NASA, is necessary for the telerobotic capture, retrieval, and re-deployment of satellites serviced and salvaged by Raptor.

A reusable, Apollo-derived CTC will be used for missions requiring technicians at the GSSP. The requirements for the CTC are cited in Section 17 of this report.

Finally, the integration of modularity into satellite design is assumed. This will allow for more efficient economies of repair, and provide another possible source of revenue through the upgrading of existing satellites.

4.0 Service Tasks

Three services will be offered by the GSSP to successfully restore satellites to operational capability. These include component replacement, component repair and refueling. All of these services will be rendered by telerobotic operation from either the GSSP Operations Module or the Ground Based Telerobotic Command Center (GBTCC). The most desirable scenario would have all tasks performed via telerobotic operation from the GBTCC; however, current reviews of the projected state of robotics development for the years 2005 - 2010 indicate that this capability will not be feasible due to the dextrous manipulations required for component repair coupled with the time lag in communications [1].

4.1 Component Replacement

The primary service task performed during GSSP operation will be component replacement. Table 4.1 gives an indication of the failure characteristics of typical communication satellite components [2]. Note that amplifiers, pre-amplifiers, and receivers comprise over 75% of the component failures.

Table 4.1 Failure Data for Communication Satellite Components [1:761]

# per satellite	Component	Failures	
		Predicted	Actual
24	Travelling-wave tube amplifier	58.3	36
4	Receiver, pre-amplifier	13.8	34
2	Attitude control electronics	6.1	3
12	Command decoder	5.4	0
2	Transponder switches and filters	4.1	0
2	Telemetry encoder	3.9	2
2	Thruster (set of three)	2.8	4
2	Power amplifier (attitude control)	2.0	0
2	Earth sensor	2.0	3
2	Command receiver	1.6	0
2	Sun sensor	1.3	0
2	Hydrazine tank (pair)	1.1	0
2	Telemetry transmitter	1.1	1
2	Battery and control	0.8	6
2	Spot beam	0.7	0

Component replacement has been chosen as the primary repair service because operational capability can be restored in a more timely and simplistic manner, as opposed to removing the component from the satellite, repairing it and replacing the unit. The primary equipment used for replacement will be telerobotic service arms with multiple end-effector capability. All component replacements will be performed in the service bay to contain any resulting debris from the repair operation. Additionally, service bay operations will provide a form of diagnostic servicing to correctly identify the failed component and expedite repair service.

4.2 Component Repair

A secondary capability, component repair, will be retained onboard the GSSP. This service will be used in two specific instances: 1.) if the failed component is readily repairable; or 2.) replacement of the component is unfeasible. An example of an unfeasible replacement would be a component which is unique to a single satellite, proving to costly to manufacture and deliver a replacement component to the GSSP. However, Raptor does not anticipate this type of problem to be frequent in the communication satellites which will make up the bulk of GSSP customers.

Similar to component replacement tasks, component repairs will be performed by telerobotic operations inside the service bay. Specialized end effectors will be provided for use on dedicated servicing robots for repair operations. However, since a service robot cannot realistically be provided for every possible failure, the crew may be called upon to perform manual repairs using specialized tools. This operation entails removing the component from the satellite and placing it in the Operations Module airlock, thus allowing the crew to bring the component inside and complete repairs.

4.3 Refueling

Satellite refueling will not require retrieval of the satellite to the GSSP. This task will be performed on-orbit, at the satellite location. This mode of operation assumes the incorporation of modular fuel cells that can be switched out when the fuel supply is exhausted. Another technology required for this operation is a 'dripless valve', where the fluid circuitry could be disconnected and reconnected without the risk of corrosion by residual fuel.

References: Service Tasks

1. Tesar, D., "20 Year Forecast of NASA Robotics Requirements for Space Exploration," Report from the Consortium of Texas Research Universities, September 11, 1989.

2. Morgan, Walter L., and Gordon, Gary D., Communications Satellite Handbook, John Wiley & Sons: .N.Y.,N.Y.,1989, p. 761.

5.0 Orbit Selection

The orbital placement of the GSSP was chosen to optimize mission cost and time, thus maximizing the overall project profit. Raptor has considered three possible orbits for the facility:

1. In Low Earth Orbit (LEO) near the Space Station (SS);
2. Near GEO (inside or outside GEO in circular orbit); and
3. In GEO at an optimum location.

At all three locations, the SRV would initially be based at the facility. Satellites would then be brought to the facility and re-deployed by SRV's in multiple Hohmann transfers (to minimize fuel consumption). The orbital geometry for each of these locations is shown in Figures 5.1 - 5.3 for the LEO, near GEO and in GEO orbit locations respectively.

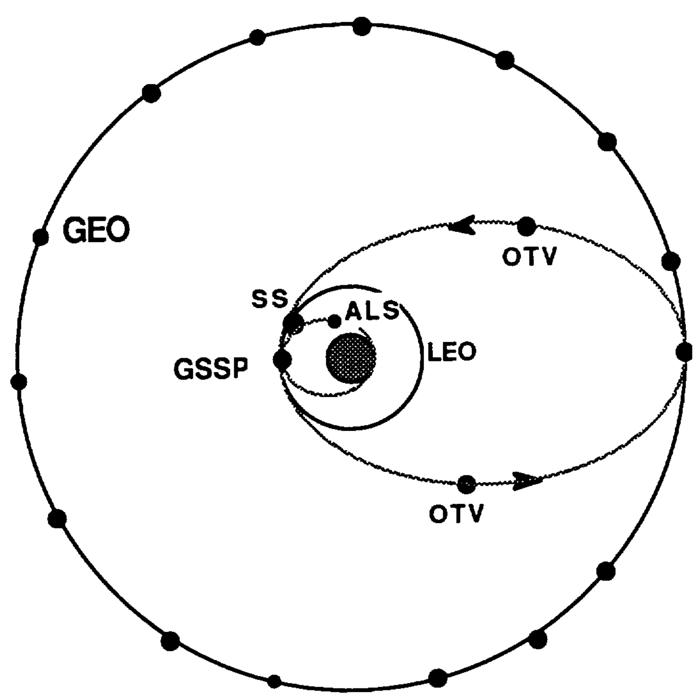

Figure 5.1 Orbital geometry for the LEO GSSP location.

5.1 LEO Orbit Placement

The LEO option offers several advantages to the GSSP. The proximity of the Space Station would limit hazardous in-orbit travel by technicians. In addition, deployment of the facility would cost much less in LEO than in GEO; however, satellite service operations from LEO were estimated to cost six times as much as the same operations from GEO [1]. Therefore, Raptor has eliminated the LEO option.

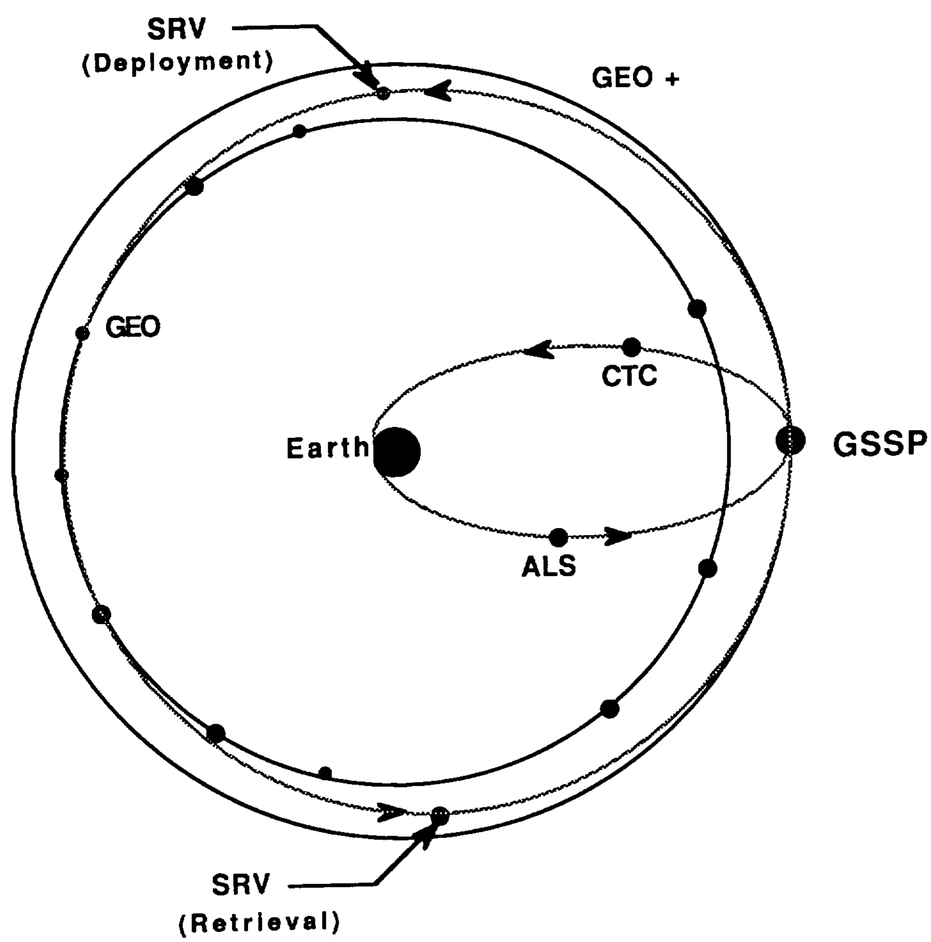

Figure 5.2 Orbital geometry for the near GEO GSSP location.

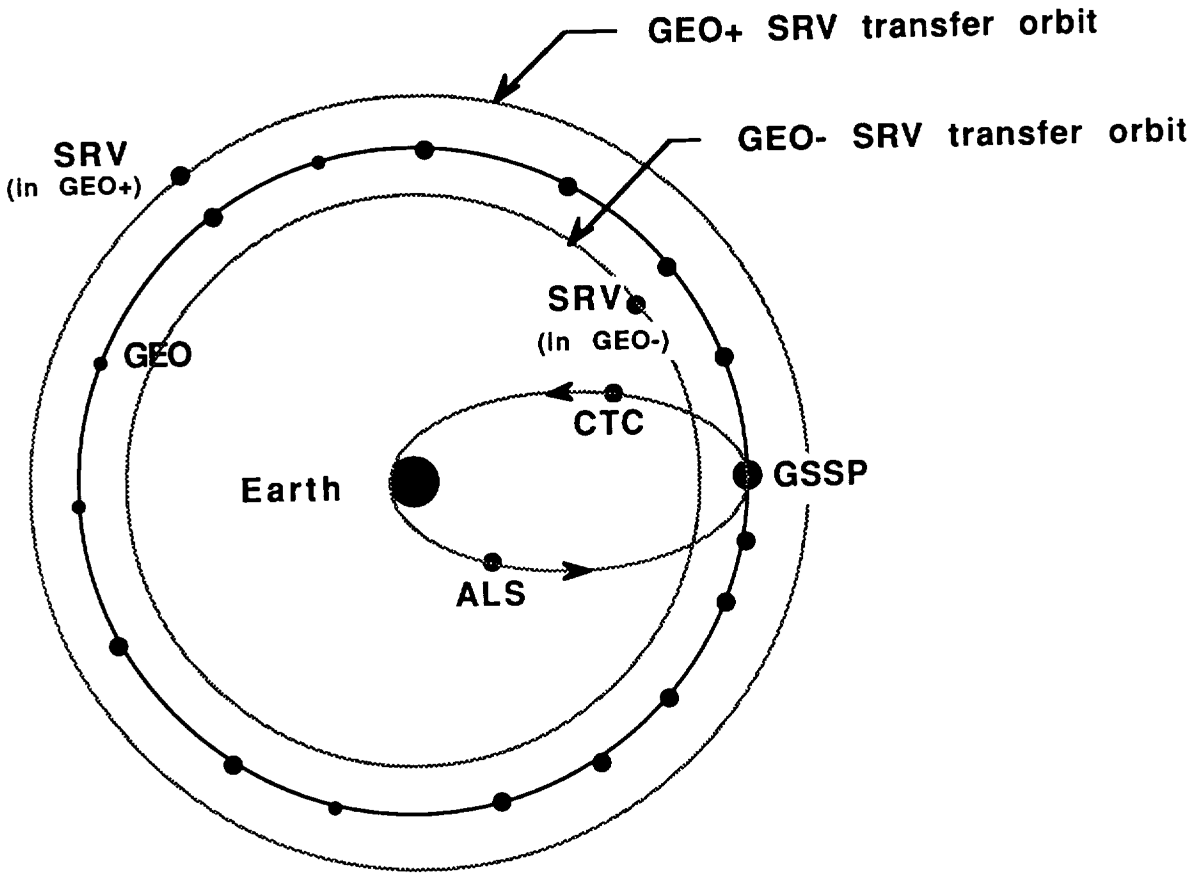

Figure 5.3 Orbit geometry for the in GEO GSSP location.

5.2 Near GEO Orbit Placement

There are two major benefits of a near GEO orbit. First of all, it offers decreased SRV delta-V burns for satellite retrieval and deployment. The overall delta-V for a typical satellite deployment or retrieval mission with no plane change would be less than 100 m/s. In addition, the facility moves relative to the satellites, providing ideal SRV launch windows for satellite rendezvous.

However, there are significant problems associated with the near GEO orbit. The greatest problem is SRV mission periods and delays. In each mission, the GSSP must be in orbital launch phase for a Hohmann maneuver with the satellite that the SRV is to retrieve. Therefore, the SRV's may have to wait at the GSSP for up to 60 days before departure. These delays can be reduced by careful mission planning, but a single SRV failure could result in missed launch windows and seriously disrupted SRV operations. Additionally, the estimated number of service missions per year would require at least four SRV's, which is not desirable.

5.3 In GEO Orbit Placement

There are numerous advantages associated with the GEO orbit. The GEO orbit is beneficial to the following areas of GSSP operations:

1. Communications
   - The facility can have direct communication to U.S. ground stations.
2. Mission Planning
   - The facility can be located near U.S. satellites, which will be the largest market for GSSP services. This will greatly reduce SRV mission time.
   - Satellite deploy and retrieval missions may be combined in a single SRV mission, which would reduce SRV fuel costs as much as 35% by reducing the number of Hohmann transfers. In addition, the combined mission would take about the same time as a separate deploy or retrieval mission alone, thus greatly reducing mission time.
   - The crew transfer capsule uses the same descent / reentry trajectory for all missions,
   - SRV operations are not delayed by missed launch windows,
3. Project Profit
   - Shorter SRV mission periods (up to 10 times less than near GEO missions) resulting in more missions completed per year, thus creating more profit for the overall project.
   - Stationkeeping costs are minimized by positioning the facility in GEO at the stable location of 255 degrees East longitude.

In addition to the above reasons, "preliminary estimates indicate that two GEO based Orbital Maneuvering Vehicles (OMV's) performing twenty satellite servicing missions per year would save 1.6 billion dollars in satellite replacement costs during the first year of operation [2]".

The above reasons firmly establish the need for a GEO based facility. The only problem is boosting the facility to GEO, which is addressed in the next section.

References: Orbit Selection

1. "2010: A Conceptual Design for a Manned Rotating Geosynchronous Space Station", Advanced Mission Design Project: University of Colorado, Boulder, June 18, 1986, p. 2.

2. Lemoine, F G. and Morris, C. J., "A Preliminary Mission and Hardware Design for an Orbital Maneuvering Vehicle Operating in Geosynchronous Orbit," Department of Aerospace Sciences: University of Colorado, Boulder, March 24, 1986, p. 17.

6.0 Launch Vehicles and Facilities

GSSP will rely upon both manned and unmanned launch vehicles throughout its operational lifetime. As a result, the delivery of the facility to GEO, and subsequent supply of technicians, consumables and parts will depend on twenty-first century launch vehicle capabilities. Therefore, Raptor has had to predict future launch vehicle development and determine the most probable launch vehicle options that will be available for the GSSP project.

Raptor has identified two possible launch options for GSSP deployment and subsequent resupply:

1. Launch to LEO and transfer to GEO by a Space Transfer Vehicle (STV), or an upper stage engine
2. Direct launch to GEO in smaller payloads.

The first option would probably require assistance from the Space Station (SS) for upper stage mating to the payloads or for STV services, which are assumed to be provided by the SS. Payloads may be deployed to LEO by the Shuttle, Titan IV, Shuttle C or the Advanced Launch System (ALS).

The second option, direct launch to GEO, is currently limited to a payload of 13,400 lb, which is the capability of the Titan IV. However, development of ALS, with a design goal of launching payloads up to 150,000 lb into LEO at $300/lb, would substantially increase this limit, while decreasing launch costs tenfold [1:43].

Raptor has decided to avoid relying on NASA services such as the STV and SS as much as possible because of scheduling conflicts and problems that are almost certain to arise and disrupt GSSP operations. Therefore, Raptor has chosen to depend upon the development of ALS for launch services. Current goals call for the development of the ALS technology by the year 2000 [1: 42], which is 5 to 10 years previous to the anticipated GSSP startup date.

Should the development of the ALS be extended beyond the GSSP project start date, the GSSP would be deployed via the Shuttle or Titan IV, and then transferred to GEO as stated in the first option above. Once the facility is in GEO and functioning, resupply and manned missions may be separately sent directly to GEO via Titan IV, until ALS is functional.

References: Launch Vehicles and Facilities

1. Scott, W B., "ALS Cost, Efficiency to Depend Heavily on Process Improvements", Aviation Week and Space Technology, 131:17, October 8, 1989, p.41-3.

7.0 Facility Construction

Due to the projected 15 year time frame before construction of the GSSP facility, an ALS is assumed to be available. This system has a projected capability of launching 50,000 lbs into GEO.

Four launches.are required to place the GSSP components into GEO, as summarized in Table 7.1.

Table 7.1 GSSP launch schedule.

ORDER OF LAUNCH	MASS	DESCRIPTION OF PAYLOAD
1	35,000 lbs	•Operations Module •platform truss structure •MRMS track and MRMS, •half of the Solar Arrays, •radiators and the boom supporting them.
2	39,000 lbs	•Habitation Module (without sub-systems), •space truss frame and Kevlar panels for the Service Bay
3	32,000 lbs	•Habitation Module sub-systems, •crew safe-haven, •the remaining solar arrays,and •initial supplies necessary for full facility operations.
4	30,000 lbs	•Two technicians, •All remaining expendables and stores including fuel, water and food, tools and replacement parts for satellite service.

Construction and deployment of the truss structure which forms the support platform for the facility will begin via telerobotics. Once the truss, the MRMS track, and the solar arrays have been deployed, the operations module will be fastened to the truss. The MRMS will then construct the service bay.

Upon completion of the service bay the habitation module will be mated with the operations module and secured to the truss. The final unmanned part of the construction phase will include insertion of the subsystems into their respective modules.

Once the remaining solar array and heat pipe radiators are in place, the facility will undergo a systems check. This will insure that all systems are functioning correctly and are maintaining a safe living environment when the technicians arrive. Detailed, final work may involve the use of the crew members and may require EVA. EVA will be limited to complex manipulations that the MRMS end effectors can not perform.

8.0 Structural Configuration

The GSSP will consist of a habitation module, an operations module, an extensive truss structure, a service hanger and two large booms which suspend the solar arrays and radiators. A conceptual design of the GSSP facility is shown in Figure 8.1.

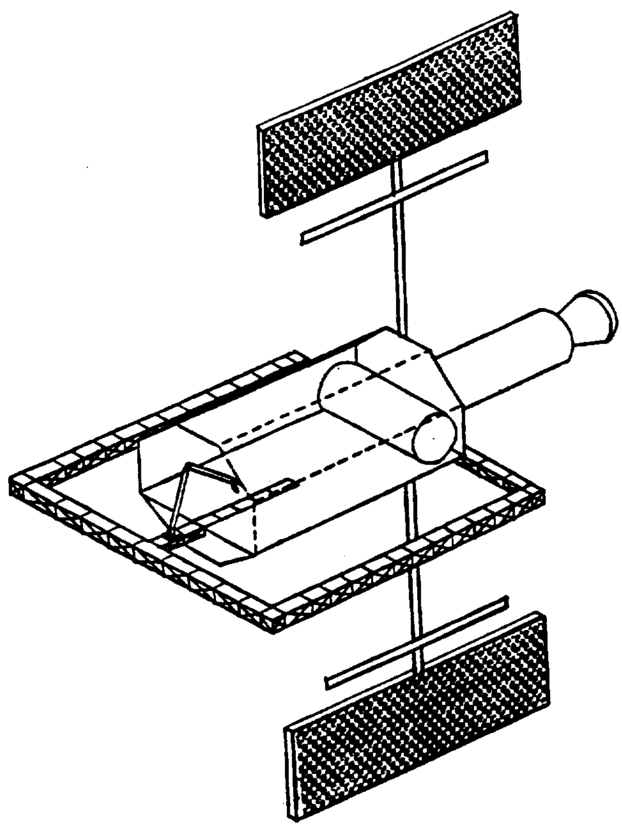

Figure 8.1 Conceptual Design Configuration of the GSSP.

8.1 Crew Modules

The crew modules are cylindrical with a berthing mechanism and umbilical interfaces at each end. They will be pressurized to .694 atm. and shielded to afford the crew maximal comfort and safety. Two space station common modules will be modified to satisfy the crew module configurations incorporated into the GSSP design; one for the habitation module and one for the operations module. Figure 8.2 below is an example of a space station common module along with a break down of its subsystems.

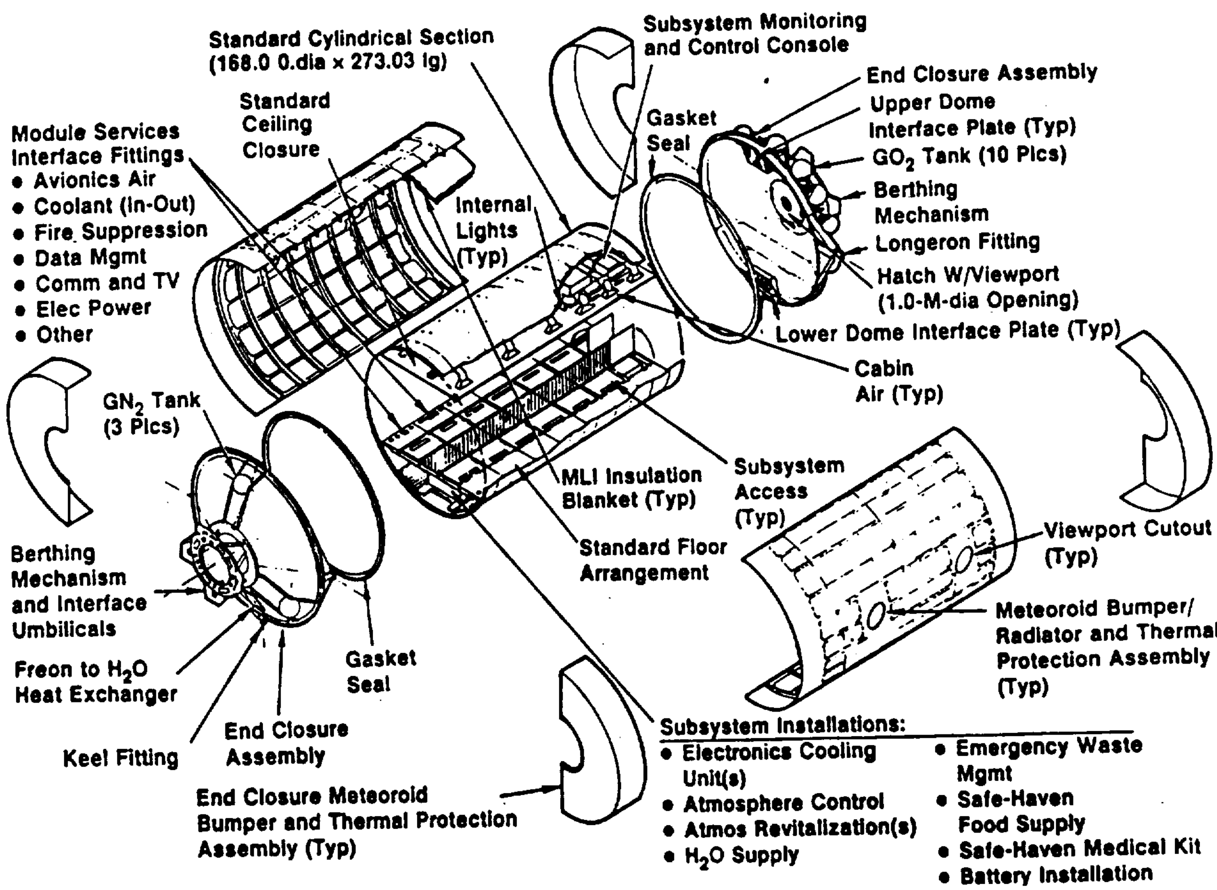

Figure 8.2 Space Station common module and subsystem breakdown [1:74].

8.1.1 Habitation Module

The habitation module is 30 ft long and 14 ft in diameter with 3,000 ft^3 of living area pressurized to 10.2 psia. Provisions will be made for the following subsystems:

- the floor and ceiling are used as storage,
- there will be separate areas outfitted for cooking, sleeping and personal hygiene,

•an exercise area will be available,
•repair station space will be allocated(including space and mass allowances for electronic testing equipment),
•computational workstations will be available to aid the crew in system diagnoses and a multiple of other functions..

Figure 8.3 below, depicts a possible configuration of the GSSP habitation module. For additional information, Appendix B provides a breakdown of the mass and subsystem requirements of a typical space station habitation module.

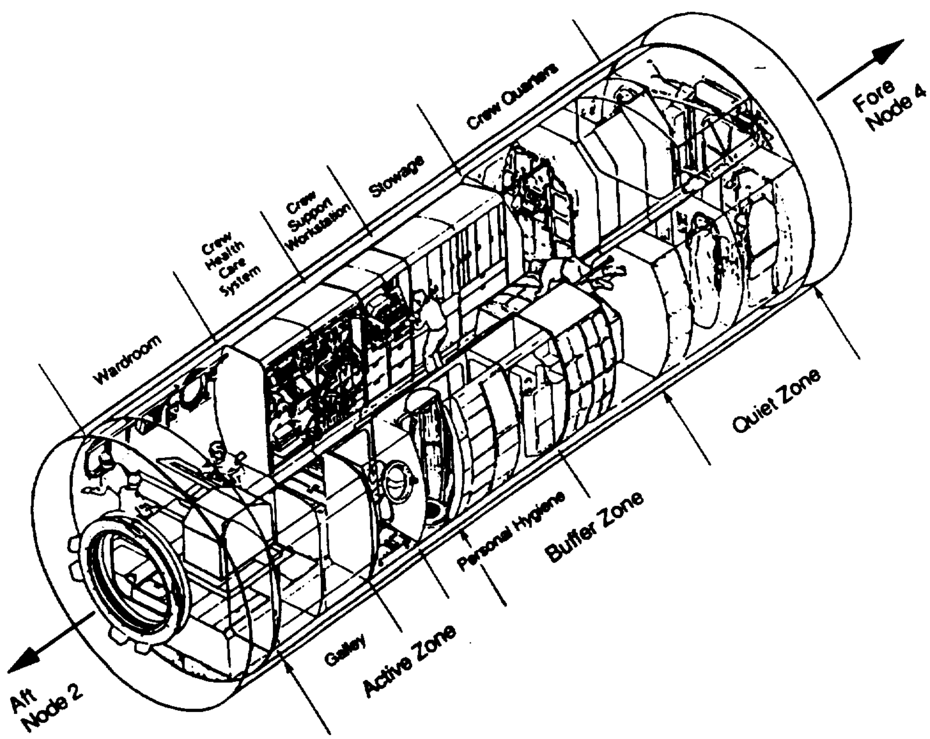

Figure 8.3 Proposed GSSP habitation module [3:43].

8.1.1.1 Living Space

The approximate volume for each crew member can be determined from the Celetano criterion. According to this very conservative space allotment, a 2 man crew with a 14-21 day mission requires a minimum volume of 100 ft^3 per person [1:125].

8.1.1.2 Exercise Station

Approximately 50 ft^3 will be devoted to an exercise station. Studies have shown that humans have an excessive biological ability to adapt to "zero g" environments. Significant muscular debilitation can occur in as little as two weeks, with legs loosing up to 1.2 cm^3 and arms up to 0.3 cm^3 of muscle mass. This regression in performance can be held to a minimum with 1 to 2 hours of exercise per day [3:126].

8.1.1.3 Storage Areas

Storage onboard the GSSP is provided for food, clothing, and electronic parts. Storage will be located in the floor, ceiling, and other compartments located throughout the habitation module.

8.1.2 Operations Module

The GSSP operations module is based upon the resource node structure used by NASA for the space station [3:31]. It has been scaled down to 20 ft in length and 14 ft in diameter, and has been equipped with two umbilical interface portals. The operations module has 1200 ft^3 of usable volume and houses all communications and telerobotic equipment. Figure 8.4 below, shows a possible configuration of the GSSP operations module.

Part of the operations module serves as an airlock. The airlock is a two chamber configuration in which the first chamber is a minimal volume space that serves as an egress/ingress port with hyperbaric capability. The second chamber is a small room for donning and removing EVA suits.

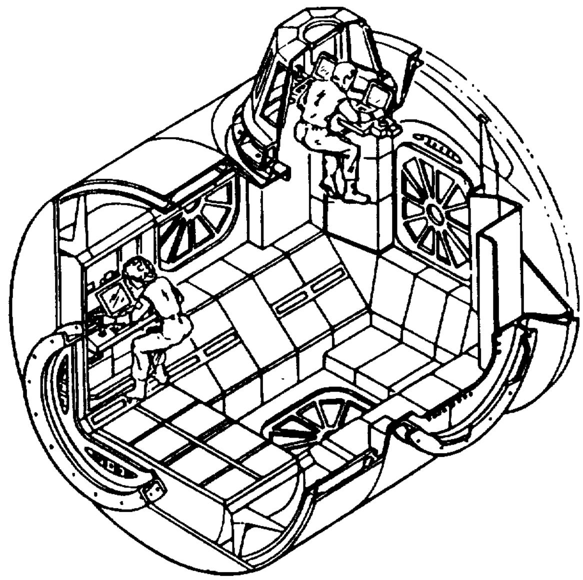

Figure 8.4 Proposed GSSP operations module [3:35].

8.2 Service Bay

The service bay is an enclosed octagonal structure with dimensions 30 ft wide by 30 ft high by 40 ft long. It is constructed of an aluminum space-frame enclosed with monocoque sheets of Kevlar. The enclosure protects the robotic equipment and tools from the harsh space environment. It also shields the technicians from micrometeorites during EVA service procedures and disperses the intense solar radiation.

The service bay can be directly observed from the operations module through a window as depicted in Figure 8.5, and may be accessed via an EVA airlock located in the operations module. The bay will be used to house the satellites during service. It will also serve as storage facility for any fuel tanks, spare parts and consumables.

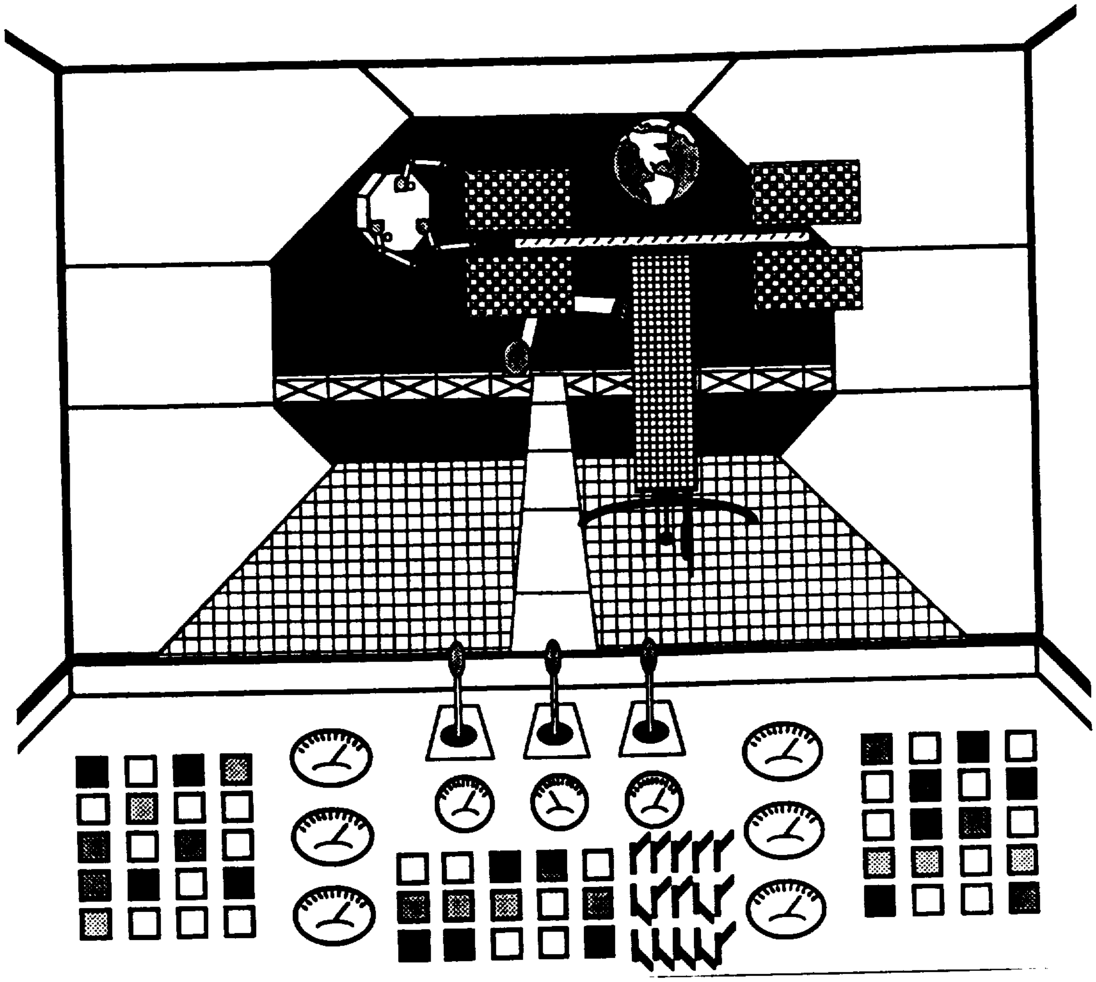

Figure 8.5 View of the service bay as seen from the operations module.

8.3 Truss

The truss assembly provides a structural foundation for construction of the GSSP and a track system for the MRMS. It also insures the structural integrity of the station and reduces attitude control problems by making the GSSP a near ridged body. Furthermore, the truss serves as a supporting structure for utility lines and temporary satellites storage.

For ease of repair, a tetrahedral box truss has been selected. The tetrahedral box truss is very rigid and is easily repaired because of its redundant structure design. Figure 8.6 displays the geometrical concept for such a truss system. An additional advantage of the tetrahedral truss is its relatively lightweight and compactness. For example, when using 2 inch diameter longerons, a 216 ft truss structure is only an 8 ft long package before deployment [1:74].

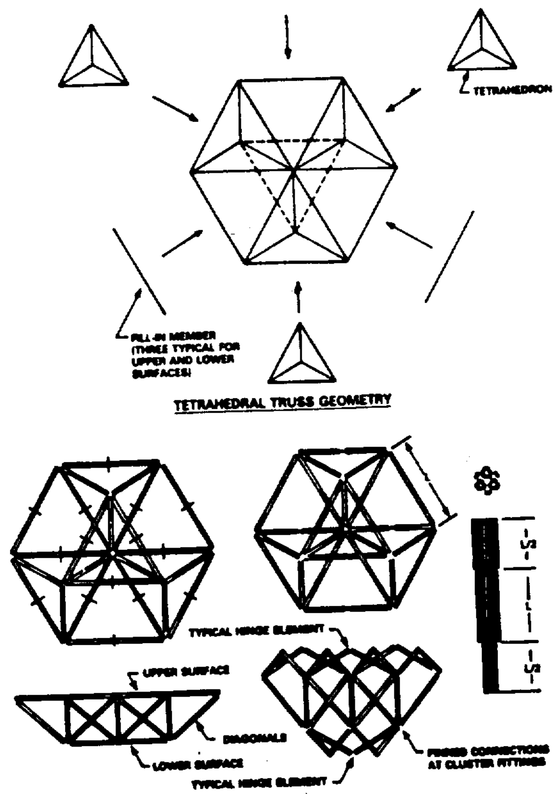

Figure 8.6 Tetrahedral truss geometry and possible connection nodes [1:75].

8.4 Docking Assembly

Typical docking velocities between spacecraft are on the order of 0.3 m/sec (1 ft/sec) with errors of +/- 0.1 m/sec. Typical position errors for docking procedures are approximately 15 cm and a few degrees. A typical docking port can take these piloting errors into consideration [1:53].

The GSSP docking port is modeled after the space station common docking node. This commonality gives the CTC the capability to dock with the space station in the event of an emergency, or for transfer of supplies (although interaction with NASA facilities is not expected). The common docking node is shown in Figure 8.7 below.

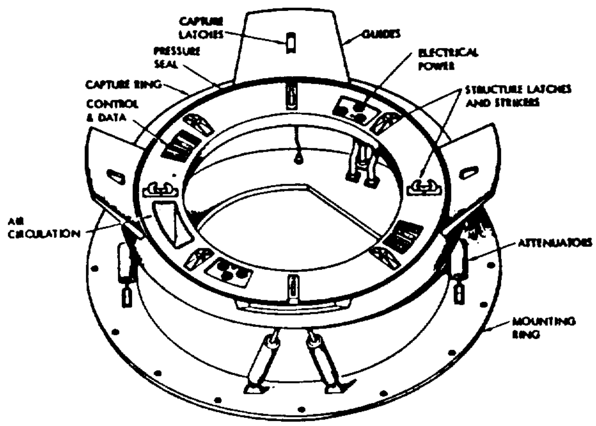

Figure 8.7 Space Station common docking node [1:58].

8.5 Radiation Shielding

Radiation shielding is a major concern in the GEO environment. To shield against this deadly environment, bulk shielding was chosen for its safety and cost effectiveness. Other forms of shielding, such as plasma and magnetic shielding, were considered too costly and complicated to use. In addition, both of these forms of shielding require large amounts of energy.

8.5.1 Radiation Environment at GEO

The radiation in the GEO environment is much greater than at LEO. At GEO the shielding benefits from the earth's magnetic field are negligible. Radiation levels in GEO are about 3 orders of magnitude worse than in LEO [4:6]. The radiation consists mainly of high speed particles from solar particle events (SPE), galactic cosmic radiation (GCR), and trapped energetic particles in the Van Allen radiation belts.

SPE's are proton storms that accompany solar flares. They can last hours or even days at a time. Lethal SPE's occur approximately 2 days in a 20 year period [5:34]. SPE particles are relatively low in energy but high in flux density, and are known to produce secondary radiation in shielding materials like aluminum. Secondary radiation occurs when shielding becomes radioactive from the radiation striking it. SPE's are hard to predict accurately, but events can be detected about an hour before the protons arrive, which should allow adequate time for astronauts to seek shelter [3:A7].

GCR consist primarily of protons. The proton energy levels are extremely high but have a very low flux density. Due to the low flux density, exposure to GCR does not exceed NASA radiation exposure limits of 50 REM per a year in blood forming organs. However, the secondary radiation produced by GCR may become a problem after long periods of exposure in GEO.

Trapped radiation in the Van Allen Belts consists of energetic protons and electrons. Raptor is concerned with energetic electrons since they have a higher energy level and flux density than energetic protons. Due to their high energy, energetic electrons produce large amounts of secondary radiation particles. Spacecraft traveling through this region must be properly grounded or dangerous charging of the ship may occur. Ship charging occurs when opposite sides of a spacecraft develop opposite charges. When the charges are strong enough, electric arcing may occur [6:7]. To prevent such dangerous discharges, all components of the spacecraft must be grounded to each other.

8.5.2 Bulk Shielding

Two layered bulk shielding will be used to shield both the habitation and operations modules. The outer layer will consist of low-Z material with the inner layer being one with high-Z material. Z represents the atomic weight of the material. The low-Z material ideally consists of a substance containing hydrogen, while the high-Z material is the aluminum (Al) structure of the modules themselves [1:67]. The two layer construction was chosen to reduce the formation of secondary radiation and to reduce weight. For example, approximately 6 g/cm^2 of two-layered shielding is equivalent to 20 g/cm^2 of pure aluminum shielding. Shielding thickness for the habitation and resource modules will be approximately 6 g/cm^2 of Al.

A heavily shielded safe haven will be provided in the case of a major SPE. At least 10 g/cm^2 of Al will cover the safe haven [6:A12].

8.6 Micrometeorite Shielding

Micrometeorites have flux densities that vary according to their size. Higher flux densities are present for smaller micrometeorites as compared to larger ones. Thus, small micrometeorites pose the greatest threat. A double wall construction will be used to shield the habitation and operation modules against micrometeorites. The double wall construction was chosen for its efficiency in dissipating energy and for its low weight. The double wall construction consists of a thin, bumper wall that will vaporize incoming micrometeorites, and a back wall that will absorb the impact of the remaining vapor cloud [6:C14]. A two inch space will separate the bumper wall and the back wall. The bumper wall will be constructed from a material with high energy dissipation qualities (for example Kevlar), while the back wall will be the space structure itself. Non-conductive supports will be used to support the bumper wall in order to protect against ship charging (as discussed in Section 8.5.1 above) [2:542]. In addition to shielding from micrometeorites, the shield will also serve as additional thermal insulation and radiation shielding.

References: Structural Configuration

1. Woodcock, G R., Space Stations and Platforms, Orbit Book Company: Malabar, Fla., 1986.

2. Engineering and Configurations of Space Stations and Platforms, NASA JSC Systems Engineering and Integration Space Station Program Office Houston, Texas, Noyes Publications: New Jersey, 1985, p.545-6.

3. "Space Station Freedom Media Handbook", NASA, April 1986, p.31.

4. "SICSA Outreach", Vol. 2, No. 3, Special Information Topic Issue, University of Houston College of Architecture, July-Sept., 1989, p.6.

5. Letaw, J.R., and Clearwater, S., "Radiation Shielding Requirements on Long-Duration Space Missions", Severn Communications Corporation, July 21, 1986, p.34.

6. "2010: A Conceptual Design for a Manned Rotating Geosynchronous Space Station", Advanced Mission Design Project: University of Colorado, Boulder, June 18, 1986, p.A7-A12.

9.0 Environmental Control and Life Support Systems (ECLSS)

There are three different types of ECLSS's: open, partially closed, and fully closed systems. An open system requires that everything be resupplied from earth and that nothing be recycled. This includes gases that are required to maintain the atmosphere, water for various uses, and all other consumables. A partially closed system closes the water and atmosphere reclamation loops partially (carbon dioxide and water are partially recycled). Losses from these recycling process will be resupplied. Finally, a fully closed system would be totally self sufficient. It would be capable of recycling all consumables.

An open ECLSS has been chosen for the GSSP. This system was chosen because it is cost effective for a crew size of two with a mission duration of two weeks, where it is cheaper to resupply all consumables rather than bring up costly reclamation equipment [1]. The functional requirements of the ECLSS are to control atmospheric conditions, supply consumables, manage waste, support extra-vehicular activity, and provide the crew with a safe haven.

9.1 Atmospheric Control

The atmosphere of the crew modules must be maintained at the proper pressure, temperature, composition, and humidity. The pressure of the modules will be maintained at 10.2 psi to ensure safety and to reduce prebreathing time for EVA activities. The composition of the atmosphere must be maintained with the proper partial pressures, shown in Table 9.1, to ensure the comfort and safety of the crew. For example, if the partial pressure of carbon dioxide is between 0.19 psia and 0.39 psia, discomfort is felt. Furthermore, if the CO_2 partial pressure goes beyond 0.39 psia unconsciousness may occur [2]. The partial pressure of O_2 should never drop below 2.3 psia or become more than 30 percent of the total pressure [3].

Table 9.1 Atmosphere Requirements [3].

Temperature, deg F	65-75
Dew Point, deg F	40-60
Ventilation, ft/min	15-40
CO_2 Partial Pressure, psia	0.058 max
O_2 Partial Pressure, psia	2.7-3.2
N_2 Partial Pressure, psia	6.9-7.4
Total Pressure, psia	10.2

9.2 Consumable Supply

All consumables are resupplied for each mission. The average amount of consumables required per a man per a day is listed on Table 9.2. All gases required for maintaining the atmosphere in the crew modules are stored in high pressure tanks. Stored gases will be used to replenish gas that has been lost due to leakage or consumption. Drinking and hygiene water will be supplied from storage tanks, and some of the hygiene water will be provided by condensate collected from the humidity control unit. Perishable and freeze-dried food will be provided. Perishable foods consist of fresh fruits and vegetables which need to be refrigerated. Freeze-dried foods do not require refrigeration, but do need to be rehydrated and heated.

Table 9.2 Crew Consumption [3:24].

Metabolic Oxygen	0.91 kg/man-day
Drinking Water	3.64 kg/man-day
Hygiene Water	5.45 kg/man-day
Food	0.59 kg/man-day

9.3 Waste Management

The average waste output per man per day is shown below in Table 9.3. All waste will be stored, not dumped overboard. Carbon dioxide is filtered out of the air by a lithium hydroxide system. Waste water and human wastes are stabilized biologically and stored. All other wastes are compacted into waste receptacles. These waste receptacles will be flown back to earth where the waste will be disposed. Due to the high value of water in space, waste water may be flown to the Space Station for processing.

Table 9.3 Crew Waste [3:24].

CO2	1.02 kg/man-day
Water Vapor (Perspiration & Breath)	2.50 kg/man-day
Waste Wash Water	5.45 kg/man-day
Human Wastes	1.61 kg/man-day
Metabolic Heat	12000 BTU/man-day

9.4 EVA Support

The ECLSS provides oxygen and supplies for EVA operations. In addition, it is also capable of supplying gases for the airlock/hyperbaric facility for pressurization and compensation for leakage. Wastes from the EVA operations will be processed as explained in the previous section. EVA operations are further detailed in Section 14.

9.5 Safe Haven

A safe haven is provided in case of emergencies, such as lethal solar particle events. Extra shielding is added to a portion of the habitation module in order to form the safe haven. The total amount of shielding around the safe haven will be approximately 10 g/cm^2 thick. Supplies such as food, water, wet and dry wipes, clothes, sleeping restraints, and trash and waste storage are provided within the safe haven for a crew of two for up to 5 days (the most intense part of a solar particle event does not usually exceed 2 to 3 days [4]). A portable control console will also be provided to monitor and control some of the GSSP main systems. Finally, the safe haven will function as the sleeping quarters for the crew during normal operations to provide added security should a SPE occur..

References: Environmental Control and Life Support Systems

1. Brose, H. F., "Environmental Control and Life Support (ECLS) Design Optimization Approach", Space Station : Policy, Planning and Utilization, American Institute of Aeronautics and Astronautics, New York, New York, 1983, p.189.

2. Woodcock, G. R., Space Stations and Platforms, Orbit Book Company, Inc., Malabar, Florida, 1986, p.95

3. "2010: A Conceptual Design for a Manned Rotating Geosynchronous Space Station", Advanced Mission Design Project: University of Colorado, Boulder, June 18, 1986, p.24.

4. "SICSA Outreach", Vol. 2, No. 3, Special Information Topic Issue, University of Houston College of Architecture, July-Sept., 1989, p.C12.

10.0 Power

The requirements for the GSSP power generation system included safety for both men and equipment, reliability, redundancy, and minimal system mass. A 35 kW continuous power rating was deemed sufficient for initial GSSP operations. With these considerations in mind, three power system options were compared: isotope (RTG and DIPS), nuclear, and solar (photovoltaic and solar dynamic) power generation.

10.1 Power Generation System Comparisons

A comparison of the major advantages and disadvantages of the three power system types is presented in Table 10.1.

Table 10.1 Power System Comparisons.

SYSTEM	ADVANTAGES	DISADVANTAGES
ISOTOPE	• long life • no required maintenance • proven in space • no intermediate storage required	• scarce, hazardous fuels • extensive shielding required for crew and equipment • designed for low power
NUCLEAR	• excellent high power applications • proven in space • compact • low mass per power output • no intermediate storage required	• waste disposal problems • refueling requirements • extensive shielding required for crew and equipment • proximity to crew in case of accidents
SOLAR	• safe for crew and equipment • proven in space • easy to deploy and upgrade • redundant--single failure does not result in total system failure	• higher mass • lower efficiency • some require intermediate energy storage (batteries)

Given the requirements for power generation, the decision matrix shown in Table 10.2 was employed to evaluate the systems. Each system was rated from 1 (worst) to 3 (best), and each category was weighted according to its relative importance.

Table 10.2 Power System Decision Matrix

POWER SYSTEMS (1-3)	SAFETY FOR MEN AND EQUIPMENT	RELIABILITY	HIGH POWER APPLICATIONS	MINIMUMAL MASS	REDUNDANCY	TOTAL RATING (BEST-HIGH)
ISOTOPE SYSTEMS	1	2	1	2	1	24
NUCLEAR SYSTEMS	1	2	3	2	1	26
SOLAR SYSTEMS	3	3	2	1	3	44
CATAGORY WEIGHT FACTOR	X5	X4	X1	X3	X4	

The decision matrix shows that solar power generation is the most advantageous of the three systems for GSSP power generation (mostly due to safety considerations), and thus, was the system chosen for the GSSP. Furthermore, it is a well established, "off-the-shelf" technology.

10.2 Solar Power Systems

There are two types of solar power systems--photovoltaic (PV) and solar dynamic (SD). Photovoltaics convert sunlight into electricity via photoelectric cells, while solar dynamic systems use the sun's heat to power a turbine. Because SD systems utilize heat that can be conveniently stored during eclipse cycles, they do not require intermediate energy storage; unlike photovoltaic systems which require depletable batteries. A comparisons of SD and PV systems is shown in Table 10.3.

Table 10.3 Solar Power System Comparisons.

TYPE	ADVANTAGES	DISADVANTAGES
SOLAR DYNAMIC	• smaller area • smaller volume • higher system efficiency	• unproven in space • complex design, deployment • stringent pointing accuracy required (milliradians)
PHOTO-VOLTAIC	• proven in space • simple design • easy to deploy and upgrade • lower initial system weight • redundant--single cell failure will not result in system failure • low cost	• lower system efficiency • PV cells degrade over time • requires heavy, depletable energy storage batteries

Because of its simplicity, and proven applications in space, PV was chosen for the GSSP [1]. The available PV systems include concentrator array and planar array systems.

A typical solar concentrator array is depicted in Figure 10.1. These systems typically use high-efficiency gallium-arsenide (GaAs) cells that operate at higher temperatures than silicon cells, resulting in a smaller array size (often more than a 1/3 smaller) than a comparable planar array. The smaller array size lowers mass, however, concentrator arrays require a specified pointing accuracy [2].

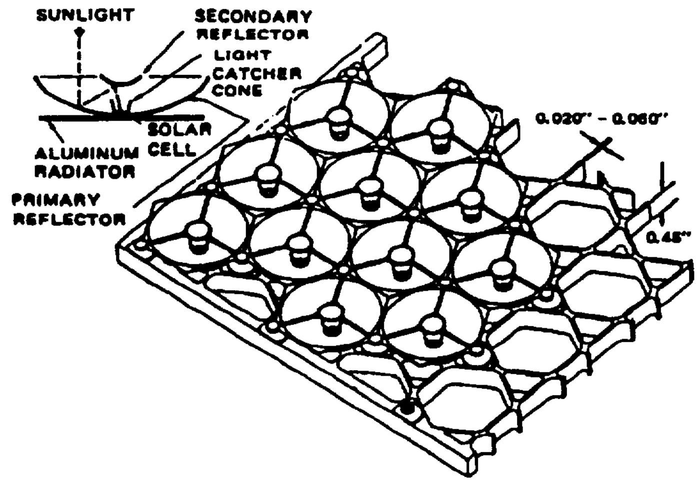

Figure 10.1 A typical solar concentrator array [2:343].

A typical photovoltaic planar array is depicted in Figure 10.2. Planar arrays are made of silicon cells, and are either folded or rolled (blanket). The greatest disadvantage of planar arrays is that they require a relatively large area per kW of power generation. They were chosen for the GSSP because of proven applications, ease of storage, minimal pointing accuracy, and simplicity in upgrade.

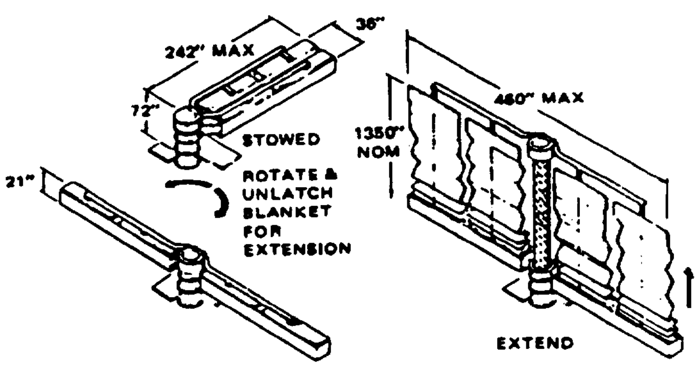

Figure 10.2 A typical photovoltaic planar array [2:344].

10.3 Power System Specifications

The system chosen for power generation was the planar array photovoltaic system with Nickel-Hydrogen storage batteries. To provide 35 kW of continuous power, the required array area is approximately 650-850 m^2; resulting in a system mass of approximately 2000-2500 kg [1,3]. An object in GEO undergoes eclipse for about 70 minutes/day a few times a year. For this reason and for use as backup in case of an emergency, a battery system mass of 400 kg has been selected. Therefore, the total in-orbit system mass is approximately 2500-3000 kg; and the final system mass (over the life of station assuming a battery lifetime of 7-9 years) is approximately 4000 kg.

References: Power

1. "Space Power Technology: Progress and Perspectives", a report presented to NASA/USRA by University of Michigan and Power Technology Div. (NASA/Lewis), April 4, 1988, p.85.

2. Bekey, I and Daniel H (editors), Space Stations and Space Platforms--Concepts, Design, Infrastructure, and Uses, Vol. 99, American Institute of Aeronautics and Astronautics, N.Y., N.Y., 1985, p.343-344.

3. "Space Power Architecture Study (SPAS)", a report presented to Air Force Space Technology Center (AFSTC), Dec. 10, 1986, p.73.

11.0 Thermal Control

Thermal heat rejection systems are important for a facility in GEO. Using past heat rejection technology, the size of the resulting radiator could account for up to 40% of the total weight of the facility [1]; thus, state of the art thermal controls must be implemented to reduce radiator size. The requirements of the GSSP thermal rejection system are: a minimum of 50 kW of heat rejection, low mass, ease of deployment, maintainability, reliability, and redundancy. The radiator systems studied for heat rejection were liquid drop radiators (LDR), and ammonia heat pipes (similar to those designed for the Space Station).

11.1 Liquid Drop Radiators (LDR)

The LDR use a drop generator to make billions of tiny droplets a few hundred microns in diameter. These droplets are released into space and cool as they fly controlled trajectories toward a droplet collector. After collection of the liquid droplets into a conglomeration, they are spun back into a liquid. This liquid is pumped back to begin another cycle. The working fluid is exposed to space and must therefor have a low vapor pressure (typically less than 10 to 7 torr), and be chemically stable.

11.2 Ammonia Heat Pipe Radiators

The ammonia heat pipe radiators contain pipes in panel arrays. A typical system contains two working fluids. Ammonia or other toxic liquids are used for heat transfer away from the crew while non-toxic liquids such as water (or Freon) are used around the habitat (to provide safety for the crew). Waste heat from water/Freon system is exchanged with the ammonia system for circulation through panel arrays.

11.3 Thermal System Comparisons

The advantages and disadvantages of the two thermal systems that were considered for use onboard the GSSP are listed in Table 11.1.

Table 11.1 Comparison of heat rejection radiator systems.

RADIATOR TYPE	Advantages	Disadvantages
Liquid Drop	• 35-90% less massive	• currently only rated for high thermal loads over small temperature ranges • unproven in space • fluid loss or contamination • complex design, deployment • loss of maneuverability • no redundancy
Heat Pipe	• well understood technology • will be proven in space (S.S.) • low complexity design, deploy • simple redundancy in pipes	• considerably more massive

An ammonia heat pipe radiator system (with water or Freon around habitation areas) was chosen for the GSSP. The specifications for 50 kW heat rejection capacity require an approximate area of 325 m^2, and an approximate mass of 2000-3500 kg [2].

References: Thermal Control

1. "Big Savings from Small Holes", Aerospace America, Vol. 27, No. 5, May 1989, p.32.

2. "Space Power Architecture Study (SPAS)", Dec.10, 1986, p.54.

12.0 Guidance, Navigation and Control

The guidance and navigation systems of a vehicle allow it to fly a desired trajectory or path. Additionally, the attitude control system maintains the spacecraft in a desired orientation with respect to its environment. An inherent coupling exists between the guidance and navigation, and the attitude control systems. For example, external forces on a space vehicle, such as gravity, atmospheric drag, or solar radiation pressure, may perturb the vehicles trajectory and thus cause short-period dynamic motions which alter the attitude of the vehicle [1]. Because of the coupling between guidance, navigation, and attitude control, the system designed to perform these functions is referred to as the guidance, navigation and control system (GNC). A spacecraft GNC system must determine the orbital trajectory and attitude of the spacecraft, determine whether the spacecraft is on course and oriented correctly, and generate commands to correct any deviations from the desired trajectory and attitude. The reference frame used for guidance and navigation can be inertial or relative, whereas the reference frame used for attitude determination must be inertial or fixed to a reference body (such as the Earth).

The GSSP will be the origin of an inertial reference frame for GNC operations. The primary motivation for using an inertial guidance and navigation system onboard the GSSP, is to provide the SRV, which uses a relative navigation scheme, with an inertial frame of reference. The current design for the SRV is based upon the McDonnell Douglas orbital maneuvering vehicle (OMV). The OMV is presently designed to use the Global Positioning System (GPS) for guidance and navigation [2]. Since the geosynchronous orbit altitude of the GSSP is well above the constellation of GPS satellites, the OMV's will require onboard relative navigation. Placing the inertial reference point at the GSSP provides superior SRV navigation during GSSP proximity operations, since position and velocity errors will be minimized as the SRV approaches the platform.

The GNC system must sense orbital deviation or drift and compensate by applying thrust to maintain the desired orbit parameters. It is important to note that the GSSP will not perform any orbit transfer maneuvers, therefore, the guidance and navigation system is designed primarily for orbit maintenance. Furthermore, since the GSSP will be allowed to drift near geostationary orbit, conservative delta-V requirements were developed by assuming a geosynchronous orbit. The orbit perturbations presented below are based upon such an orbit.

12.1 Orbit Trajectory Perturbations

Any geosynchronous satellite orbit can be described by three parameters: semi-major axis (a = 42,164 km), eccentricity (e), and the inclination (i). Orbit maintenance, or stationkeeping, requirements for the GSSP are based on three perturbation forces which cause the greatest change in these orbit parameters: the gravitational attraction of the sun, the Earth, and the moon. The dominant term in the Earth's gravitational attraction is its oblateness. Other perturbations such as ocean tides, tidal effects of the moon, and solar radiation pressure were considered negligible for the current design. In order to minimize delta-V requirements and reduce the number of thrusters, pumps, and fuel lines required for stationkeeping purposes, the planned location for the GSSP is at 255° East longitude. At this stable longitude point, shown in Figure 12.1, east-west stationkeeping is not required since small perturbations of the GSSP orbit will dampen out , and the GSSP will return to 255° East longitude .

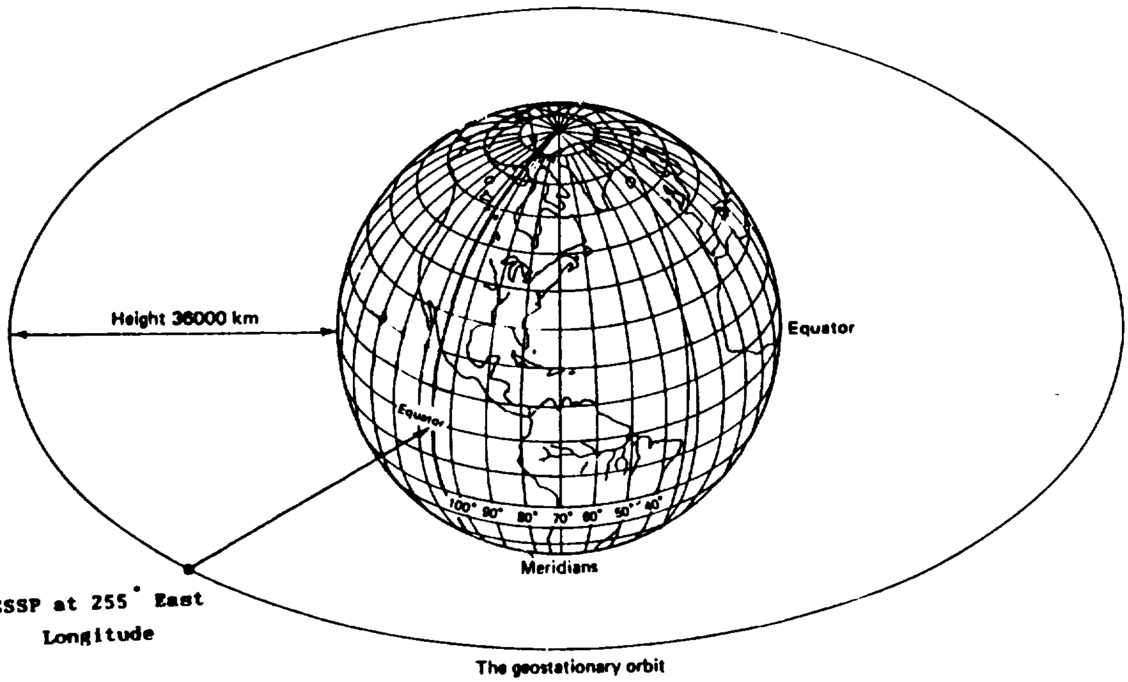

Figure 12.1 View of geostationary orbit showing the planned location of the GSSP at 255° East longitude [3].

12.1.1 Perturbation Due to the Sun

The orbital perturbation due to the gravitational attraction of the sun, produces a drift in the inclination . The inclination drift rate at geosynchronous orbit is a function of the right ascension of the satellite's ascending node (omega), and is computed as

di/dt = -0.269° / year at omega = 270° , and

di/dt = 0.269° / year at omega = 90° [4].

With omega at 270°, the inclination of the satellite will decrease at a rate of 0.269°/year until it reaches zero. Upon reaching zero, omega will change to 90° and begin to increase at the same rate, until it reaches an allowable limit. The allowable limit is the inclination angle constraint placed on the orbit of the geosynchronous satellite. When the allowable limit is reached, a stationkeeping maneuver is performed by the control system to change omega from 90° to 270°, and the process begins again.

12.1.2 Perturbation Due to the Moon

The orbital perturbation due to the gravitational attraction of the moon also causes a drift in the satellite's inclination, however, the inclination drift rate is not only a function of the satellite's ascending node, but is also a function of the moon's inclination. The orbital inclination of the moon decreases from a maximum of 28.60° to a minimum of 18.30° over a period of about 18 years [4:79]. The inclination drift rate due to the gravitational attraction of the moon can be expressed as

di/dt = 0.4780° / year at omega=90°, i=18.3°, and

di/dt = 0.674° / year at omega=90°, i=28.6° [4:80].

12.1.3 Perturbation Due to the Oblateness of the Earth

Since the Earth is not a perfect sphere, it does not possess a spherical gravitational field. The Earth's bulge creates a gravitational perturbation force causing a drift in the ascending node of a geosynchronous satellite, of approximately

d omega/dt = 4.9° / year [4:81].

12.1.4 Combined Perturbation Effect

The effects of the solar and lunar gravitational perturbations and of the Earth oblateness perturbation can be combined linearly into an equivalent inclination drift rate of

$0.747° /year < di/dt < 0.943° /year$ [4:82].

The orbit correction that must be applied to compensate for the combined inclination drift rate is referred to as north- south stationkeeping.

12.2 GNC Sensors

In order for the GSSP to operate for extended periods of time with as little government support (i.e. NASA) as possible, an autonomous stationkeeping system is planned. Such a system has been designed and flown onboard the Lincoln Experimental Satellites (LES) 8 and 9 [5]. The GSSP autonomous stationkeeping system will not be as complex as the LES station keeping system, utilizing only a star tracker and a high accuracy oscillator to measure the north-south drift. Recall that east-west drift will not be measured since the GSSP will be positioned at a stable longitude point. The star tracker may be replaced by a single Polaris star tracker in order to reduce the complexity and power requirements of the system [6].

For attitude sensing, the GSSP will use an infrared scanning-mirror earth sensor for pitch and roll sensing, and two sun-transit azimuth sensors and an earth-shadow sensor for yaw sensing. This system is also onboard the LES 8 and 9 satellites. Typical location of GNC sensors is shown for the LES 8 satellite in Figure 12.2.

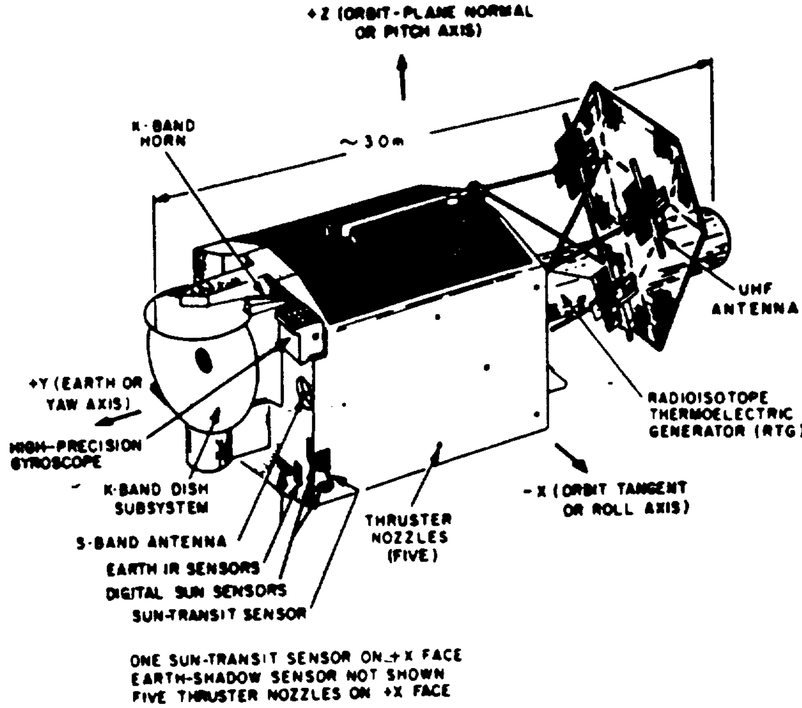

Figure 12.2 Guidance, navigation and control sensor locations for the Lincoln Experimental Satellite [5:189].

12.3 GNC Propulsion System

In order to design propulsion systems for stationkeeping purposes, the delta-V requirements must first be examined. In order to help compensate for the lack of east-west drift control, a stringent inclination limit of 0.1° is planned. This inclination limit requires delta-V burns of 10.7 m/sec every 86.14 days [4:88].

Several propulsion systems were examined in order to determine which system could best support both the stationkeeping and attitude control requirements of the GSSP. The results of the decision matrix shown in Table 12.1, were used to choose electrothermal hydrazine thrusters for the stationkeeping and attitude control propulsion systems. The primary reason for choosing electrothermal hydrazine thrusters was a 28% higher specific impulse as compared to catalytic hydrazine thrusters (300 seconds versus 235 seconds) [4:172].

Table 12.1. GNC Propulsion System Decision Matrix (lower numbers reflect superior quality).

PROPULSION DEVICE	SPECIFIC IMPULSE	POWER REQUIREMENT	FUEL REQUIREMENT	PROVEN TECHNOLOGY	SAFETY	TOTAL RATING
CATALYTIC HYDRAZINE	3	1	2	1	1	27
ELECTROTHERMAL HYDRAZINE	2	2	2	1	1	23
ION THRUSTER	1	3	1	3	3	31
CATAGORY WEIGHT FACTOR	X5	X1	X2	X3	X4	

12.3.1 Electrothermal Thrusters

An electrothermal hydrazine thruster, as shown in Figure 12.3, is currently being used for stationkeeping of the INTELSAT V satellite. The electrothermal thruster operates by electrically augmenting the enthalpy of the propellant in the vortex heat exchanger, increasing the energy of the propellant just prior to ejection from the nozzle. Though the electrothermal hydrazine thruster system does require a substantial power requirement (approximately 1 KW/N of thrust), the short burn duration and low delta-V requirements for stationkeeping purposes suggest that the currently designed power system of the GSSP will supply more than enough power to make using electrothermal thrusters possible.

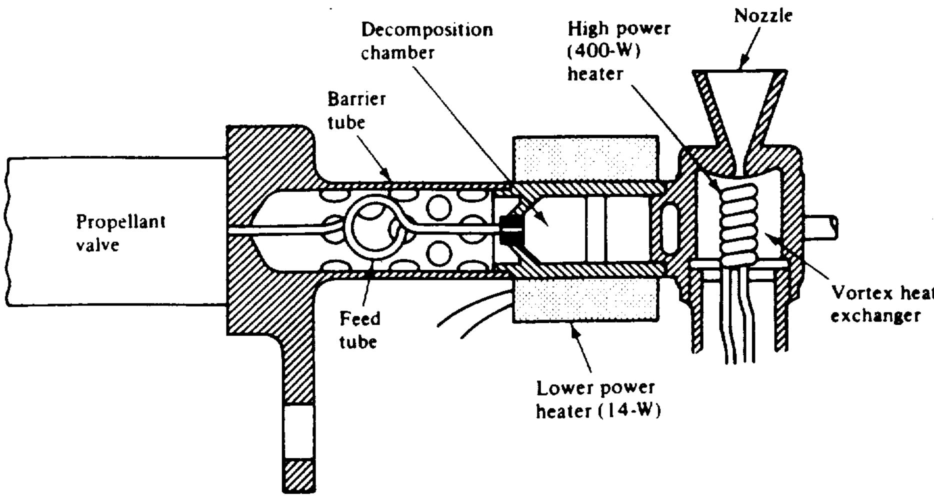

Figure 12.3 Typical electrothermal thruster configuration [4:173].

12.3.2 Catalytic Thrusters

A typical catalytic propulsion system is shown in Figure 12.4. One of the primary reasons for selecting a catalytic hydrazine propulsion system as a backup system, was because it uses approximately the same supply pressure as the electrothermal hydrazine thrusters, thus a common propellant feed system can be used for both propulsion systems [4:172]. Another reason for choosing a catalytic backup propulsion system was that such a system does not require the high energy cost that the electrothermal system does.

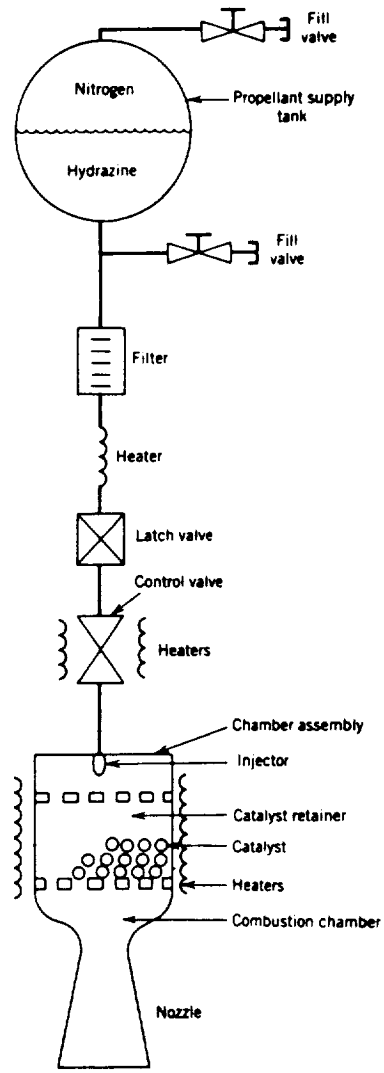

Figure 12.4 Typical catalytic monopropellant propulsion system [7].

12.3.3 Propellant

A commonly used monopropellant, anhydrous hydrazine, was chosen to be the fuel used for both the stationkeeping and attitude control propulsion systems. Anhydrous hydrazine is a colorless, toxic, clear liquid with a distinct ammonia-like odor. Among its many advantages over other monopropellants include: it is a very stable chemical, it is insensitive to shock or friction, and it can be stored for long periods of time without decomposition [7:653]. Using anhydrous hydrazine for propellant, and assuming a total GSSP weight of approximately 100,000 lbs, results in a total propellant mass of 12,500 kg over the 25 year design life of the GSSP facility.

12.4 GNC Accuracy

An estimation of the accuracy of the proposed GNC system for stationkeeping, is supported by the experimental work done on the autonomous stationkeeping system of the LES 8 satellite. During flight experiments, the LES 8 spacecraft autonomously acquired and maintained its north-south station position to within +/- 0.06° [5:188]. In comparison, current satellites using fixed area coverage beams are now maintained within +/- 0.05° of the sub-satellite latitude and longitude [5:189].

Since the attitude control system planned for the GSSP is the same as that currently onboard the LES 8 and 9 satellites, a similar estimation of the measurement accuracy of the system can be suggested by the experimental results of the LES 8 and 9 systems. The LES 8 and 9 satellites were able to measure their pitch and roll angles to within +/- 0.03° [5:191]. Current infrared sensors used for pitch and roll maintenance, typically possess accuracies of +/- 0.05° [7:660]. Since the GSSP and the LES satellites do not use the same system for yaw maintenance, an estimated accuracy of the GSSP system cannot be deduced from the LES system. However, current yaw maintenance systems, like those onboard the INTELSAT V satellite, typically possess accuracies of +/- 0.41° [7:660].

References: Guidance, Navigation and Control

1. Greensite, A. L. Analysis and Design of Space Vehicle Flight Control Systems. New York: Spartan Books, 1970, p.260.

2. Lundberg, J. Personal Communication. Austin, TX: The University of Texas Dept. of Aerospace Engineering. November 9, 1989.

3. Roddy, D. Satellite Communications Design. New Jersey: Prentice-Hall, Inc., 1989. p. 10.

4. Agrawal, B. N. Design of Geosynchronous Spacecraft. New Jersey: Prentice-Hall, Inc., 1986. p. 85.

5. Srivastava, S. "Autonomous Stationkeeping System for the Lincoln Experimental Satellites (LES) 8 and 9," AIAA Guidance and Control Conference, August 20-22, 1984. 188-195.

6. Lundberg, J. Personal Communication. Austin, TX: The University of Texas Dept. of Aerospace Engineering. October 11, 1989.

7. Morgan, W. L. Communication Satellite Handbook. New York: John Wiley & Sons, 1989. p. 653.

13.0 Communications and Tracking

The Communication and Tracking System (CTS) of the GSSP will link the ground station, Space Station, CTC, SRV and other GSSP traffic.

13.1 Functional Requirements

Crew members in the CTC will communicate with the ground and the Space Station. Crew members inside the GSSP will also be capable of communicating with the ground and the Space Station as well as throughout the crew modules, berthing ports and airlocks. The CTC and SRV will be tracked at all times from the ground.

13.2 Design and Performance Requirements

The CTC and GSSP will incorporate a direct communications link with the ground and will communicate with the Space Station through the Tracking and Data Relay Satellite System (TDRSS). Tracking information of the CTC and SRV will be processed through TDRSS. The tracking system onboard the GSSP will use radar and visual contact to support the docking procedures of the SRV and CTC during proximity and berthing operations. Docking of the CTC will be operated manually by the crew members, and docking of the SRV will be remotely controlled from the ground.

13.3 TDRSS

TDRSS is a data relay satellite system that consists of three geosynchronous satellites positioned at 41° West and 171° West with a spare at 61° West, as shown in Figure 13.1.

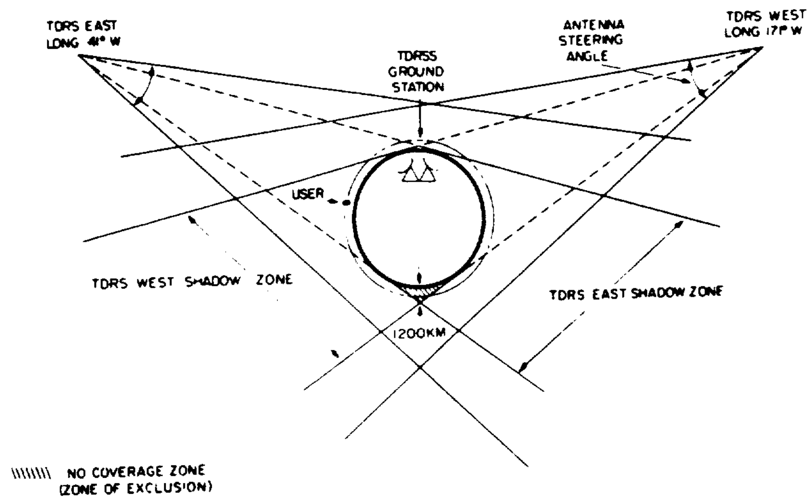

Figure 13.1 TDRSS Configuration [1].

The single TDRSS ground station is located at White Sands, New Mexico [1:259-60]. Data from this station may be transferred to the Raptor ground station directly or via satellite link. As shown in Figure 13.2, TDRSS covers 85% of the Earth's surface, it is unable to cover the region of central India and the mid-Indian Ocean, called the zone of exclusion, for spacecraft at 500 km [2].

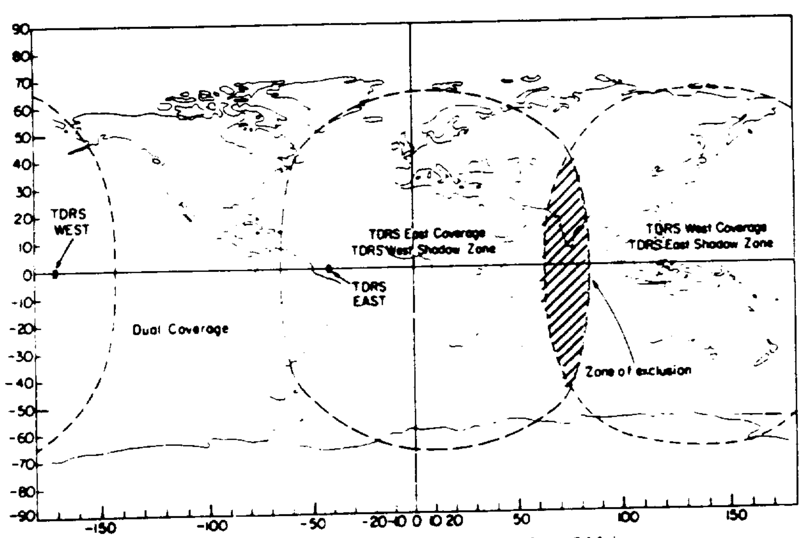

Figure 13.2 Zone of Exclusion up to 500 km [2:336].

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TDRSS has a designed operational lifespan of ten years, and is expected to reach the end of its projected lifespan in the late 1990's [1:260]. TDRSS will either be upgraded as an interim measure, or be replaced by a more advanced yet similar system [2:338]. The CTS will be designed modularly to grow with the technological expansion of the GSSP.

13.4 CTS Satellite Network

TDRSS's steerable antennas are not capable to cover all of the geosynchronous orbit. A system of tracking and relay satellites are needed in LEO to insure interactment between the GSSP, CTC, SRV and the ground at all times, as shown in Figure 13.3. If such a system does not exist at the time of GSSP operation, then a LEO relay data satellite system will be provided by Raptor.

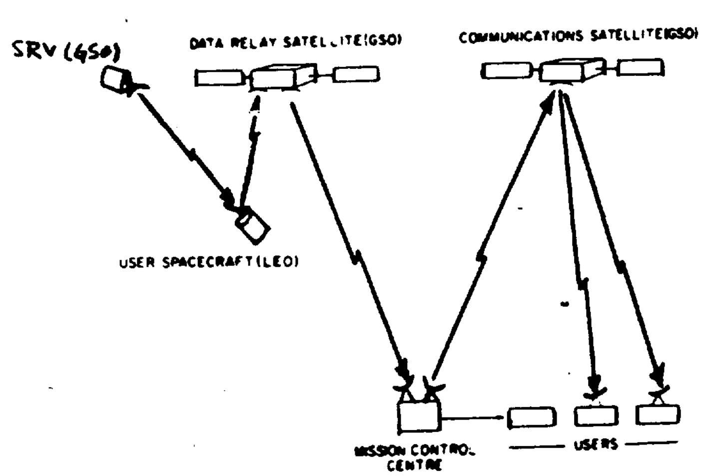

Figure 13.3 Communications Network with Relay System in LEO [1:256].

TDRSS offers a multiple access S-band service which provides a return link of data of up to 50 kb/s, and a forward link with a maximum bit rate of 10 kb/s [2:338]. Similarly, the GSSP will use two S-band transponders which are powered by two 50-watt traveling-wave tube amplifiers in parallel.

References : Communication and Tracking

1. Long, M., World Satellite Almanac, Second Edition, Howard W. Sams and Company, Indianapolis, Indiana, 1987, p. 256-60.

2. Evans, B. G., Satellite Communication Systems, Peter Peregrinus Ltd., London, U. K., 1987, p. 336-8.

14.0 Extra-Vehicular Activity Support

For extra-vehicular activity (EVA), an advanced technology 8.0 psi hard suit with adequate radiation and micrometeorite shielding will be used. Figure 14.1 shows an example of such a suite. Furthermore, the existence of a constant volume glove is assumed [1]. This will allow technicians to perform tasks which, due to their nature, cannot be performed robotically, nor can they be brought in through the airlock to be worked on, due to their excessive size. In order to support EVA operations, several important factors must be considered including mobility, suit limitations, and most importantly safety.

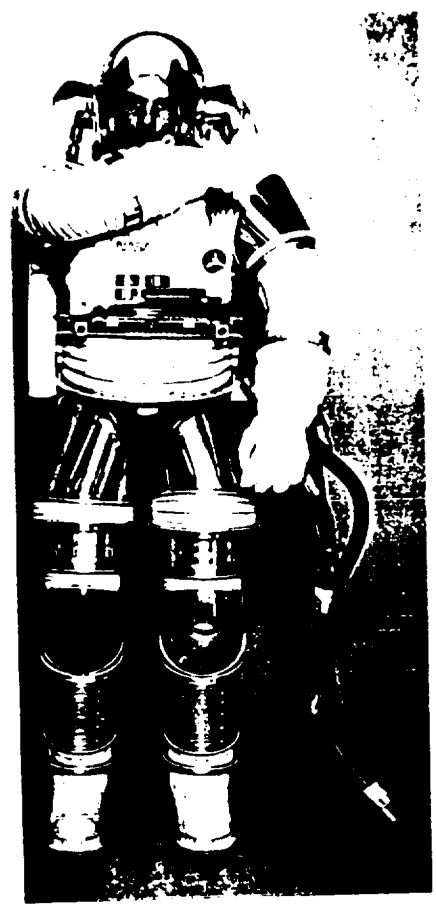

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Figure 14.1 Typical 8.0 psi hard suit [1:137].

14.1 Mobility

Mobility for EVA is provided by Manned Maneuvering Units (MMU) as shown in Figure 14.2. These units will have full attitude control capability, including a gyroscope package [1:139].

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Figure 14.2 Typical Manned Maneuvering Unit [1:139].

14.2 Suit Limitations

EVA suits cause many limitations on normal movements. One major limitation is that arm reach is very limited, particularly overhead arm reach. Another limitation is that the field-of-view is restricted by the inability of the helmet to move with the crew members head. Another limitation that must be considered is that the 8.0 psi suit being considered for EVA activities will require prebreathing before it can be used; although the 10.2 psi environment of the habitation module will reduce that required time as compared to the 14 psi environment proposed for the space station.

14.3 EVA Safety

Safety factors must be considered in all extra-vehicular activities. The EVA suit will therefore be constructed thick enough to afford protection from punctures, with additional thickness added for protection from the radiation hazards found in GEO. All EVA will be conducted with one crew member monitoring communications and control systems while the other conducts the necessary EVA.

When conducting EVA outside of the service bay a technician will be equipped with an MMU or some form of positive restraint. Restraint must be provided to counteract torque forces imparted on the crew members. During EVA operations, foot holds and hand holds will be provided along the outside of the GSSP and inside the service bay to provide additional safety.

References: Extra-Vehicular Activity Support

1. Woodcock, G. R. Space Stations and Platforms, Malabar: Orbit Book Co., 1986, p.10.

15.0 Automation

Many advantages can be realized by automating procedures aboard the GSSP. Most important among these is the removal of the crew from scenarios involving hazardous working conditions. In addition, tasks which are long term and repetitive in nature are performed most efficiently by automated systems.

15.1 Telerobotic Equipment

Telerobotic equipment is being heavily emphasized in the GSSP project to safely and cost effectively carry out the GSSP mission. Telerobotic operation offers the unique combination of remote operation and human control, thus eliminating the requirement for sophisticated software capable of making complex decisions. The telerobotic hardware implemented for the GSSP mission includes at least two Satellite Retrieval Vehicles (SRV's), a space arm manipulator system and servicing robots for use inside and outside the GSSP service bay.

15.1.1 Satellite Retrieval Vehicle (SRV)

The SRV is a semi-autonomous, free-flying vehicle, primarily used to rendezvous with and capture a single satellite. The vehicle is operated by a technician via telerobotic control from either an Earth based command center [1] or the operations module at the GSSP. The SRV capabilities are described in greater detail in Section 16.

15.1.2 Main Remote Manipulator System (MRMS)

The MRMS is a seven degree of freedom (7 - DOF) telerobotically operated space arm, with a multi-purpose end-effector, modeled after the Remote Manipulator System currently aboard the Space Shuttle. The MRMS is mounted on a traversing base which travels along a set of rails within the truss assembly. The MRMS can be operated from either the operations module or from a ground based telerobotic command center. The primary function of the manipulator is grappling and maneuvering payloads around the GSSP. Furthermore, the multi-purpose end-effector is equipped with a video system that can be used for visual inspection

15.1.3 Flight Telerobotic Servicer (FTS)

The FTS is an advanced telerobotic system used to grapple objects and perform operations requiring high degrees of dexterity. In addition to telerobotic operation, the FTS is capable of limited autonomous operation. An advanced vision system is incorporated to provide video imaging for telerobotic control and image recognition software, during periods of autonomous operation. The FTS is designed to be mounted on a dynamic platform such as the SRV or MRMS [2].

15.1.4 Servicing Arms

A set of specialized servicing arms reside in the service bay and are telerobotically operated by the crew from the operations module. In order to provide a flexible array of repair services, these systems are capable of changing end-effectors. The operator can select the appropriate end-effector from a set to be developed specifically for satellite servicing.

15.2 Telerobotic Tasks

To perform the specific satellite service tasks previously discussed, several supporting tasks must be accomplished. Similar to the specific servicing tasks, these have been targeted for telerobotic application, including satellite deployment and retrieval, satellite berthing in the GSSP service bay, platform construction and platform maintenance.

15.2.1 Satellite Deployment and Retrieval

Satellites which require service at the GSSP will be transferred there by the SRV, controlled by a technician at a ground based telerobotic command center. The SRV will rendezvous with the satellite, capture it using a grappling robot such as the FTS, and return the satellite payload to the GSSP. Likewise, satellite deployment operations are similar to those for retrieval. Prior to berthing at the GSSP service bay (see the following section), the satellite remains attached to the SRV in order to maintain nulled transitional and attitude rates.

15.2.2 Satellite Berthing

Satellites returned to the GSSP are berthed in the service bay by the MRMS. Once the satellite is maneuvered into the MRMS task space, the MRMS operator grasps the satellite, at which point the SRV disengages. Next, the MRMS traverses about the truss rails to maneuver the satellite into the service bay. The MRMS supports the satellite until service operations are completed. Throughout the berthing procedure, the MRMS and SRV are controlled by a task oriented, semi-autonomous mode in which simple tasks that can be performed without human input are integrated into a complex maneuver scenario by a telerobotic operator [3].

15.2.3 Platform Construction

The MRMS is the primary tool used to construct the platform. Furthermore, construction is supervised by technicians from a ground station. Three tasks make up the construction sequence. First, the truss sections must be extended and assembled.

Next, the operations and habitation modules are connected, and finally, the service bay frame is assembled and the covering is attached.

15.2.4 Platform Maintenance

Ideally, maintenance efforts will be minimized; however if the needs arise, external maintenance service will be supported by MRMS and service bay operations. A possible method for repairing structures outside the service bay utilizes the FTS, attached to the MRMS. This allows delicate operation (e.g. piping or truss repair) to be supported outside the service bay.

15.3 Artificial Intelligence

Artificial intelligence (AI) represents a wide range of emerging technologies aimed at enabling machines with the ability to reason. Examples of these technologies include expert systems, knowledge engines, and image recognition systems.

Future developments in the AI fields are crucial to the success of the GSSP project. The most important fields are sensor technology and machine image recognition and analysis [4]. These fields will play prominent roles in CTC rendezvous and docking, GSSP attitude control schemes, ECLSS control, and telerobotic servicing operations. Autonomous rendezvous and docking will utilize visual sensing, such as laser ranging, coupled with a proximity operations expert system. Similarly, attitude control and environmental control is to be provided by expert systems. Finally, machine vision technologies will be extensively relied upon to provide accurate data for telerobotic supervision of on-orbit service operations.

References: Automation

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3. Bailey, Robert, Personal Communication, LinCom Corporation, Houston, Texas, November 2, 1989.

4. Tesar, D. "20 Year Forecast of NASA Robotics Requirements for Space Exploration," Report from the Consortium of Texas Research Universities, September 11, 1989, p. 30-33,51.

16.0 The Satellite Retrieval Vehicle (SRV)

The SRV is a modified version of a free-flying, remotely controlled, unmanned spacecraft called an Orbit Maneuvering Vehicle (OMV) NASA intends to use the OMV for construction and operation of the Space Station and is projecting initial flights to begin in the early 1990's [1].

The primary function of the SRV's used at the GSSP will be to retrieve communication satellites from geosynchronous orbit, bring them to the GSSP for service and redeploy them once they have been repaired. In addition the SRV will also have on-orbit repair and refueling capabilities.

16.1 SRV Characteristics

The structural mass of the SRV is estimated at 2000 kg, with a fuel capacity of 3200 kg. It has the dimensions of one meter in length and fifteen meters in diameter. The SRV uses a fuel/oxidizer biopropellant system of monomethyl hydrazine and nitrogen tetroxide with a specific impulse of 315 seconds [1:11]. Without a payload, the SRV is capable of a total delta-V of 2.657 km/sec. The SRV will be serviced at the GSSP, which will primarily involve modular subsystem change-outs such as fuel and battery cells.

The SRV will use a range/range rate radar to position itself near the satellite. A pan/tilt/zoom camera is included on the SRV so that it can be controlled remotely from the ground during docking procedures. Communications with the SRV from the ground and the GSSP will be processed through TDRSS [2].

16.2 Satellite Capture and Docking

To capture and control a satellite in a 3-axis tumble a Tumble Arresting Large Oscillation Nullifier (TALON) can be used. A TALON is a large, unmanned, teleoperated satellite detumbling device [3]. TALON can have up to four articulated limbs with a weighted tip at the end of each limb, which can obtain a system of arbitrarily positionable mass [3:4]. A conceptual design of a TALON is shown in Figure 16.1.

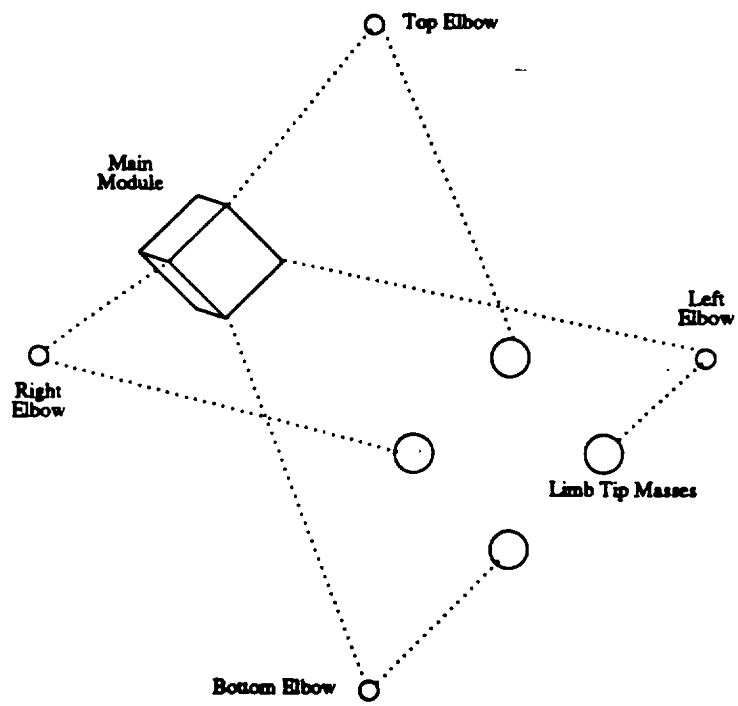

Figure 16.1. Conceptual Design for TALON [3:4].

Once the sum of the tip masses equals that of the tumbling satellite, the center of mass of the total system would be located at a point near TALON's geometric center. Therefore, if TALON's arms surrounded a tumbling satellite, the center of mass of the combined masses would be the center of mass of the tumbling satellite. TALON would then perform a controlled maneuver in order to match the satellite's tumbling attitude motion. After this, the satellite would not be moving relative to TALON and could be easily grappled. The attitude control system of TALON could then detumble the combined masses [3:5]. The arms of TALON are lightweight, rigid trusses hundreds of feet in length. Such a configuration could be able to detumble the Space Telescope or even a Space Shuttle [3:6].

A device such as TALON would be connected to the SRV and released as it approached a tumbling satellite. Once TALON has gained control of the tumbling satellite, it could then dock with the SRV for the trip back to the GSSP.

16.3 SRV Mission Scenarios

The SRV will be sent on several different mission scenarios. These include:

1.) a deploy mission,
2.) a retrieval mission,
3.) a combined deploy and retrieval (CDR) mission, and
4.) an on-site service mission.

A trip is defined as a trajectory from GEO to an upper or lower orbit and the subsequent return to GEO.

A CDR mission will consist of three trips:

1.) deploying a satellite to its initial location from the GSSP,
2.) retrieving another satellite, and
3.) returning back to the GSSP.

A deployment mission will consist of two trips:

1.) deploying a satellite to its initial location from the GSSP, and
2.) returning directly back to the GSSP.

A retrieval mission will consist of two trips:

1.) retrieving a satellite from the GSSP, and
2.) returning directly back to the GSSP.

A service mission will consist of the SRV servicing the satellite on location. On site services might include refueling or simple modular change-outs. A service mission will consist of two trips:

1.) servicing a satellite by coming from the GSSP or another satellite, and
2.) returning to the GSSP or going to another satellite.

The most efficient missions are the CDR and service missions. The deployment and retrieval missions are used only when the SRV is incapable of traveling the CDR mission of three trips due to high inclination or heavy payload. Typically, the inclination of a.geosynchronous communication satellites is approximately 4° with a maximum of inclination of 9°. The average mass of a geosynchronous satellite ranges from approximately 2000 kg to 2300 kg [1:10].

The SRV will have sufficient fuel to conduct a CDR mission with a heavy payload and an inclination of 4°, as shown by Figure 16.2.

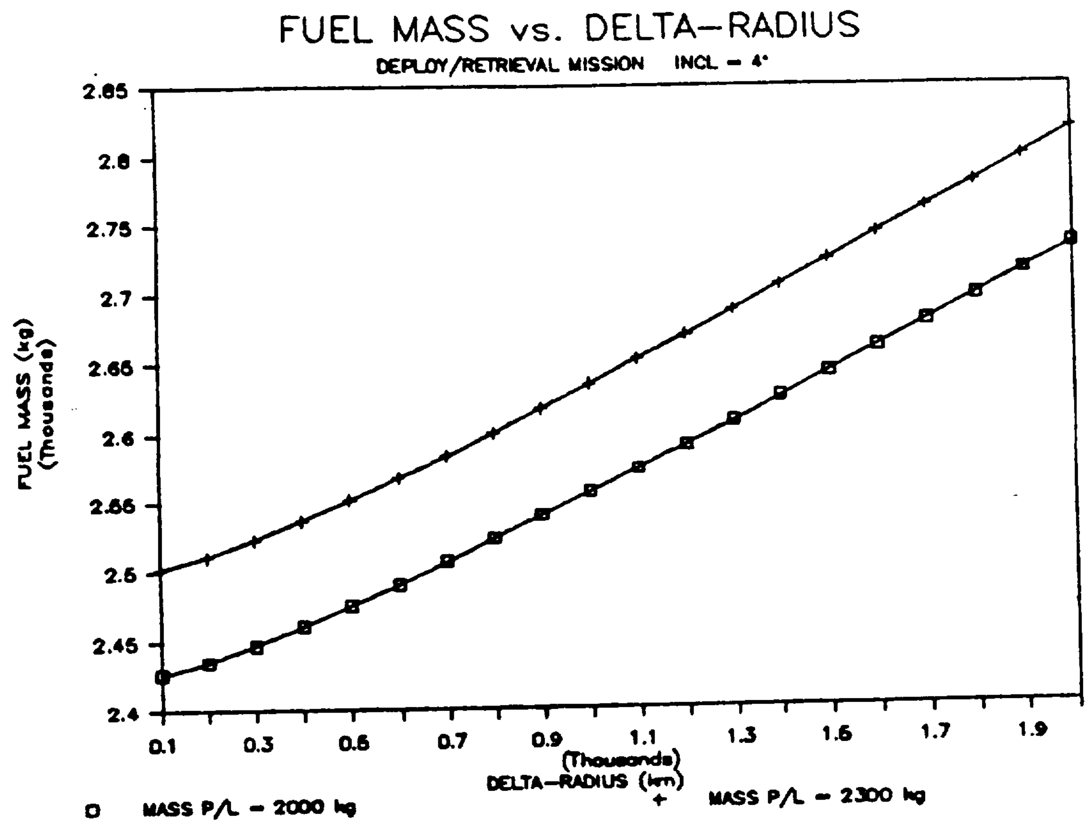

Figure 16.2 Fuel Mass vs. Delta-Radius for a CDR Mission (Inclination = 4°).

The SRV will not have enough fuel for a successful CDR mission with an inclination of 6°, as shown in Figure 16.3; however, with an inclination of 6°, the SRV will be capable of a deployment mission with a heavy payload, as supported by Figure 16.4. For disabled satellites with an inclination of 9° the SRV will be able to conduct a successful deployment mission, as supported by Figure 16.5. Thus, all satellites currently in geosynchronous orbit can be brought back to the GSSP to be repaired.

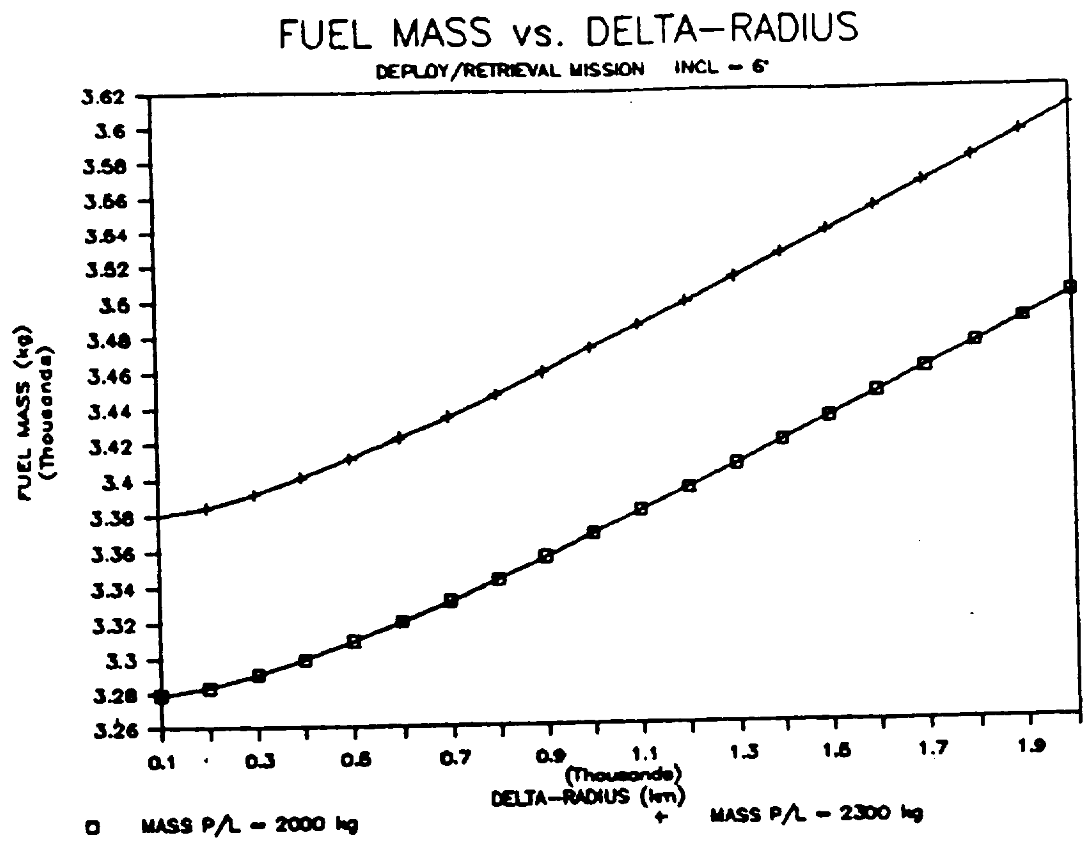

Figure 16.3 Fuel Mass vs. Delta-Radius for a CDR Mission (Inclination = 6°).

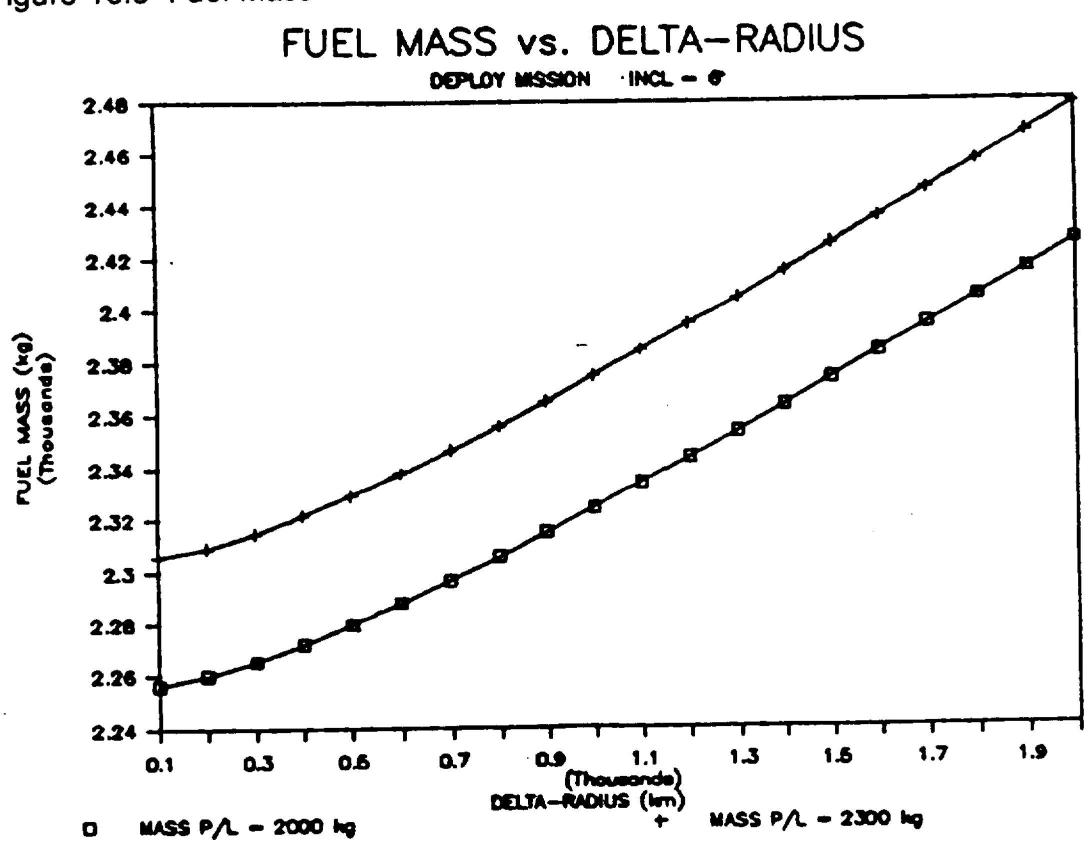

Figure 16.4 Fuel Mass vs. Delta-Radius for a Deploy Mission (Inclination = 6°).

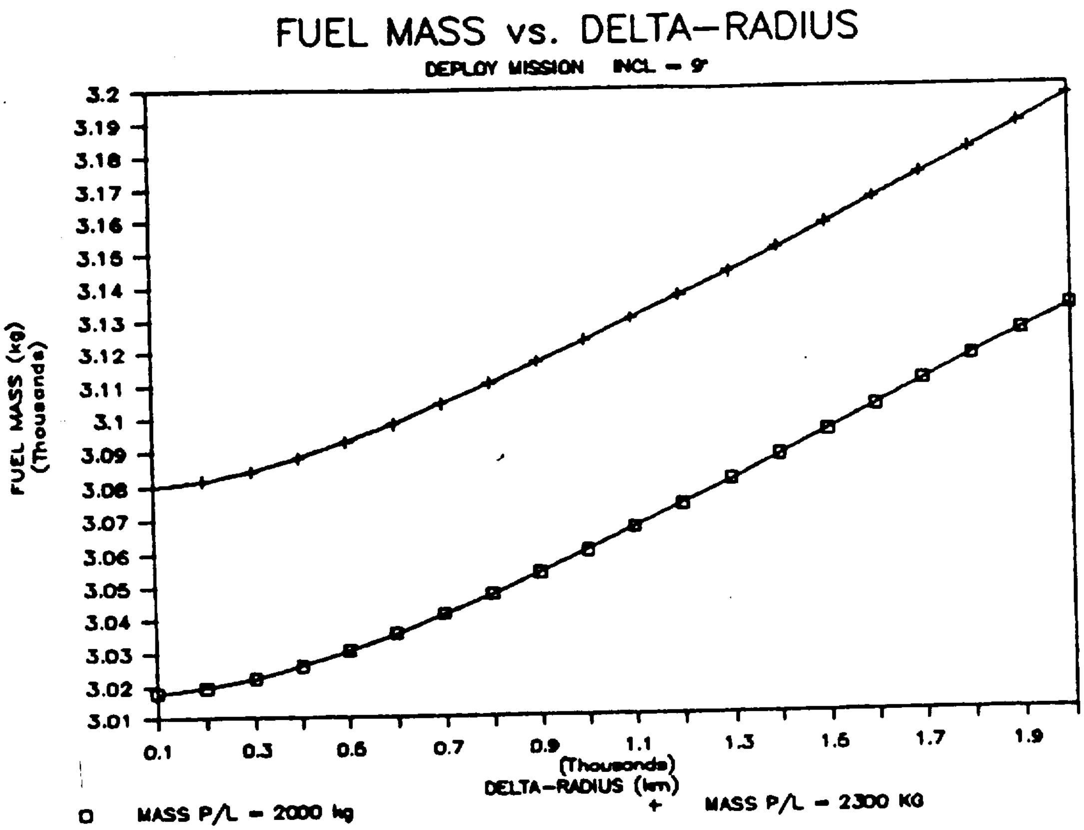

Figure 16.5 Fuel Mass vs. Delta-Radius for a Deploy Mission (Inclination = 9°).

Figure 16.6 shows a plot of the maximum trip time against the delta-radius of the lower orbit. The maximum time of one trip is defined as the time of flight from GEO to a lower orbit, plus the synodic period of the two orbits, plus the time of flight from the lower orbit back to GEO. The dominant factor of the maximum trip time is the synodic period between the two orbits. Thus, the average trip time is one half that of the maximum trip time.

Figure 16.2 through Figure 16.5 were generated by a FORTRAN code, Program SRV, included in Appendix C.

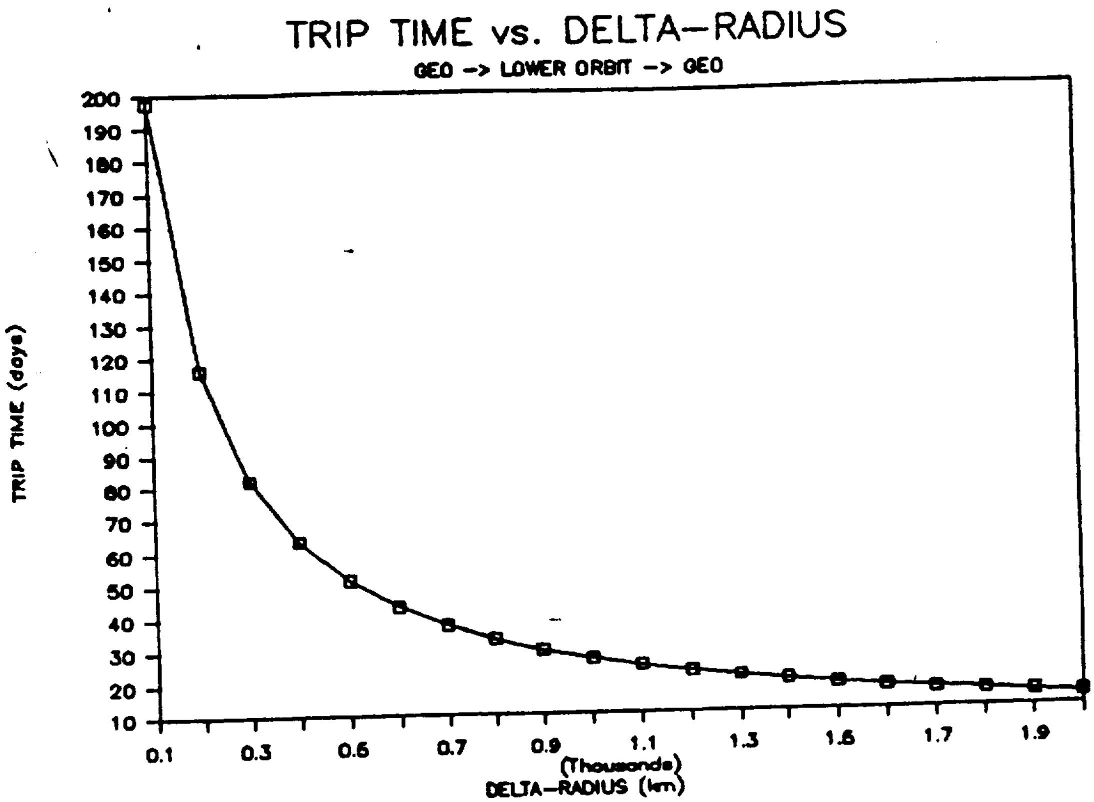

Figure 16.6 Maximum Trip Time vs. Delta-Radius for all SRV Missions.

References : The Satellite Retrieval Vehicle

1. Lemoine, F. G. and Morris, C. J., "A Preliminary Mission and Hardware Design for an Orbital Maneuvering Vehicle Operating in Geosynchronous Orbit," Department of Aerospace Sciences: University of Colorado, Boulder, March 24, 1986, p. 1.

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3. Idle, D., "TALON and CRADLE - System for the Rescue of Tumbling Spacecraft and Astronauts - A Preliminary Design", Dissertation: The University of Texas at Austin, May 1989, p. 6.

17.0 Crew Transfer Capsule (CTC)

The CTC is the GSSP crew and supply link with earth. The CTC must satisfy three requirements: transport the crew to and from the GSSP, transport supplies to the GSSP, transport waste products from the GSSP to the space station, and serve as an emergency escape vehicle for the crew while at the GSSP.

17.1 CTC Design

The preliminary design for the CTC is an Apollo derived command module, as shown in Figure 17.1. The CTC design was chosen because it utilizes proven technology, reduces design costs, and provides all necessary requirements for a crew transfer vehicle.

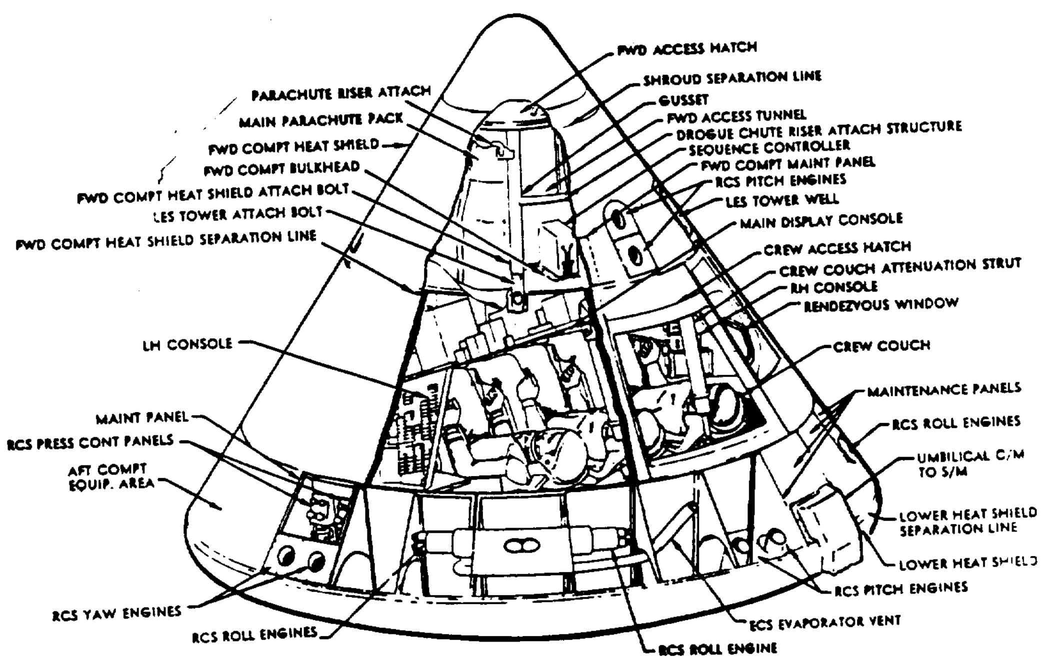

Figure 17.1 Apollo Command Module General Arrangement [1].

Besides a general system upgrade of the CTC using current technology, three major modifications will also be performed. First, the CTC will be modified to carry a two man crew. The sleeping station, as shown in Figure 17.2, will be removed. These modifications will allow most of the 71 cubic feet of living area to be used for supplies and return waste material [1:376]. Second, in order to allow the CTC to dock with the space station, it will be refitted with a Space Station common docking node. Similar docking nodes will be located on the GSSP. Finally, for reusability purposes, the CTC will be fitted with a disposable, ceramic heat shield. The disposable ceramic heat shield was chosen because of its low weight compared to titanium or other metal based heat shields.

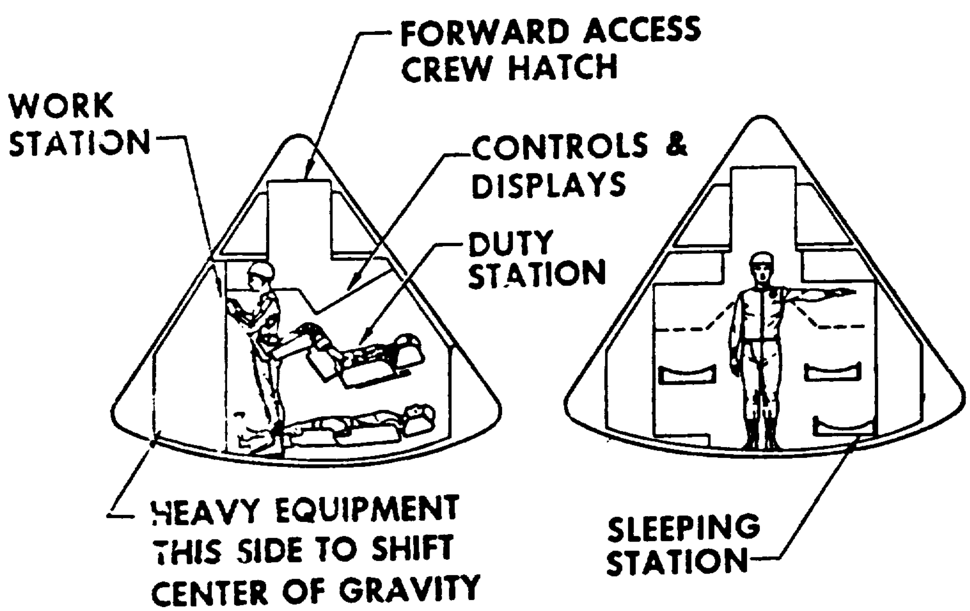

Figure 17.2 Command Module Living Area [2:377].

17.2 CTC Launch Methods

Two launch methods are proposed in the preliminary design of the CTC. The weight and diameter of the CTC, 11,000 lbs and 12 ft respectively, were the primary constraints on the launch system selection process [1:325]. The first method of launch requires the Space Shuttle to transfer the CTC to LEO, and the STV to complete the transfer to GEO. The second launch method utilizes a Titan IV to transport the CTC directly into GEO. This latter method is preferred because it is independent of NASA shuttle operation scheduling and would not require STV support and maintenance.

17.3 CTC Return Methods

There are two proposed return methods for the CTC. The first method would be a standard earth descent and splashdown, followed by retrieval of the CTC via helicopter or ship. The second method of return would include a stop at the Space Station before returning to earth by splashdown or onboard the Space Shuttle. The second method would be used under emergency circumstances, where GSSP crew members required immediate medical attention or were unable to survive the splashdown return to earth. Another reason for using the second method of return, would be to drop off valuable waste water, collected at the GSSP, at the Space Station.

References: Crew Transfer Capsule

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18.0 Recommendations

The GSSP concept is a unique and lucrative venture into the commercialization of space; however, it is not a concept that will be realized immediately, but 15 - 25 years in the future. The attempt to project the state of technology and industry that will be available at this time has proven a tremendous challenge to the Raptor Corporation. The GSSP concept will undergo many beneficial design revisions in the coming years, and Raptor avidly encourages its continued development to meet the original goals of service and profitability. To instigate this process, Raptor is recommending continued investigation and development of the following subjects.

1. At this time, it has become unclear whether a crew-tended facility is necessary for successfully completing the GSSP mission. Issues have surfaced about the possibility of performing telerobotic servicing entirely from a ground based command center. Since the crew requirement makes up a significant portion of the cost to develop, build, and operate the GSSP, a huge benefit could be reaped by successfully eliminating this requirement; however, it should not be eliminated entirely. Experience gained from NASA's attempt to service the Solar Max satellite in 1984 graphically illustrated the limitations of machines in adapting to unexpected problems. For this reason, Raptor would encourage the development of a "crew-visited" concept as a compromise between crew-tended and solely autonomous operations.

2. Similar to the GSSP hardware design, the cost/benefits analysis performed by Raptor is purely a preliminary measure. Again, the attempt to project the space environment 15 - 25 years from the present severely limits the accuracy that could be expected of a more current analysis. Raptor has established that a market for satellite servicing exists and that this market is rapidly growing. A

comprehensive research effort in this area could substantiate the viability of the concept and would serve to confirm Raptor's original projections. Additionally, this search could lead to the identification of new technologies which could enhance the GSSP as a financial venture.

3. In the event that the crew-tended requirement cannot be removed from the design, one area must be considered for review. The current size of the habitation module is too large for a two person, two week mission. Alternate, smaller module(s) should be considered during the next design cycle. Additionally, a more detailed study of the materials required for radiation protection should be performed. Currently, information on solar particle events is quite theoretical. Thus, the crew safe haven and habitation module shielding requirements should be reviewed as new information becomes available.

4. An area that could be drastically effected by a number of future developments is the delivery of the platform to orbit and subsequent construction. This is a monumental task given the current mass and volume targets of the GSSP. As techniques for launching and building large scale space structures are developed for construction of the Space Station Freedom, this task should become more defined. Once this capability is demonstrated, a review of the process detailed by Raptor should be commenced and modified as necessary.

5. Finally, the development of enabling technologies should be closely monitored over the span of the GSSP design. Space is an extremely expensive environment to operate in and a new environment to the industrial community. For this reason, advances in equipment which are is less massive, smaller (volumetrically), automated, and energy efficient is of the highest priority.

Specifically targeted areas for these advances include solar power generation, thermal rejection, and telerobotics.

Appendix A GSSP Proposal

A Proposal
for an
Earth Orbiting Satellite Service and Repair Facility

GEOSHACK

Submitted to:

George W. Botbyl

The University of Texas at Austin
Department of Aerospace Engineering
and Engineering Mechanics

Presented by:

Raptor Corporation

October 9,1989

Executive Overview - Project GEOSHACK

This document outlines the proposed design of a satellite servicing facility. The primary function of the facility - GEOSHACK - is to provide a base of operation for the retrieval, repair, replenishment and replacement of satellites in geosynchronous equatorial orbit. The Raptor Corporation will focus upon:

1. The economical deployment of the facility and crew;
2. Appropriate structural configuration of the GEOSHACK, along with subsystems and associated vehicles; and
3. Cost-effective scenarios for retrieval, repair, salvage, re-supply and transfer.

The GEOSHACK Project will be a commercial enterprise. Therefore, the design aspects will be limited to existing or feasible enabling technologies to minimize the project expenses.

TABLE OF CONTENTS

1.0 Summary

This section of the report summarizes the background, operation, assumptions and limitations, of the GEOSHACK project.

1.1 Background

An unexplored area of space commercialization involves the prospect of retrieving and repairing satellites in Geosynchronous Equatorial Orbit (GEO). Hundreds of these satellites are disabled, and the owner is helplessly stuck with the expense of replacing it, at a cost from fifty to one hundred million dollars. Therefore, a definite market exists to the entrepreneur who is able to retrieve and repair these damaged satellites.

The Raptor Corporation proposes to design an orbiting facility (GEOSHACK), to be located at or near GEO, which will serve as a base for retrieving, repairing, and salvaging geosynchronous satellites.

As a private enterprise, cost effectiveness will be the prime consideration. Therefore, many 'off the shelf' parts will be utilized to minimize costs. In addition, the Raptor Corporation will only consider existing and currently developing technologies for the GEOSHACK and its infrastructure; however, the future possibilities for design evolution and the ultimate project goals will be presented in the final report.

1.2 Operation

The GEOSHACK will be the center of operations for manned and unmanned satellite servicing, with only short duration manned occupation. It will be composed of three major components: the habitation, service, and storage modules. Satellite Retrieval Vehicles (SRV's) will be based at the GEOSHACK with autonomous capabilities of rendezvousing with candidate satellites, docking with them, and delivering them to the GEOSHACK facility, where they will be stored. When several (3-6) satellites have been retrieved and stored, a manned team with fuel, consumables, parts, and tools will be sent to the facility from Lower Earth Orbit (LEO) via a Space Transport Vehicle (STV). The team will focus on repairing the stored satellites by remotely operated robotic arms, Extra Vehicular Activity (EVA), and, if necessary, the pressurization of the service module to provide a shirt-sleeve environment. When servicing is complete, the technicians will return to LEO and the SRV's will replace the satellites in their respective orbits. This cycle will be repeated up to six times per year; however, only two missions per year are estimated for the first year.

1.3 Assumptions

The GEOSHACK design will be based on the following assumptions about the existing infrastructure and transport vehicles:

1. The Space Station is complete and functional.
2. An operational STV is at the Space Station with a minimum payload of 10,000 lb. to GEO.
3. Vehicles for satellite retrieval (SRV) are commercially available.

1.4 Project Limitations

Since this project is a commercial venture, the feasibility is based upon the profit margin. Therefore, the cost to repair and replace satellites, while maintaining a profit, must be considerably less than the cost to build and launch new satellites.

2.0 Technical Proposal

Project GEOSHACK:

The GEOSHACK will be a man-tended vehicle, capable of supporting a two man crew for periods up to fourteen days. Raptor engineers have chosen a two man crew concept primarily for safety reasons. This concept is similar to the 'buddy system' used by underwater divers.

The facility will be capable of servicing several satellites during the manned period. Initial service capability projections are four satellites serviced per mission with up to three missions completed within a 12 month time span.

Success of the project is directly dependent on the existence of a supporting infrastructure. Most important is the availability of a Space Transfer Vehicle (STV) that will shuttle payloads between low earth orbit (LEO) and geosynchronous earth orbit (GEO). The STV is assumed to have a minimum useful payload of 10,000 lb. Another vehicle critical to the GEOSHACK project is a Satellite Retrieval Vehicle (SRV). The SRV will be used to capture a satellite and transfer it to the GEOSHACK for service. After servicing is complete, the SRV will redeploy the satellite in its original position. Additionally, the US Space Station is assumed to be operational. The station may be used as a rendezvous point for STV flights and as a base for on-orbit assembly of the GEOSHACK.

2.1 Orbit Determination

The orbit placement of the GEOSHACK facility will optimize mission cost and time. After due consideration, Raptor has arrived at two prime choices:

1. Equatorial orbit near GEO (inside or outside of GEO); and
2. Placement in GEO at an optimal location.

The orbit geometry for both of these options is shown in Figures 2.1 and 2.2 respectively.

The first option, near GEO, offers the advantage of a location close to the satellites, with a radial distance between 500 and 1000 km. The satellites may be retrieved by the SRV's in simple Hohmann transfers from the facility to the satellite and back. The overall mission time for satellite retrieval will vary from approximately 30 to 60 days, and the velocity changes will be between 30 and 75 m/s for each mission. In addition, the GEOSHACK facility will move relative to the satellites, allowing scheduling of retrieval missions based on the movement of the facility.

The second orbit option, at GEO, offers nearly the same benefits as the previous option, but the retrieval mission will consist of eight burns instead of four, and the associated velocity changes will be about twice as much per retrieval mission. However, this configuration will allow for constant positioning of the facility and fewer communication problems. In addition, the retrieval mission period will vary from about 5 to 60 days, based on the orbit location of the satellite, relative to the GEOSHACK.

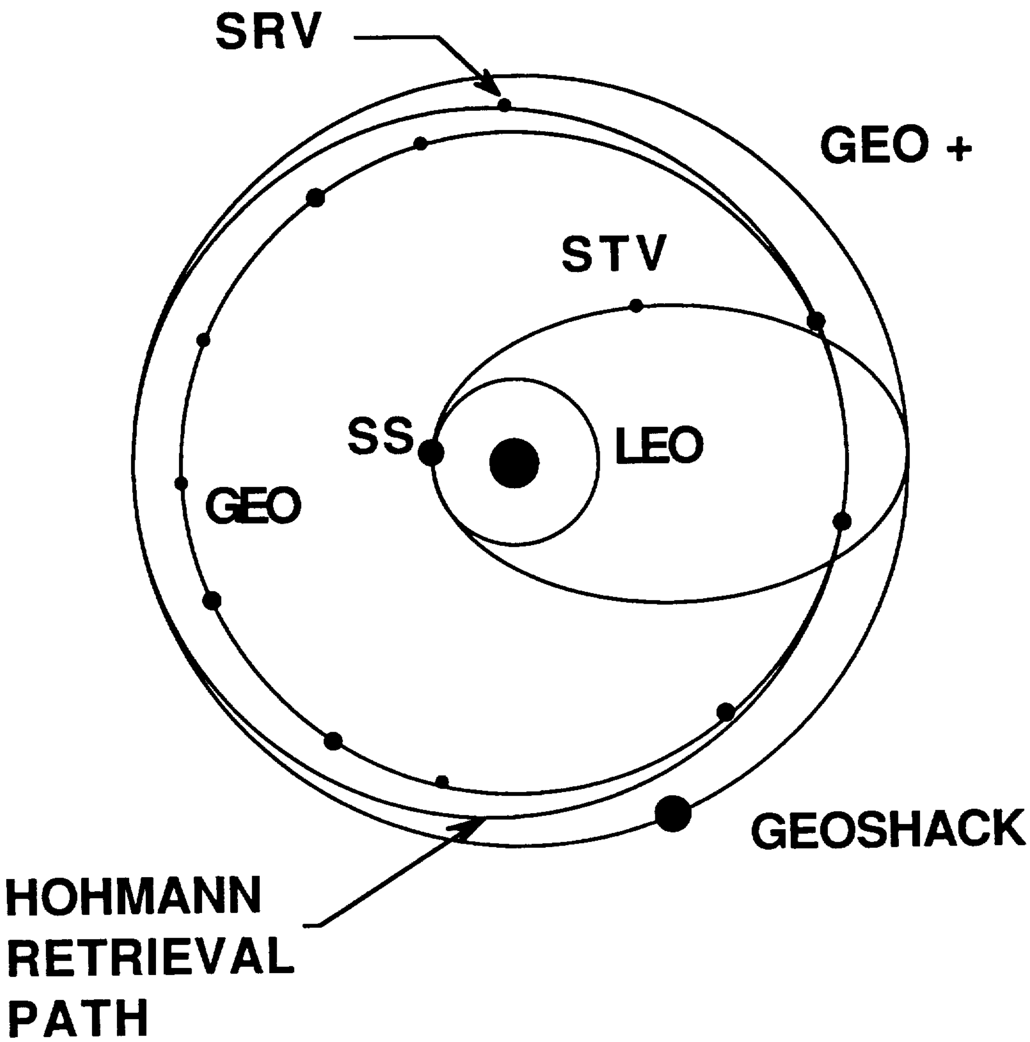

Figure 2.1. Scenario Geometry for the Near GEO location of the GEOSHACK Facility.

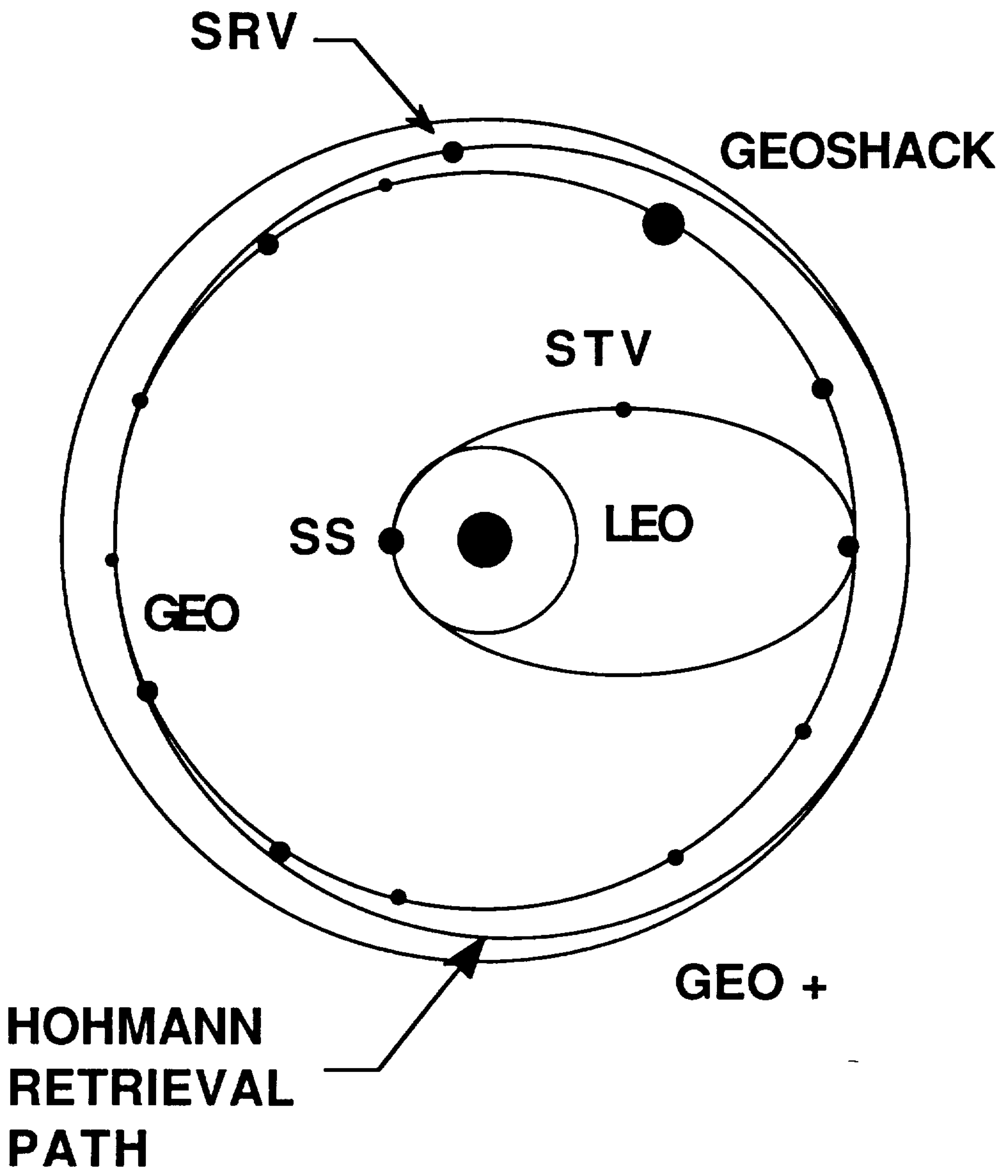

Figure 2.2. Scenario Geometry for the in GEO location of the GEOSHACK Facility.

Raptor will determine the most efficient orbit for the GEOSHACK facility by analyzing fuel required, mission period and communication advantages.

2.2 Structural Design

The structural design includes consideration of modular design and integration, assembly, radiation shielding, and docking assemblies.

2.2.1 Modular Design and Integration

Modular design concepts offer flexibility to the overall design of a vehicle. Modular systems and subsystems can be easily modified or replaced should the need arise. In addition, modular components give the long term advantage of enabling facility expansion.

Current conceptual GEOSHACK designs have separate modules for crew habitation and satellite servicing. The habitation module(s) will provide the crew with a shirt-sleeve living and working environment. The following systems are under consideration for integration into the habitation module:

1. Private personal quarters for each crew member.
2. Ward area including TV, stereo, and table space.
3. Personal hygiene facility with shower, lavatory, and sink.
4. Galley complete with refrigerator, freezer, microwave oven, and dry goods storage.

5. Health maintenance facility with a complete supply of medical provisions.
6. Workstation/command center with Earth /GEOSHACK communications, database and information systems, and robotic systems interfaces.

Based upon our reviews of current space station designs and requirements for extended duration orbiter (EDO) missions, a pressurized volume of 100 m^3 has been targeted. This space should provide sufficient room for the integration of these systems, while allowing for unencumbered motion of the crew.

The service module of the GEOSHACK may consist of two separate servicing bays where satellites will be tended by robotic systems and/or crew members. A fundamental design concern is pressurization of the service bays. Initial conceptual designs of the space station called for a unpressurized satellite servicing bay. This option appears to be the most economical, considering the tremendous loss of resources resulting from the depressurization of a large service bay. Furthermore, an unpressurized environment would enhance the role of automated systems, spurring development of new systems. In addition, a large pressurized service area could impose severe mass and volume penalties on launch performance. However, consideration must still be given to a pressurized service module, since the space industry lacks significant experience working in an unpressurized environment. Moreover, the dexterity gained from a shirt sleeve working environment (i.e. not requiring an EVA support suit to perform manual repair tasks) may be necessary.

2.2.2 Assembly

The GEOSHACK modules will be placed in LEO by a series of launches and subsequently assembled. Some assembly and integration of subsystems (most notably in the habitation module) may be performed in LEO by astronauts temporarily based at the space station. The integrated packages may then be boosted to GEO by the STV. Final assembly at GEO will be required, due to the overall mass of the vehicle and the assumed lift capability of the STV. The time required from initial launch of hardware to the completion of the facility should require 12 - 18 months.

2.2.3 Radiation Shielding

Radiation shielding for the GEOSHACK must be sufficient to shield the crew and equipment from excessive radiation. Studies have shown that astronauts should not absorb more than 50 REM/year. Thus, shielding material(s) must meet this requirement.

Three known types of radiation are present in GEO: energetic electrons from the Van Allen Belts, galactic radiation (GCR), and solar energetic particles (SEP). During solar flares, SEP reaches extreme intensities. Therefore, special attention will be paid to avoiding the danger of these flares. During times of extreme radiation, a radiation shelter or a means of evacuation will be provided for the crew. Raptor will further study the intensities of GEO radiation to determine the level of protection necessary.

Shielding materials will be carefully studied and then evaluated on the basis of cost, safety and dependability.

2.2.4 Docking Assemblies

A docking assembly will be attached to the habitation module to transfer the crew and any needed supplies from the STV to the GEOSHACK. This assembly will be derived from the space station common docking node design to decrease development costs and preserve hardware commonality for space station support purposes.

2.3 Environment Control and Life Support Systems (ECLSS)

A partially-closed ECLSS for a two men crew is being considered for the GEOSHACK. A fully closed ECLSS will not be required, since the GEOSHACK will be only a man-tended facility. Future expansion of the GEOSHACK may require a closed ECLSS. Water and oxygen will be reclaimed, while other consumables will be resupplied. The reclamation process will be used to improve GEOSHACK efficiency. The ECLSS should be modular in design to ensure ease of maintenance and allow for future expansion. If further studies show that a partially-closed ECLSS is not economically feasible, an open ECLSS will be used. A list of the services provided by ECLSS follows:

- Atmosphere control (temperature, pressure, composition, and humidity)
- Regeneration of water and oxygen
- Supply consumables (food, nitrogen, and compensation for unrecoverable water or oxygen)
- Waste management
- EVA servicing

The atmosphere control system will monitor and control total pressure, oxygen and nitrogen partial pressures, ambient temperature, and humidity. Furthermore, it will provide a means of air ventilation and fire detection and suppression.

The reclamation system will provide the means to reclaim oxygen and water. Metabolic CO_2 will be reduced to water and carbonaceous products. Water from CO_2 may be combined with water condensed from the humidity control process and used for drinking and food preparation. Waste hygiene water will be filtered and then used to produce oxygen by electrolysis. Nitrogen will be supplied from either a cryogenic or high pressure tank, and other consumables will be resupplied for each mission as necessary.

The waste management system will collect waste hygiene water for recovery. Waste hygiene water consists of urine/flush, shower and wash water. Furthermore, it will collect and store fecal matter. Urinals and commodes will be based on existing technologies that are currently used in the shuttle.

EVA servicing system will provide supplies for EVA operations and life support services. Supplies consist of fuel, air, water, and food for EVA activities. The space suits used for EVA should operate with a pressure of 8 psi which will make prebreathing unnecessary. An airlock will be used to provide a controlled rate of pressurization and depressurization, and it will act as a hyperbaric chamber for treatment of rapid decompression sickness. An airlock gas recovery system will be used for airlock chamber depressurization to conserve consummables .

The ECLSS will provide the crew with a safe and pleasant environment for periods up to two weeks. The system will be modular in design and will have the capabilities for future improvements and expansions.

All conceptual designs stated above may be changed in the future if further studies indicate they are not economically feasible.

2.4 Guidance, Navigation and Control (GNC)

The GEOSHACK GNC functions will include guidance, navigation, attitude control, orbit maintenance and traffic control. The GNC must accommodate for modular buildup and possible growth phases of the GEOSHACK. The GNC system will also be able to accept and respond to ground backup commands.

2.4.1 Functional Requirements

The guidance and navigation system will establish and maintain a GEOSHACK state vector and provide for orbit maintenance, proximity operations and traffic control. Collision avoidance maneuvers and docking and deployment of berthed satellites will be aided by GNC position and velocity information.

The Attitude Control and Stabilization (ACS) system will employ Momentum Exchange Devices (MED) and reaction control thrusters to provide for a three axis attitude torque control. The ACS system may be operated automatically or manually for support of docking, berthing and deployment of other space vehicles with GEOSHACK. The ACS will include a survival mode which would have a sufficient power collection in the event of multiple failures on GEOSHACK.

2.4.2 Design and Performance Requirements

The GNC must provide the GEOSHACK with orbit and attitude accuracy, stability and relative position control. The GNC sensors will determine the position, attitude and velocity of GEOSHACK and its traffic. The sensors will also diagnose malfunctions of the GNC system components.

The MED will be employed as the primary actuator and must be capable of providing attitude control without the use of the Reaction Control System (RCS). The RCS will control the propulsion system with three axis torque capability. The RCS will provide the GEOSHACK with the necessary thrust for all orbit maintenance and berthing maneuvers. The RCS will be able to operate independently or in conjunction with the MED control system.

2.5 Power

Power Systems will be composed of both power generation and storage systems. These topics are covered in the next two sections.

2.5.1 Power Generation

Two possible sources for energy production on this orbital repair facility are solar and nuclear. A combination of these systems is possible, and may be necessary.

Solar power is a likely choice for power generation. Solar arrays convert sunlight into electrical energy via photovoltaic cells. Two types of arrays are planar arrays, made up of silicon cells, and concentrator arrays. The main disadvantage of planar arrays, depicted in Figure 2.3, are the large surface areas required for kW power generation. Concentrator arrays, depicted in Figure 2.4, typically operate at a higher temperatures than a planar arrays, resulting in a smaller array size for the same kW output.; however concentrator arrays require a specified pointing accuracy to prevent rapid decline in output. These options will be weighed to consider the most advantageous solar system.

Nuclear power is a viable option if large power applications (high kW to MW) are required. Many types of reactors, either currently available (liquid metal

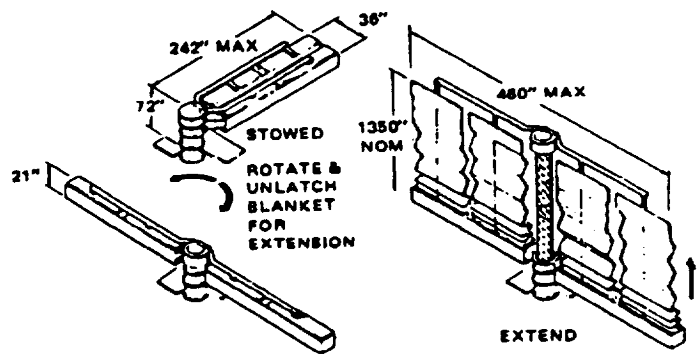

Figure ~~2.3~~ 10.1 Typical Planar Array - Source: Bekey p. 343

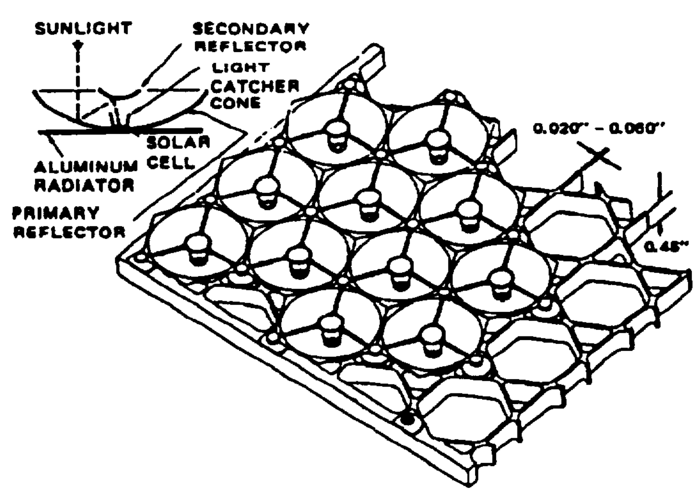

Figure ~~2.4~~ 10.2 Concentrator Array - Source: Bekey p.344

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reactors, etc.) or being developed (THOR, etc.), could be used to power the facility. Advantages are compact design, low mass, and high energy outputs. Disadvantages are waste disposal problems, refueling (over life of the facility), and added safety measures that will be required once the facility is manned.

2.5.2 Energy Storage

Nuclear energy will not require large storage devices. If solar energy is employed, an energy storage system will be required for periods when the system is deprived of solar radiation. Nickel-Cadmium (NiCd) and Nickel-Hydrogen (NiH_2) batteries are the currently under consideration for the task of energy storage. The main disadvantage is that batteries are depletable and must be replaced.

It should be noted that future energy storage possibilities include reversible fuel cells (RFC)--where hydrogen and oxygen are converted into electrical energy and water during output (eclipse), and electrolysis decomposes the water into hydrogen and oxygen during the input (sunlight) phase.

2.6 Thermal Control Systems

Thermal control is a matter of considerable importance for a facility in near GEO orbit. If a radiator were built using past heat rejection technology, the size of the resulting radiator could account for up to 40% of a facilities total weight. Consequently, state of the art thermal controls must be implemented to reduce the radiator size. Possible systems that may be employed for heat rejection include heat pipes (similar to those designed for space station) and liquid drop radiators (LDR).

2.7 Automation

Many advantages may be realized by automating procedures aboard the GEOSHACK. Most important among these is the removal of the crew from scenarios involving hazardous working conditions. In addition, tasks which are long term and repetitive in nature are performed most efficiently by automated systems.

Specific servicing tasks have been identified for automation. Satellite refueling should be performed robotically due to the toxicity of fuels used in some satellites. To reduce crew time outside the vehicle, satellites may be berthed by a crew controlled manipulator, similar to the one currently employed on the space shuttle. Similar techniques may also be used for satellite component replacement (e.g. electronic modules or solar panels). Visual inspection and diagnostic services are other possible applications of remote manipulators

Mission support tasks lend themselves to automation due to their repetitive nature. These tasks include rendezvous and docking of the STV with the GEOSHACK and environment monitoring of the crew module. Continuous monitoring of supply levels, temperature, humidity ,pressure and fire detection would reduce crew workload.

2.8 Communications and Tracking

The Communication and Tracking (C&T) system of the GEOSHACK must be able to communicate with the ground and the Space Station as well as track all GEOSHACK traffic.

2.8.1 Functional Requirements

Crew members of the GEOSHACK will be able to communicate throughout all habitation modules, berthing ports and airlocks. The communication system will also link the GEOSHACK to the ground, IVA and EVA.

2.8.2 Design and Performance Requirements

The GEOSHACK facility will be able to communicate and track the STV, SRV and GEOSHACK traffic. The C&T system may provide radio frequency and/or laser techniques to support tracking of vehicles during proximity and berthing operations. Tracking and Data Relay Satellites (TDRS) will be the primary communications link between GEOSHACK and the ground.

The GEOSHACK C&T system will be designed to technologically grow commensurate with GEOSHACK expansion.

2.9 Ground Support

GEOSHACK operations will require ground support services to complete mission objectives. Services include astronaut resources for GEOSHACK missions, as well as launch vehicles and facilities to deliver payloads to GEOSHACK

2.9.1 Astronauts and Launch Services

Astronauts, technicians and scientists may be provided by NASA for initial and early manned missions to GEOSHACK. After several successful early missions, Raptor may employ permanent astronauts and technicians for following manned missions.

Launch services from earth to the Space Station may be provided by NASA via the Space Shuttle. Transportation from the Space Station to GEOSHACK will be provided by the STV.

2.9.2 Launch Options

Two options exist for delivery of the facility to GEO. A shuttle launch would deliver the facility components to LEO, followed by use of an upper stage or a space transfer vehicle (STV), for transfer to GEO. The most attractive aspect of the shuttle STV/upper stage option is the reliable and proven format for launching payloads. Furthermore, development of Shuttle C would allow launches of larger payloads.

The second for delivery of the facility to GEO is the use of heavy lift launch vehicles with facility modules mated to upper stage boosters. The U.S.S.R. Energiya and U.S. heavy lift launch vehicle (HLLV) are examples of available and developing systems capable of reducing the number of launches required to place the facility in orbit.

Further development of upper stages capable of delivering massive loads to GEO orbit will facilitate both the HLLV option and the shuttle option. The choice between the two options will ultimately be determined by the mass of the facility and the cost to deliver this mass to GEO orbit.

3.0 Management Proposal

This section of the report discussed the management and organizational structure utilized by the Raptor Corporation in execution of Project GEOSHACK.

3.1 Management Structure

Project GEOSHACK is led by a Project Manager, whom is assisted by an administrative manager. The Project Manager is responsible for the overall actions of the firm, including control of technical, planning and scheduling aspects of the project. The Administrative Manager aids the Project Manager by coordinating the efforts of the firm, and by having responsibility for documentation and analysis of needs, accounting and scheduling.

3.2 Organizational Structure

The size of the Raptor Corporation allows for an integrated design system -- while each member of the firm is assigned to and responsible for one or more aspects of the project, all members are able to assist other members in their respective areas. This allows for rapid identification of problems, free-flow of ideas and an overall understanding of the entire design project. See Figure 3.1 for the organizational structure of the Raptor Corporation.

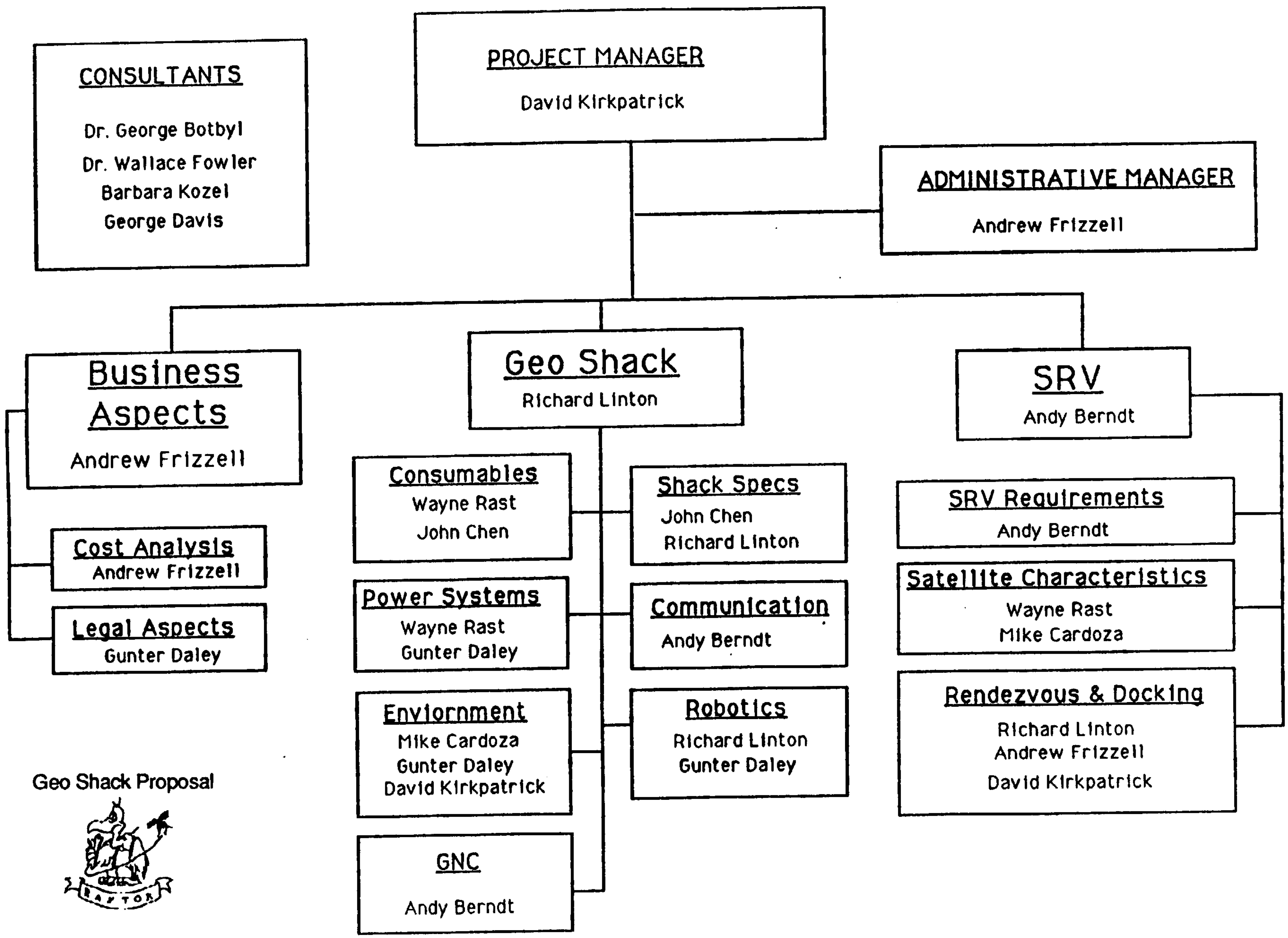

Figure 3.1 Raptor Corporation Organizational Structure

3.3 Time Line and Critical Path Analysis

Figures 3.2 and 3.3 illustrate the estimated time line and critical path considerations for design of the GEOSHACK project.

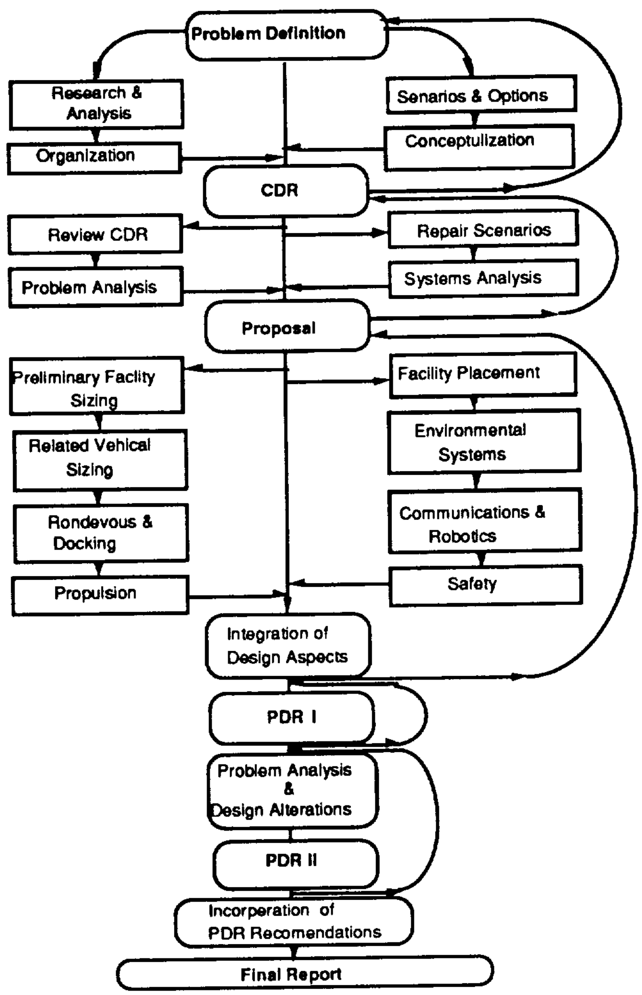

Figure 3.2 Project GEOSHACK Critical Path

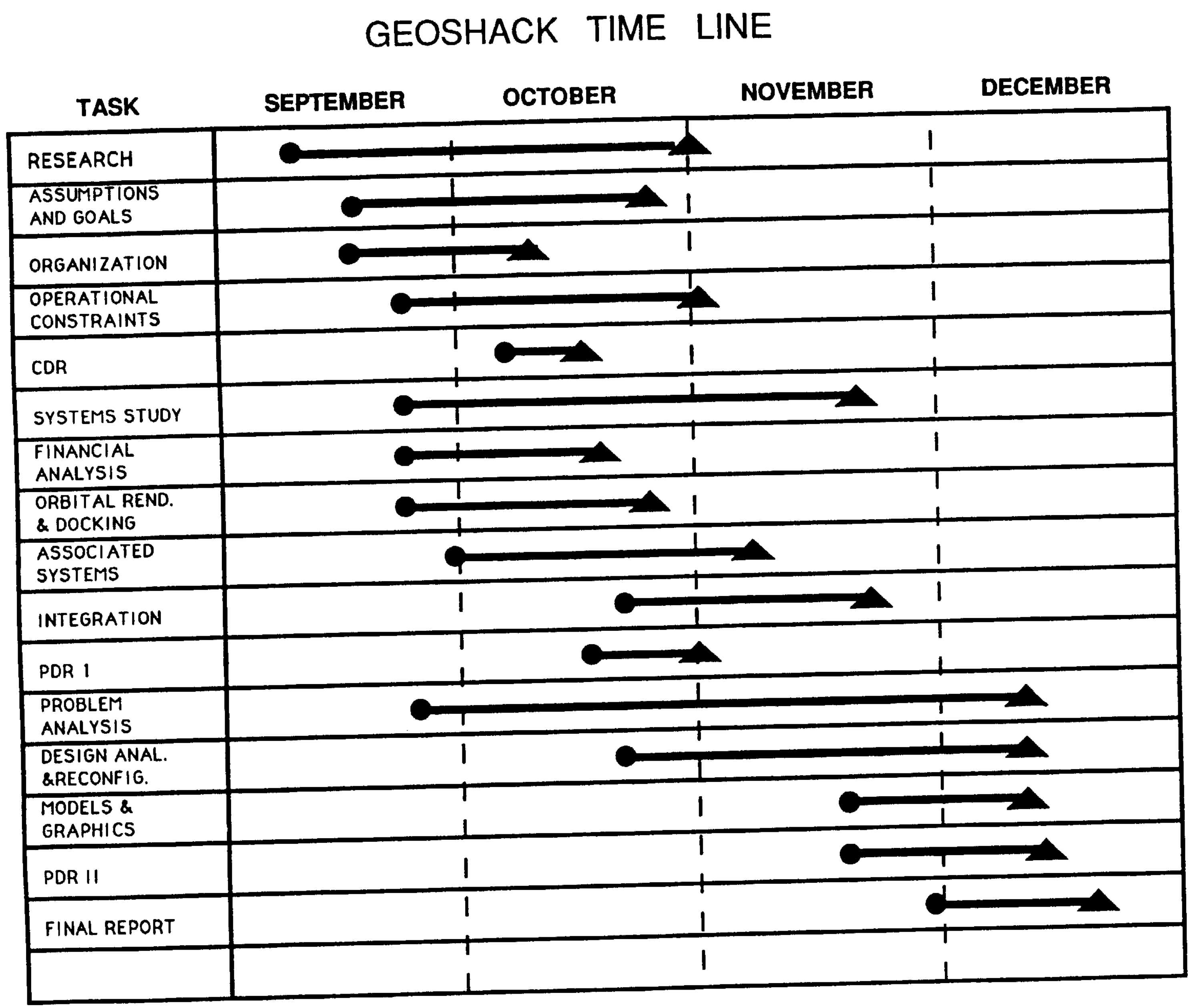

Figure 3.3 Raptor Corporation Time Line for Project GEOSHACK

4.0 Cost Proposal

The itemized and overall projected costs of the GEOSHACK project as undertaken by the RAPTOR Corporation are presented in this section. The projected costs were determined by examining the costs incurred over the first three weeks of the project. The personnel cost estimate is presented first, followed by the anticipated material and hardware costs. The Cost Proposal concludes with the total estimated cost of the GEOSHACK project.

4.1 Personnel Cost Estimate

Table 4.1 shows the personnel costs incurred in week three of the GEOSHACK project. Based on the first three weeks of the GEOSHACK project, the third week appeared to represent the average number of hours per employee. The computed weekly personnel cost was multiplied by the number of weeks allowed for the project in order to determine the projected personnel cost for the entire GEOSHACK project. The cost of technical consultants not employed by the RAPTOR Corporation was added to the projected personnel costs to comprise the total projected personnel costs for the GEOSHACK project.

July 24, 1990:

Pages 27 and 28 removed because of

funding information.

Philip N. French

PHILIP N. FRENCH

Document Evaluator

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Appendix B Space Station Habitation Module Specifications

The following tables identify the individual subsystems and mass requirements for the Space Station habitation module which is currently manufactured by Boeing Space System in Huntsville, Alabama. This module is currently being considered for implementation on the GSSP.

Geometry: 408 in. length and 174 in. overall diameter.

Table B.1 Cylindrical Sidewall Assembly.

Skin/Stringers	2,561 lbs
Primary Ring Frames	1508 lbs
Intermediate Ring Frames	957 lbs
Berthing Segment	3489 lbs
Window Segment	1101 lbs
Trunnion Longerons	667 lbs
TOTAL	**10,283 lbs**

Table B.2 Primary Structure.

Cylindrical Sidewall Assembly	10,238 lbs
Conical End Cones	630 lbs
TOTAL Primary Str.	**10,913 lbs**

Table B.3 Subsystems.

Meteoroid/debris Shield	946 lbs
Thermal Insulation	180 lbs
Remaining Subsystems	28,044 lbs
TOTAL Subsystems	**29,170 lbs**

Table B.4 Secondary Subsystems.

10% of Subsystems	2,917 lbs
TOTAL Secondary Subsystems	**2,917 lbs**

TOTAL LAUNCH

GROSS WEIGHT 43,000 lb

The weight and volume of the habitation module proposed for the Space Station is given in Table B.5 below.

Table B.5 Module masses and volumes.

Module	Weight	Volume
Habitation Module 1	37,942/43,000 lbs	3,108.3 ft^3
Resource node	19,000/21,000 lbs	1,550 ft^3

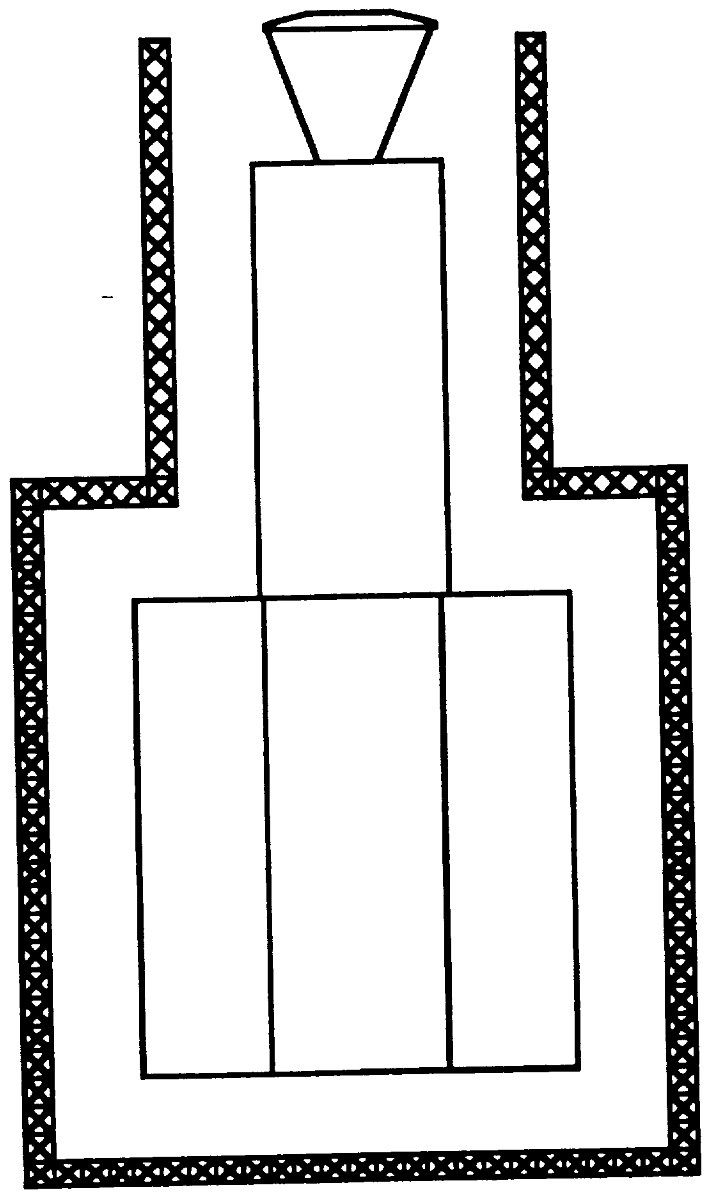
Appendix C FORTRAN Code for SRV Mission Plots

```
      Program SRV
c
c
c  Programmer:  Andrew Berndt
c  Date:        11 November 1989
c
c       Program SRV is designed to calculate the propellant mass versus
c  the delta-radius of a Satellite Retrieval Vehicle (SRV).  Propellant
c  mass is the mass of fuel used by the SRV to perform the following
c  missions: 1.) Combination Deploy/Retrieval (CDR), 2.) deploy, 3.)
c  retrieval and 4.) service.  Delta-radius is the amount of kilometers
c  the lower orbit is inside of the geosynchronous orbit.
c       Program SRV also determines the maximum trip time versus the
c  delta-radius.  The trip time is defined as the the time of flight
c  from geosynchronous orbit to the lower orbit, plus the synodic period
c  of the two orbits, plus the time of flight from the lower orbit back
c  to geosynchronous orbit.
c
c
      REAL*8 pi,mu,RadiusGeo,EfficiencyFactor,Isp,gravity,MassStructure
      REAL*8 MassPropellent,MassPayload,Inclination,InclinationHigh
      REAL*8 InclinationLow,DeltaRadius,RadiusLowerOrbit,VcGeo
      REAL*8 VcLowerOrbit,SemiMajorAxis,VApogee,VPerigee,OmegaGeo
      REAL*8 OmegaLowerOrbit,SynodicPeriod,TimeOfFlight,TripMissionTime
      REAL*8 Mass1,Mass2,Mass3,Mass4,Mass5,Mass6,Mass7,Mass8,Mass9
      REAL*8 Mass10,Mass11,Mass12,Mass13,Mass14,Mass15
      REAL*8 MassPropellent1,MassPropellent2,MassPropellent3
      REAL*8 MassPropellent4,MassPropellent5,MassPropellent6
      REAL*8 MassPropellent7,MassPropellent8,MassPropellent9
      REAL*8 MassPropellent10,MassPropellent11,MassPropellent12
      REAL*8 MassPropellentTotal
      INTEGER i
      OPEN(1,FILE='mass.prn')
      OPEN(2,FILE='time.prn')
      gravity = 9.81E-3
      pi = ACOS(-1.0)
      mu = 398601.2
      RadiusGeo = 42122.0
c
c-----SRV Structural Characteristics
c
      EfficiencyFactor = 0.9
      Isp = 315.0
      gravity = 9.81E-3
      MassStructure = 2000.0
      MassPropellent = 3200.0
c
c-----Satellite Inclination
c
      Inclination = 9.0*(pi/180.0)
      InclinationHigh = Inclination*0.98
      InclinationLow = Inclination*0.02
```

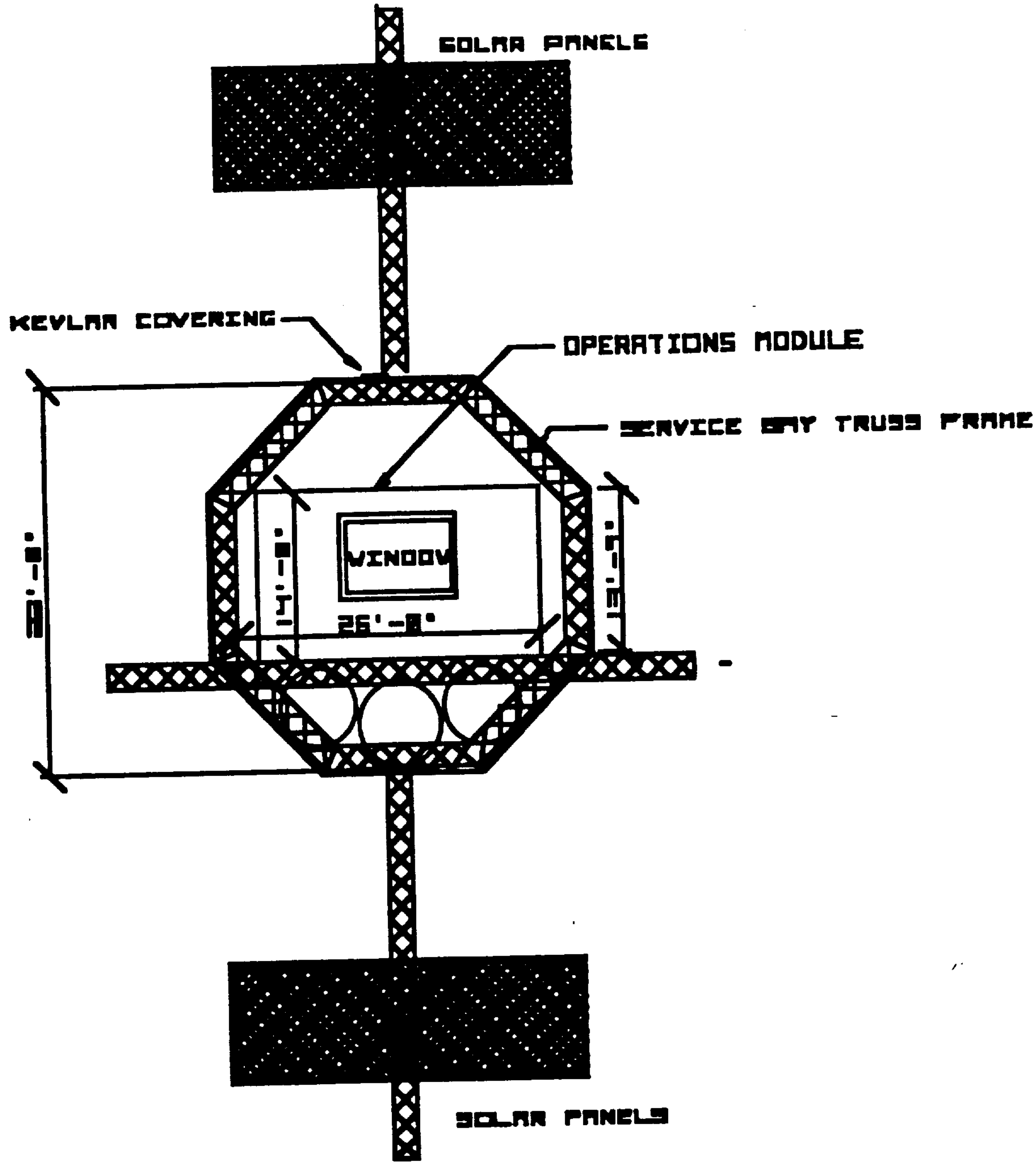
```
c-----Comment Out Next Line for Service Missions
      DO 200 j = 2000,2300,300
c-----Comment Out Next Line for CDR, Deploy and Retrieval Missions
        j = 0
        MassPayload = DBLE(j)
        DO 100 i = 100,2000,100
          DeltaRadius = DBLE(i)
          RadiusLowerOrbit = RadiusGeo - DeltaRadius
          VcGeo = SQRT(mu/RadiusGeo)
          VcLowerOrbit = SQRT(mu/RadiusLowerOrbit)
          SemiMajorAxis = (RadiusGeo+RadiusLowerOrbit)/2.0
          VApogee = SQRT((2.0/RadiusGeo - 1.0/SemiMajorAxis)*mu)
          VPerigee = SQRT((2.0/RadiusLowerOrbit - 1.0/SemiMajorAxis)*mu)
          DeltaVApogee = SQRT(VcGeo**2 + VApogee**2 - 2.0*VcGeo*VApogee*
     +                 COS(InclinationHigh))
          DeltaVPerigee = SQRT(VcLowerOrbit**2 + VPerigee**2 - 2.0*
     +                  VcLowerOrbit*VPerigee*COS(InclinationLow))
          OmegaGeo = 7.292115856E-5
          OmegaLowerOrbit = VcLowerOrbit/RadiusLowerOrbit
          SynodicPeriod = 2*pi/ABS(OmegaGeo-OmegaLowerOrbit)
          TimeOfFlight = pi*SQRT(SemiMajorAxis**3/mu)
          TripMissionTime = (SynodicPeriod + 2*TimeOfFlight)/86400.
c
c-----Trip One-----Geo to Lower Orbit to Geo with Payload
c
          Mass1 = MassStructure+MassPropellent+MassPayload
c-----Burn 1
          Mass2 = Mass1/EXP(DeltaVApogee/EfficiencyFactor/Isp/gravity)
          MassPropellent1 = Mass1 - Mass2
c-----Burn 2
          Mass3 = Mass2/EXP(DeltaVPerigee/EfficiencyFactor/Isp/gravity)
          MassPropellent2 = Mass2 - Mass3
c-----Burn 3
          Mass4 = Mass3/EXP(DeltaVPerigee/EfficiencyFactor/Isp/gravity)
          MassPropellent3 = Mass3 - Mass4
c-----Burn 4
          Mass5 = Mass4/EXP(DeltaVApogee/EfficiencyFactor/Isp/gravity)
          MassPropellent4 = Mass4 - Mass5
c
c-----Trip Two-----Geo to Lower Orbit to Geo without Payload
c
          Mass6 = Mass5 - MassPayload
c-----Burn 5
          Mass7 = Mass6/EXP(DeltaVApogee/EfficiencyFactor/Isp/gravity)
          MassPropellent5 = Mass6 - Mass7
c-----Burn 6
          Mass8 = Mass7/EXP(DeltaVPerigee/EfficiencyFactor/Isp/gravity)
          MassPropellent6 = Mass7 - Mass8
c-----Burn 7
          Mass9 = Mass8/EXP(DeltaVPerigee/EfficiencyFactor/Isp/gravity)
          MassPropellent7 = Mass8 - Mass9
```

```
c-----Burn 8
          Mass10 = Mass9/EXP(DeltaVApogee/EfficiencyFactor/Isp/gravity)
          MassPropellent8 = Mass9 - Mass10
c
c-----Trip Three-----Geo to Lower Orbit to Geo with Payload
c
          Mass11 = Mass10 + MassPayload
c-----Burn 9
          Mass12 = Mass11/EXP(DeltaVApogee/EfficiencyFactor/Isp/gravity)
          MassPropellent9 = Mass11 - Mass12
c-----Burn 10
          Mass13 = Mass12/EXP(DeltaVPerigee/EfficiencyFactor/Isp/gravity)
          MassPropellent10 = Mass12 - Mass13
c-----Burn 11
          Mass14 = Mass13/EXP(DeltaVPerigee/EfficiencyFactor/Isp/gravity)
          MassPropellent11 = Mass13 - Mass14
c-----Burn 12
          Mass15 = Mass14/EXP(DeltaVApogee/EfficiencyFactor/Isp/gravity)
          MassPropellent12 = Mass14 - Mass15
          MassPropellentTotal = MassPropellent1+MassPropellent2+
     +                         MassPropellent3+MassPropellent4
     +                         +MassPropellent5+MassPropellent6+
     +                         MassPropellent7+MassPropellent8
c-----Comment Out Next Two Lines for Deploy, Retrieval and Service
c     Missions
     +                         +MassPropellent9+MassPropellent10+
     +                         MassPropellent11+MassPropellent12
          WRITE(1,1000)MassPropellentTotal,DeltaRadius
          WRITE(2,1000)TripMissionTime,DeltaRadius
 1000     FORMAT(3x,F10.2,3x,F10.2)
 100    CONTINUE
 200  CONTINUE
      STOP
      END
```

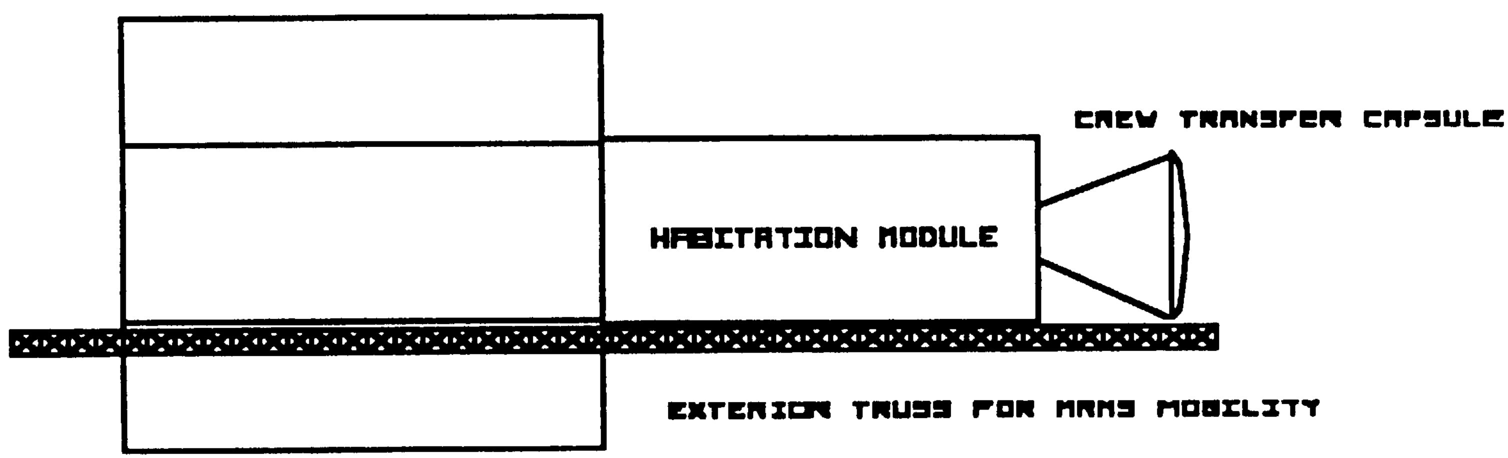
Appendix D CADD Drawing of the GSSP Facility



TOP VIEW



END-VIEW: LOOKING INTO SERVICE BAY



SIDE VIEV VITHOUT SOLAR ARRAYS