JSC-16277

Space Operations Center
a concept analysis

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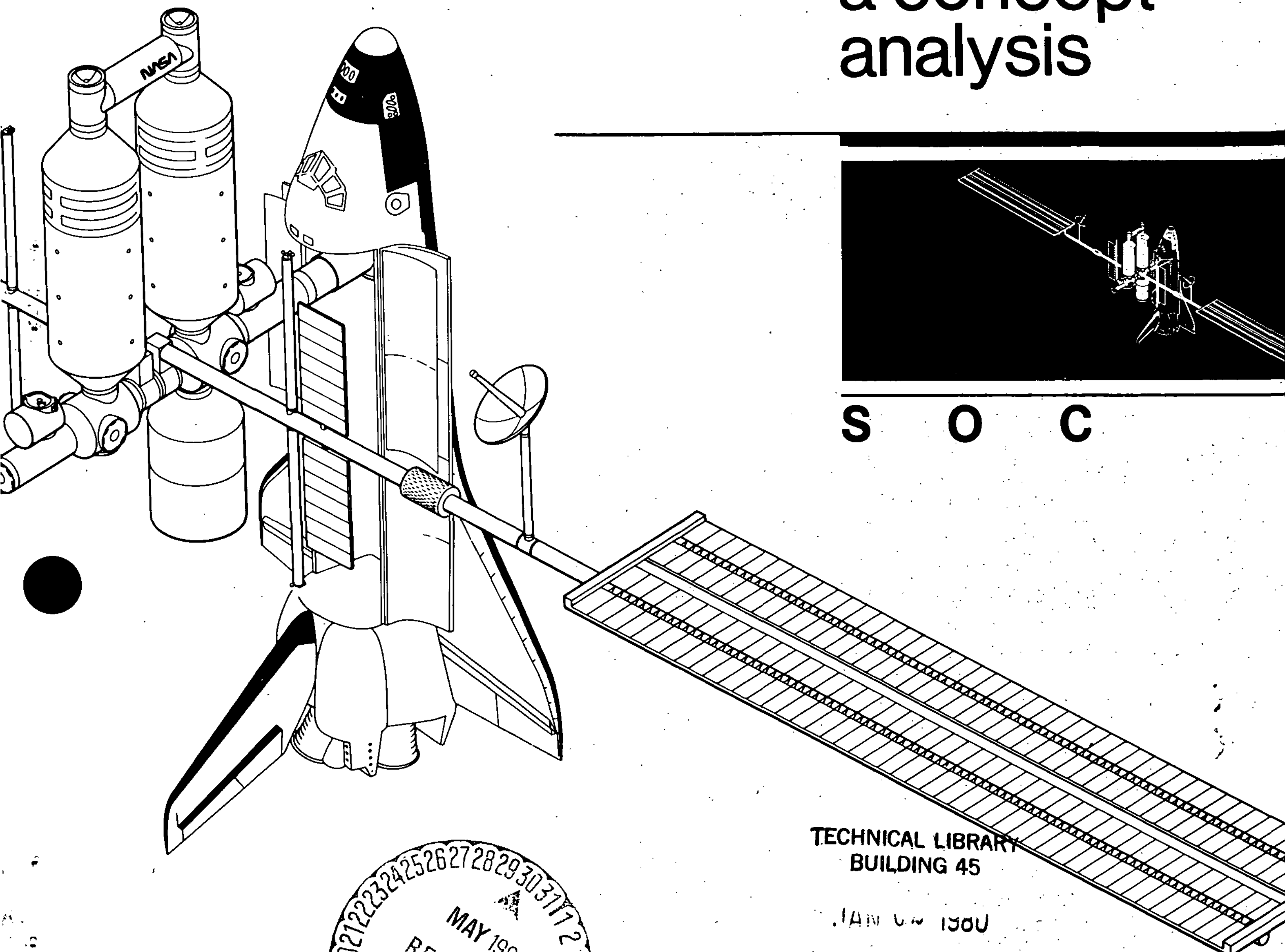

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SPACE OPERATIONS CENTER

A CONCEPT ANALYSIS

Lyndon B. Johnson Space Center
Houston, Texas

November 29, 1979

FOREWORD

The Space Operations Center is a concept for a Shuttle-serviced, permanent, manned facility in low earth orbit. An analysis of this concept was conducted by personnel of the Johnson Space Center during 1979. The results of the study are presented in this document.

It should be noted that there are no NASA plans at present to implement such a concept. The study reported herein and currently planned follow-on studies are intended to explore the concept and develop material for consideration in future planning.

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1.0 SUMMARY

1.1 BACKGROUND

The Apollo program established an extensive U.S. technological and operational experience base for conducting manned space activities. In the Skylab program, the Apollo hardware was utilized in assessing the capability of people to live and work productively in space for long periods of time. The objective of the current Shuttle program is to develop a transportation system which, due to its high reusability, can transport payloads to and from low earth orbit at a lower cost than could previous expendable launch vehicles. In addition, the Shuttle will provide manned support for onboard experiments, and for the retrieval and servicing of some free-flying satellites. The Shuttle also will be used in developing a space construction capability, and possibly for some level of on-orbit assembly of stages for deep space missions.

1.2 THE NEXT GOAL IN MANNED SPACE FLIGHT

1.2.1 Rationale

A compelling rationale can be drawn that it is now time to identify the next logical step in the evolution of U.S. manned space flight capability, -- at least as a goal.

The Shuttle is approaching operational status with its initial orbital flight test scheduled before the end of 1980. If the U.S. is to maintain its leadership in space, continuity in research and development is necessary. Future space activities, for which requirements and concepts are now being identified and developed, will require expanded manned operations in space; and significant advances in space operations capability inherently require long gestation and development periods. Furthermore, developments in both technology and operational capability need a long-term goal to focus their activities in order to be most effective. Although it sometimes is not stated openly, there frankly is a need for a real goal to maintain the dedication of present participants in the space program and the interest and enthusiasm of young people in space technology in order to motivate their pursuing engineering and science careers.

1.2.2 Alternatives

Although there have probably been hundreds of proposals made for the next major space goal all the way out past solar power satellites to space colonies, the major candidates for manned space flight can be generally grouped into the following five areas:

(1) Shuttle utilization.

(2) Permanent manned facility in low earth orbit (LEO).

(3) Manned geosynchronous sortie mission capability.

(4) Permanent manned facility in geosynchronous orbit (GEO).

(5) Manned lunar sortie mission capability with or without a lunar base.

The first of these, the utilization of Shuttle capabilities alone, is not an insignificant goal. The Shuttle has considerable capability which should and will, hopefully, be exploited to the maximum. Shuttle utilization, however, in its evolution will not require a new research and development thrust and does not provide the clear focus needed for on-going technology and operations development. A goal limited to Shuttle utilization only probably would not support a national policy of maintaining leadership in space, and, in any event, represents a slow pace of advancement. On the other hand, items (4) and (5), a permanent manned GEO facility or a lunar base, would bypass desirable, and perhaps necessary, evolutionary steps in technology and operational development, and both would require support capabilities that would probably exceed the scope of any early available funding. The other two alternatives, a manned LEO facility and a manned GEO sortie mission capability, both appear to have considerable value and represent reasonable technical and funding challenges.

The operational deployment of a manned LEO facility would provide a "consolidation" of our capability to operate in near space, from the standpoint of both transportation and permanency. The development of the capability for manned GEO sortie missions would extend our manned transportation capability from LEO, as provided by the Shuttle, to geosynchronous orbit. This capability would be an initial "LEO-GEO Shuttle."

1.2.3 LEO Space Stations

NASA has performed and sponsored studies of space stations off and on for several years. Figure 1.2-1 shows a concept from 1967 which illustrates the thinking of the day. At this time many people were convinced that artificial gravity was required for long-term living in space, and the concept shown has a crew habitation area which rotates around a zero-gravity hub where earth or ineritally-oriented experiments were housed. The picture also shows the dependence of the station's configuration on its launch vehicle (Saturn V), as evidenced by its diameter and the use of a spent stage for a counterweight. Other studies followed with various rotating concepts until the Apollo and then Skylab missions showed that even though a null gravity environment contributes to fluid shifts, some cardiovascular deconditioning, loss of some bone calcium and muscle mass, and modest changes in the blood, all the changes appear to be physiological in nature and reversible. There have been no changes that would preclude longer exposure times than the 83-day Skylab mission, and no changes that would suggest that a high level of performance should not be expected. Consequently, space station studies shifted to zero-G concepts in the early 1970's. Shortly after that, serious studies of a new logistics vehicle which became the Shuttle were underway, and space station concepts evolved to the Shuttle-launched configuration concept shown in the 1970 illustration in figure 1.2-2. This illustration shows modules that fitted inside the payload bay of the Shuttle concept-of-the-day, and which were assembled into a space station configuration using an early manipulator concept.

Figure 1.2-1 ARTIFICIAL GRAVITY SPACE STATION (1967 STUDY)

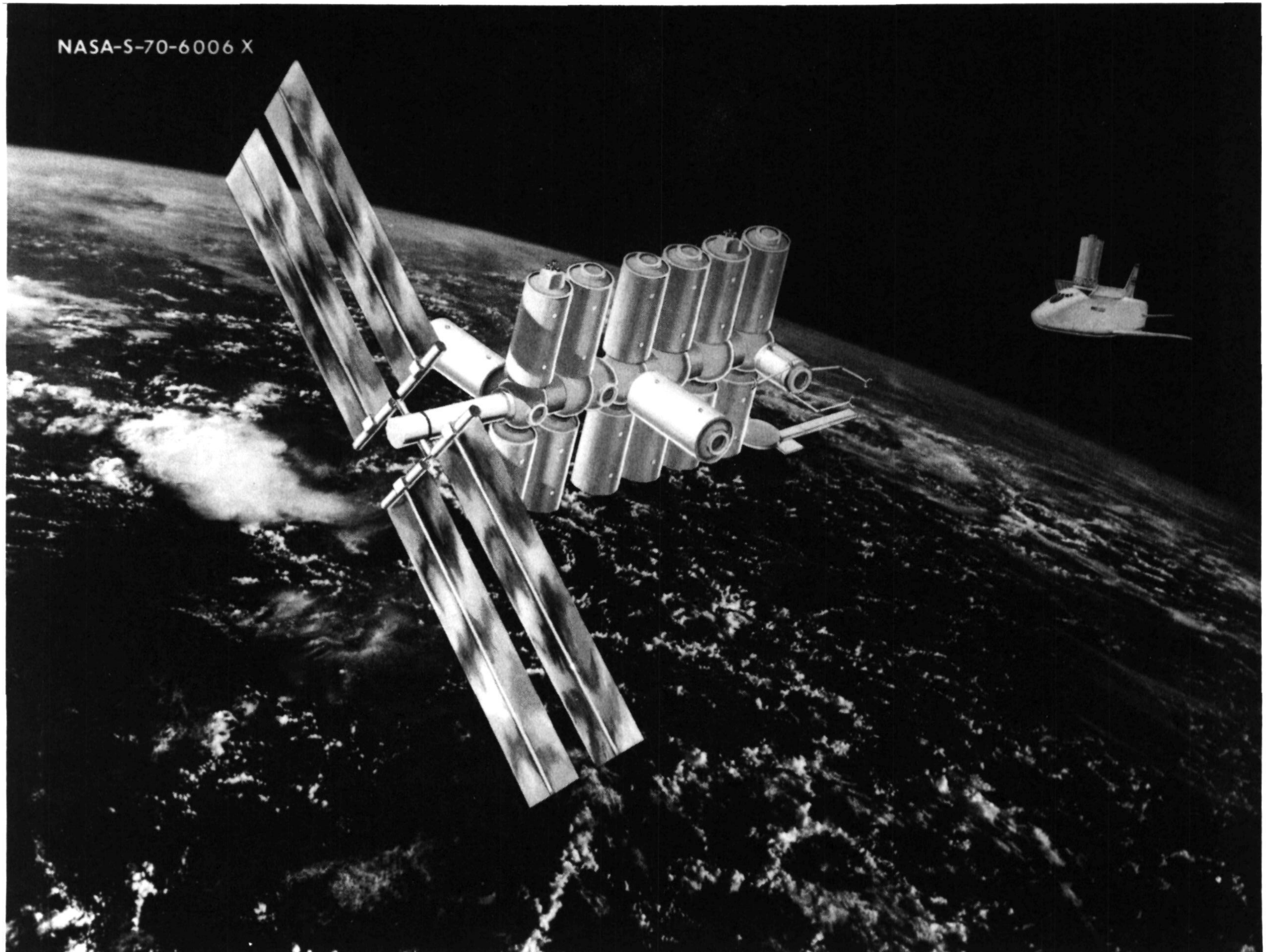


Figure 1.2-2 SHUTTLE-LAUNCHED SPACE STATION (1970 STUDY)

Beginning in 1971, the Soviet Union launched the first of six 20-ton Salyut space stations, culminating in 1979 in a two-man crew's continuous 175-day stay in Salyut 6, shown in figure 1.2-3. The Salyut space station is visited periodically by manned Soyuz spacecraft and unmanned Progress spacecraft with 5,000 lbs. of supplies. Both spacecraft have the capability of automatic, unmanned docking, and can resupply propellants across the docking interface. A Soyuz always remains docked to the station in the event that some emergency were to require immediate return to Earth. The crew performed several operational procedures, such as modular equipment replacement for station maintenance and the attachment of a 10m radiotelescope to the exterior of the station. In addition, the station contains several experiments, including multispectral earth resource survey cameras, materials processing furnaces, a liquid helium-cooled infrared telescope, a gamma ray telescope, a long-duration exposure platform, and onboard medical experiments. It is interesting to note a November 1978 quote by Leonid Brezhnev which states, "We believe that permanently-manned space stations with interchangeable crews will be mankind's pathway into the universe."

Most previous NASA studies of space station have been applications and experiment-oriented in their requirements. Consequently, the large "shopping lists" of candidate experiments had a major influence on design requirements, many of which ended up being in conflict with each other. Some experiments wanted to look one way, while others wanted to look another way. Some applications wanted very low gravity, while other liked some artificial gravity. There were also conflicts in altitude and inclination and other operational parameters. The resulting design concepts were complicated, and data handling and transmission requirements associated with the experiments were extremely high, as were estimated system costs. Consequently, space station studies never progressed past a "Phase B" stage.

As the Shuttle approaches operational status, concepts for long-duration experiments and applications are changing from "onboard" to "free-flying" with periodic services provided by the Shuttle.

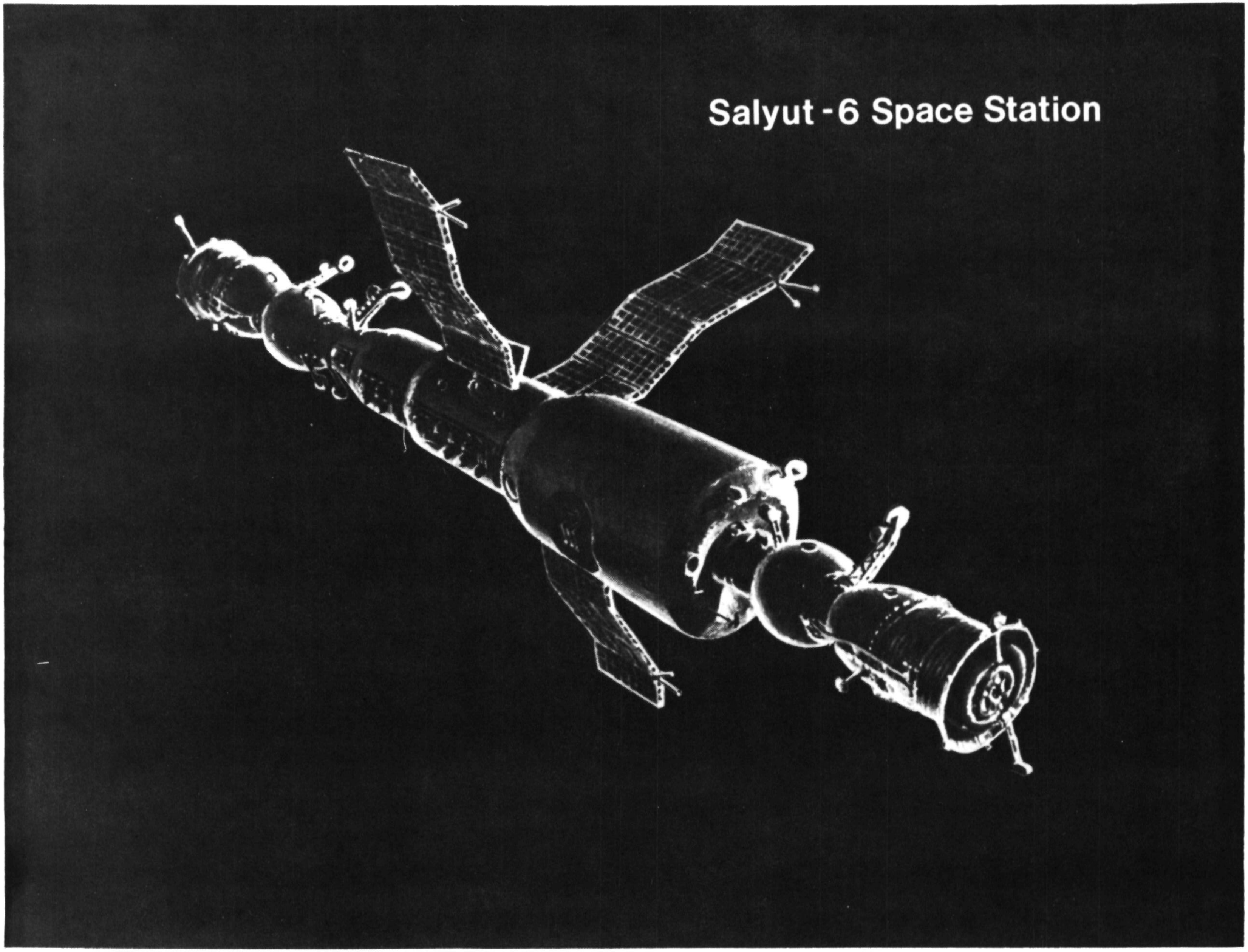


Figure 1.2-3 SALYUT SPACE STATION

In addition, studies of advanced space system requirements are showing a future need for large systems of a size that must be constructed in some fashion in space. There are places in space that it will be in the interests of this country to maintain an operational presence, -- polar orbit, some special inclined orbits of various heights, and especially geosynchronous equatorial orbit. The objectives for a permanent manned facility in this study have been formulated to meet this change in thinking.

1.3 OBJECTIVES OF A PERMANENT MANNED LEO FACILITY

If the assumption holds true that the next 10 to 20 years will include requirements for large, complex space systems, and that geosynchronous orbit is clearly a primary operational arena in space in the coming decades, the space construction and servicing of these future systems will be more effective with a permanent, manned operations center in space; i.e., a Space Operations Center (SOC).

The primary objectives of a SOC are as follows:

- The construction, checkout, and transfer to operational orbit of large, complex space systems.
- On-orbit assembly, launch, recovery, and servicing of manned and unmanned spacecraft.
- Tending of co-orbiting free-flying satellites.
- Further development of the capability for permanent manned operations in space with reduced dependence on Earth for control and resupply.

This list noticeably does not include onboard science and applications objectives, although the free-flying satellites which would be serviced would include mostly those of this genre. The primary implication of this omission is that experiment and applications requirements will not be design drivers; the SOC will be "optimized" to support the operational functions of the objectives. However, experiments or applications which can tolerate the operational parameters of the SOC can be operated onboard, or an entire dedicated module could be attached to an available berthing port. The objectives of a SOC are amplified in the following paragraphs:

Space Construction

The Shuttle will be used in the 1980's for initial space construction development and the actual construction of certain operational systems. However, current studies indicate that the capability of the Shuttle to support the construction of some of the large and complex space systems under consideration is inadequate in several respects (configuration, stay time, crew size, electrical power, etc.). As shown in figure 1.3-1, such future systems could include large power modules with solar arrays in the 200-500 kW range, communications platforms with areas as large as $4000m^2$, and high-resolution parabolic antennas with diameters of 100m or more. A permanent construction facility in space could be utilized more effectively. A SOC would support the flight development of the construction equipment and operational techniques begun with the Shuttle, and would then implement them to construct, check out, and transfer to operational orbit the large space systems required in the late 1980's and 1990's.

On-Orbit Assembly, Launch, Recovery, and Servicing

The availability of the capability to fly manned and unmanned missions to GEO is an inherent requirement in the concept of constructing, checking out, transporting, and servicing large space systems in orbit. The use of GEO is already increasing rapidly, and many potential systems being studied will operate and must be serviced and maintained there. A reusable manned orbit transfer vehicle (MOTV) will ultimately be required to perform the required services.

A single Shuttle mission can deliver a 5000 lb. payload to GEO using an interim upper stage (IUS). The assembly of two or more stages together in orbit to form a multistage vehicle too heavy for a single Shuttle launch opens up the possibility of large payloads to GEO and/or higher energy deep space missions. Studies have shown the design feasibility of assembling separately-launched stages using the Orbiter as an assembly base; however, the operational aspects appear formidable. On-orbit basing of a stage assembly capability allows not only considerable operational advantage, but also offers the economy of recovery and space servicing of reusable stages, for both unmanned vehicles and MOTV's. In addition,

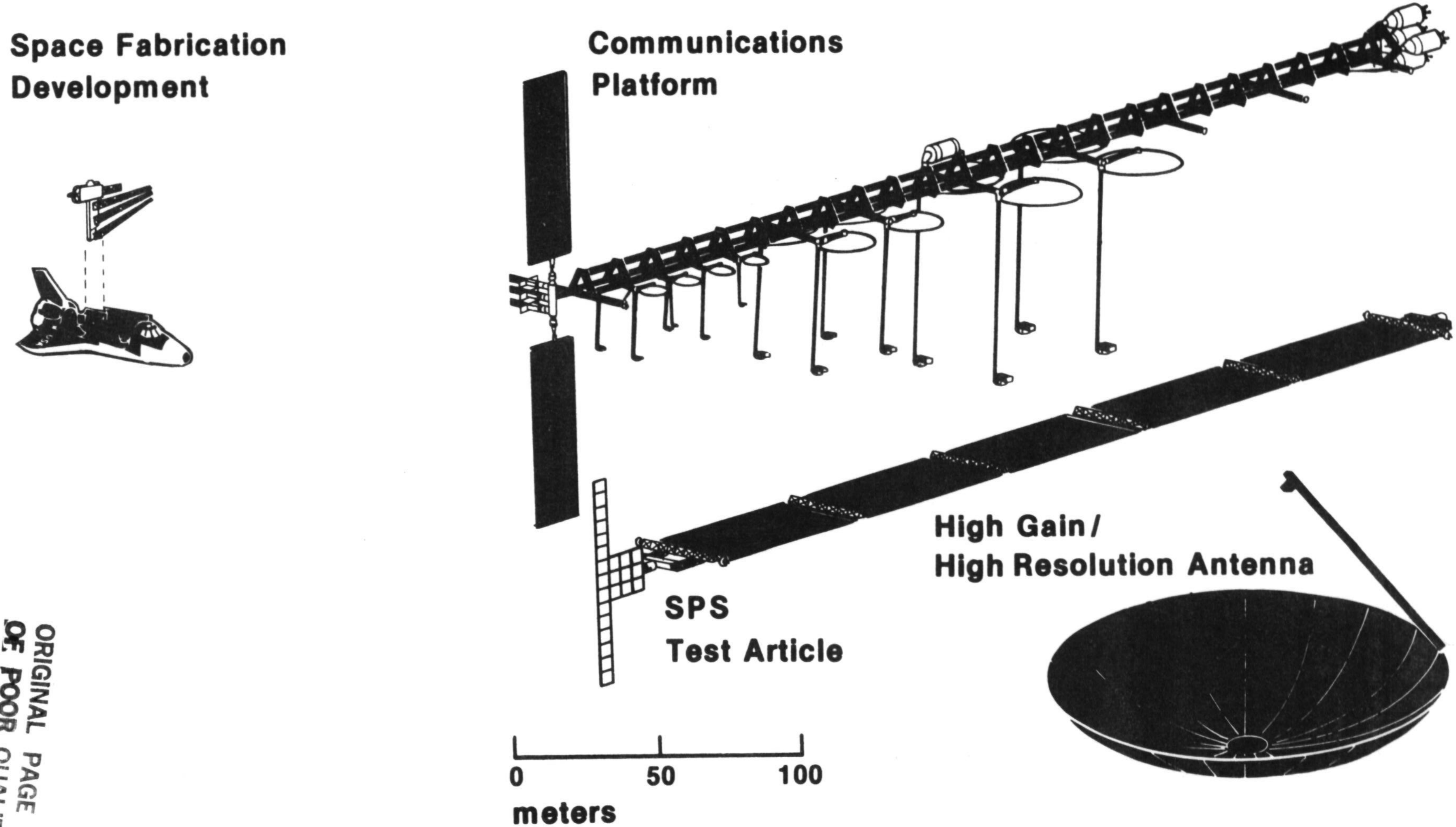


Figure 1.3-1 TYPICAL SPACE CONSTRUCTION PROJECTS

a permanent facility in orbit has, with proper orbit phasing, the potential for rendezvous and recovery of planetary sample return payloads for quarantine in orbit before risking delivery to Earth.

Tending Free-Flying Satellites

Some space operations, such as space construction, require crew participation almost continuously for best results. Others, such as routine data collection, function satisfactorily without crew intervention. An additional class of operations actually functions best without the disturbance of human presence, but does require periodic servicing, adjustment, fault detection, repair, etc., that can be managed better by a human than by an automated machine. This class includes, among others, such operations as materials processing, which requires extended periods of extremely low acceleration, and a large space telescope, which does not tolerate well the contaimination associated with a nearby crew, but may need frequent film and instrument replacement, calibration, etc.

The SOC concept operates satellites of this kind in a co-orbiting mode at whatever separation distance may be required, with recall command, rendezvous, and berthing to the SOC for servicing when necessary. The capability required for tending co-orbiting satellites is very similar to that required to support an orbit transfer vehicle. This capability includes provisions for berthing facilities for payloads the size of the Orbiter bay, access to the interior and exterior of the serviced vehicle, rendezvous and berthing remotely controlled from the SOC, and servicing and repair facilities.

Space Operations With Reduced Dependence on Earth

A SOC should have the general objective of the development of the capabilities required to provide permanent manned operations in space with reduced dependence on Earth for frequent resupply and for day-to-day control of operations. The reduced dependence on supplies from Earth has a significant influence on design requirements for electrical power generation and storage, recycling atmosphere and water, onboard health maintenance, and the configuration layout associated with comprehensive emergency considerations, which in turn involves a high degree of redundancy both in systems and living quarters.

The present mission management and control process is characterized by a people-intensive ground monitoring and control operation involving large supporting ground information and control facilities and a highly-integrated ground-flight crew operation. In order to reduce dependence on Earth monitoring and control, the SOC would have to provide for increased systems monitoring; fault isolation and failure analysis, and the ability to store and call up extensive sets of data to support the onboard control of the vehicle; and the onboard capability for daily mission and other activity planning.

1.4 SOC CONCEPT DESCRIPTION

The SOC (figure 1.4-1) is a self-contained orbital facility built up of several Shuttle-launched modules. With resupply, on-orbit refurbishment and orbit maintenance, it is capable of continuous operation for an indefinite period. In the nominal operational mode, the SOC is manned continuously, but unmanned operation is possible.

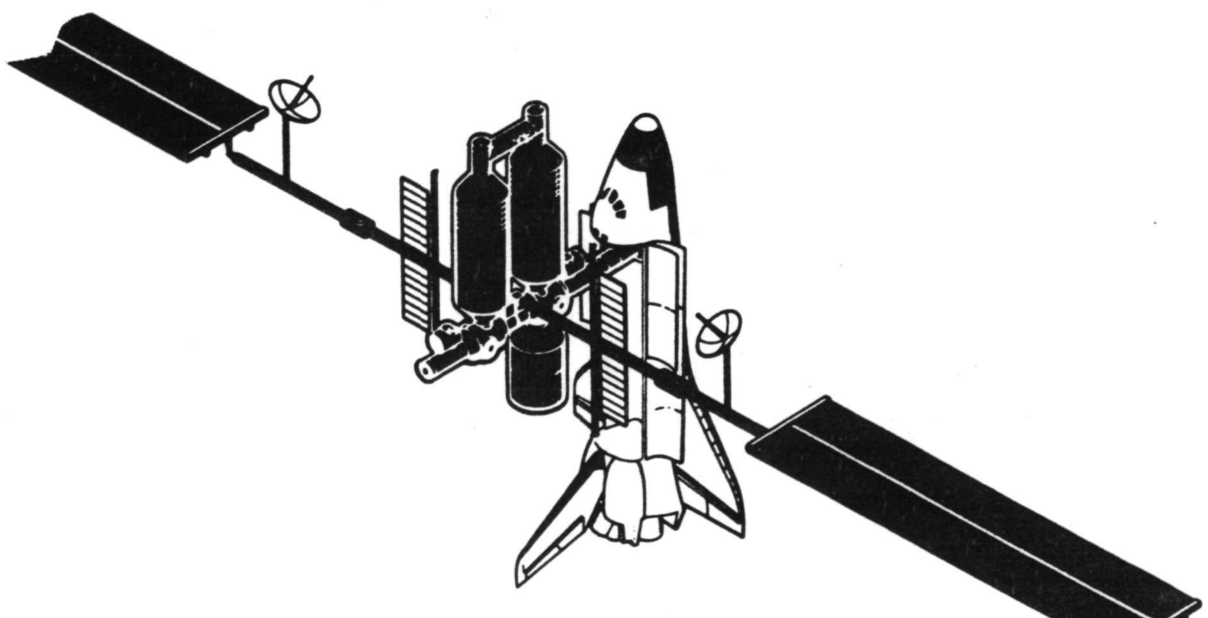


Figure 1.4-1. SPACE OPERATIONS CENTER

Safety of both the SOC and its crew is a major consideration. Subsystem and module redundancy is such that in the event of any credible failure, including the functional loss of an entire module, the SOC can sustain itself and its crew for 90 days without assistance. The continuous presence of a Shuttle is not required.

The core elements of the SOC are arranged as shown in figure 1.4-2. Two identical service module halves form a central spine with multiple docking/berthing ports for the Orbiter and for the other modules. The service module provides electrical power, generated by two large solar arrays on long booms; guidance, control and stabilization; reaction control; communications; and airlocks for EVA. With two independent but interconnected sections, the necessary redundancy of critical systems is readily achieved.

Two habitation modules are berthed to the service module. Each habitation module contains a command center capable of controlling the entire SOC; private quarters for a crew of four; food preparation, hygiene and waste management facilities; and exercise and recreation equipment. In addition, one module includes a health maintenance facility and the other module a small laboratory. The arrangement of space within the habitation modules will be governed by various factors that have not yet been adequately defined; a typical layout, but not necessarily the final one, is illustrated in figure 1.4-3.

The health maintenance facility in the first habitation module is more than a conventional sick bay. Its primary function is treatment of minor illnesses and injuries, including facilities for x-ray and minor surgical procedures. Secondarily, the health maintenance facility provides extensive monitoring of crew health and body functions. The data obtained will be used both for current observation of crew condition and as a basis for a better understanding of the physiology of living and working in space.

The two habitation modules are joined at the "top" by a tunnel to provide two means of egress from each module in case of an emergency. The tunnel also contains Shuttle docking ports as alternates to the primary docking position at the end of the service module.

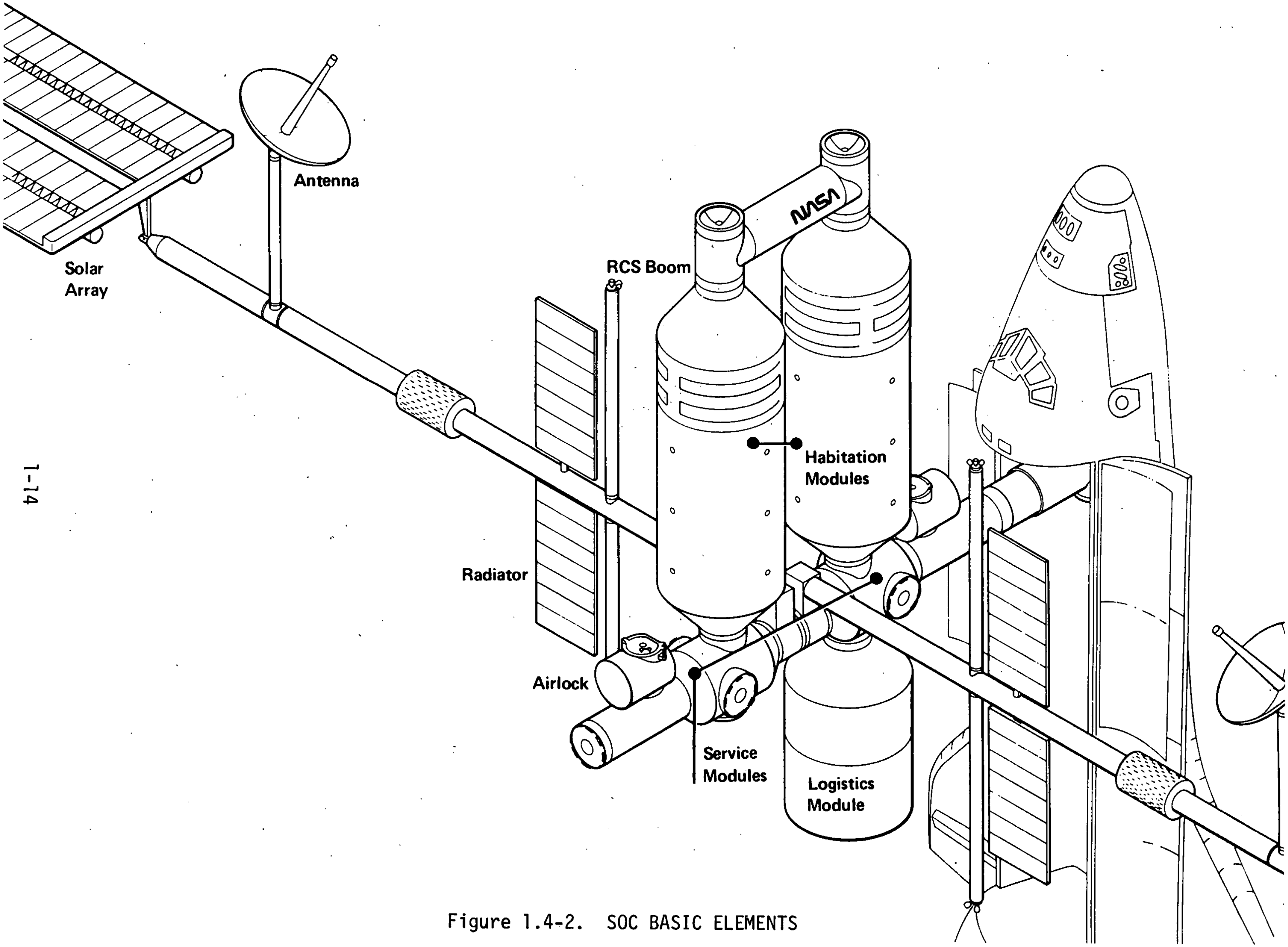


Figure 1.4-2. SOC BASIC ELEMENTS

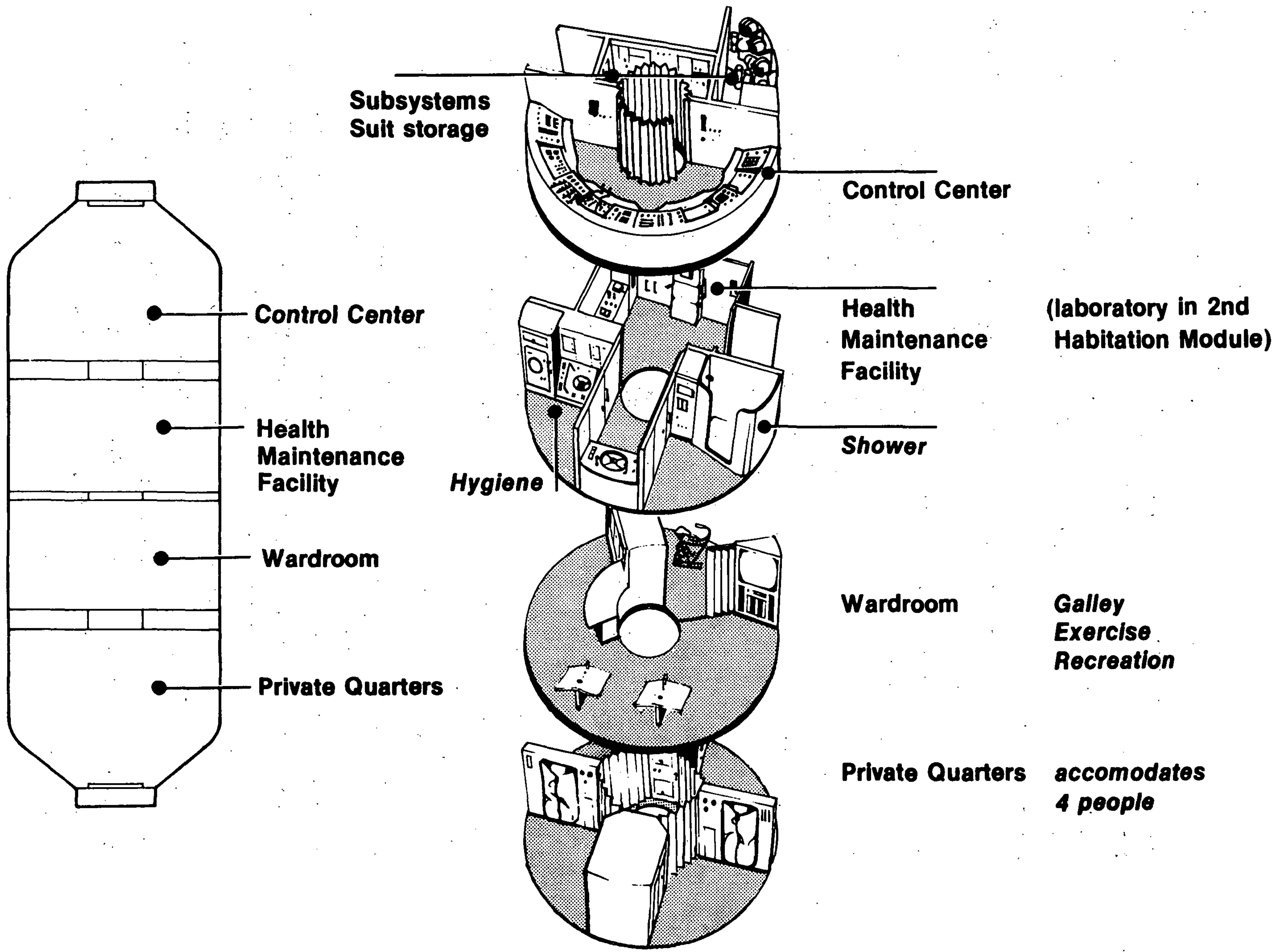


Figure 1.4-3. HABITATION MODULE

A logistics module is normally berthed to the service module. It serves as a storeroom for consumables and spare parts and is exchanged for another identical module during resupply visits by the Shuttle. This procedure avoids large-scale manual transfer of cargo. Emergency stores are maintained in the service and habitation modules at all times in case access to the logistics module is lost.

In order to minimize development costs, available subsystem technology was used where possible. Accordingly, SOC subsystems draw heavily on Skylab, Shuttle and Power Extension Package hardware. This does not in any way negate the role of the SOC as a test bed for future subsystem development; new subsystems can be added as they become available.

A logical exception to this approach is the Environmental Control and Life Support System (ECLSS). In most previous programs (except Skylab) fuel cells have provided both electrical power and water. Since the SOC uses solar cells for power, water must be either resupplied or reclaimed. Reclamation of both water and oxygen was selected to avoid very large resupply requirements. A simplified schematic of the system chosen is shown in figure 1.4-4. The only resupplied consumables are food and hydrazine; the latter is dissociated to make up both atmospheric nitrogen leakage and the hydrogen requirement of the Sabatier reactor which reduces the carbon dioxide exhaled by the crew. Hydrazine is also used as a monopropellant in the reaction control system to further simplify resupply requirements.

The regenerative ECLSS has been the subject of an extensive development effort for several years, including over 1700 hours of tests on a first generation system and several second generation subsystems. Work now scheduled includes delivery of the remaining second generation hardware and completion of prototype testing, both subsystem and integrated system, by late 1980. Subsequent planned effort will modify the system as necessary and culminate in manned system tests in a 20-ft vacuum chamber.

The communications and tracking system also represents a significant increase over previous space system capabilities. The difference in this case, however, is primarily the number and diversity of communications links (figure 1.4-5); hardware requirements can be satisfied by Orbiter-type equipment in most cases.

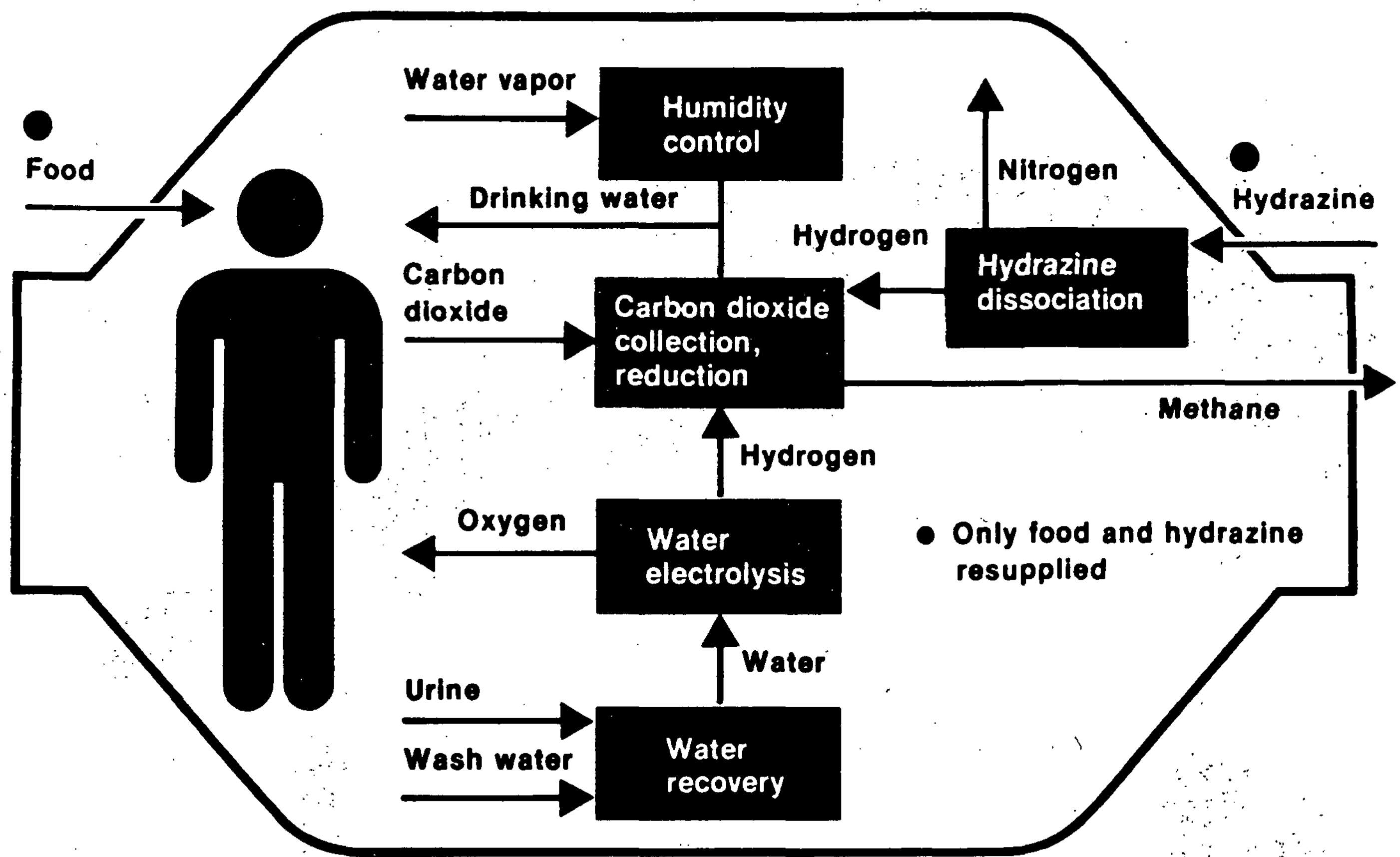


Figure 1.4-4. REGENERATIVE LIFE SUPPORT SYSTEM

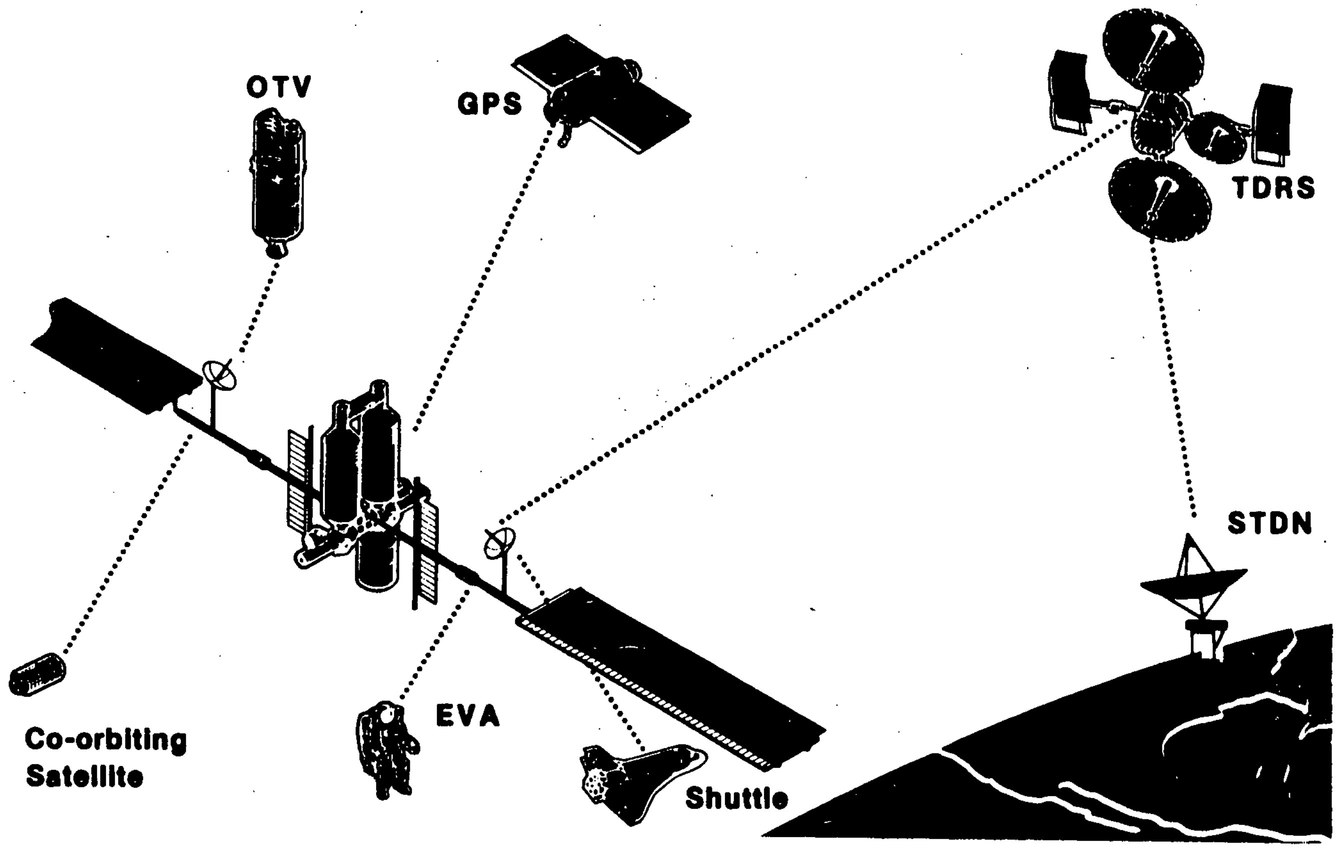


Figure 1.4-5. SOC COMMUNICATIONS

1.5 SOC SPACE OPERATIONS FACILITIES DESCRIPTION

To meet the objectives of the SOC, two major facilities are required in addition to the service, habitation and logistics modules. These are a construction facility and a flight support facility. The general arrangement is illustrated in figure 1.5-1. In addition to the two basic facilities, a control cab and Shuttle-type manipulator on a movable boom serve both operations.

1.5.1 Space Construction Facility

The primary function of the construction facility is the fabrication of large space systems. The capabilities required include fabrication and assembly of large structures; installation, integration and checkout of subsystems; and separation and launch of the completed system to its operational orbit.

The principal elements of the facility are a beam builder and a holding fixture. The beam builder fabricates, from flat stock, triangular truss beams in any desired length. The beams are joined as required to form various structural configurations. The holding fixture serves to hold the fabricated beams in the correct relationship and to position the beam builder as required to produce additional beams in the locations desired. The holding fixture also moves the structure lengthwise to allow secondary structure and subsystems installation to be carried out at a fixed work site. Since the holding fixture design depends on the article being constructed, the fixture must be replaced or reconfigured when a different structure is to be fabricated.

Subsystem installation is carried out by the manipulator or by suitable provisions on the holding fixture, as appropriate. In figure 1.5-2, for example, a solar cell blanket is being dispensed from a container attached to the holding fixture. EVA will also be required in many cases to provide the needed dexterity; most operations will not be repeated often enough to make automation worthwhile.

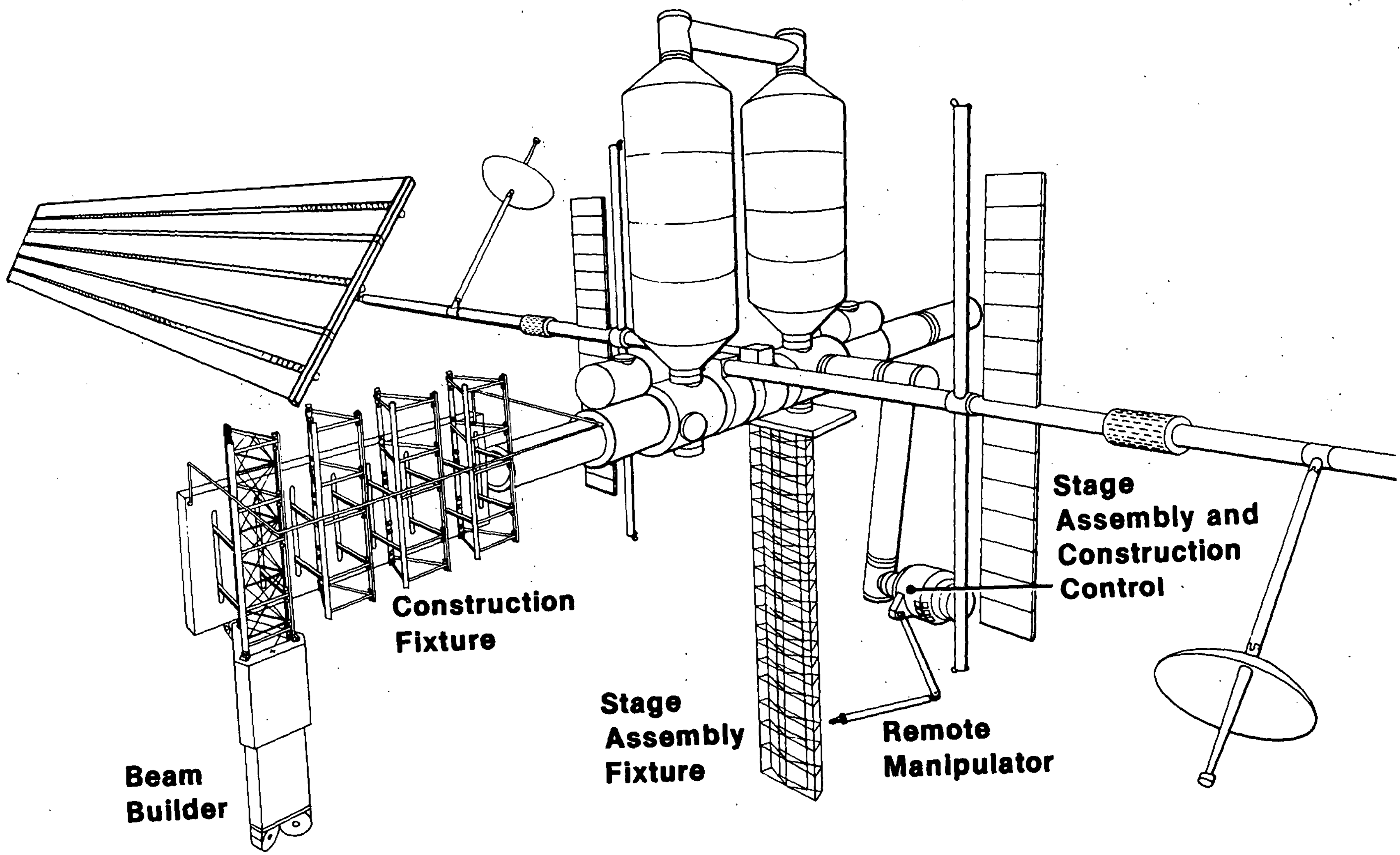


Figure 1.5-1. SOC OPERATIONS FACILITIES

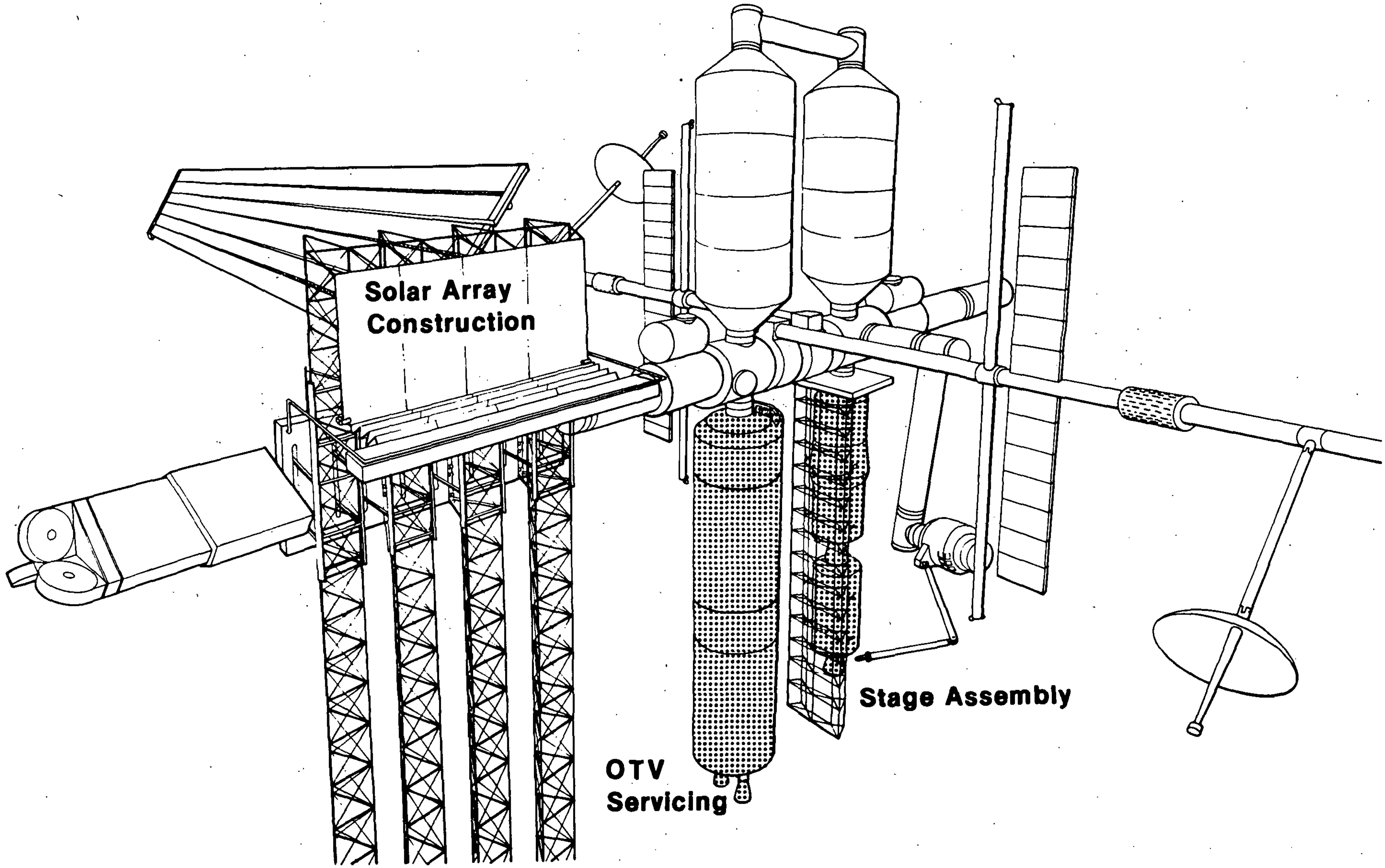


Figure 1.5-2. CONSTRUCTION AND FLIGHT SUPPORT OPERATIONS

1.5.2 Flight Support Facility

The flight support facility performs three distinct functions: assembly, checkout and launch of multi-stage solid rocket vehicles; assembly, checkout, fueling, launch and recovery of the MOTV; and recovery and servicing of co-orbiting satellites.

The principal element of the solid stage assembly facility is a strongback berthed to one of the service module ports (figure 1.5-2). As the stages and payloads are delivered by the Shuttle, they are placed on the strongback by the SOC manipulator. When all stages have been delivered, mechanisms on the strongback mate the stages and payload to complete the assembly. The vehicle is then checked out. For launch, a tilt table rotates the vehicle away from the strongback and separates it from the SOC. The vehicle then moves to a safe distance prior to final orientation and engine ignition.

The MOTV is a two stage, reusable, manned vehicle for sortie missions to geosynchronous orbit. Between missions, it is stored at one of the service module lower docking ports (figure 1.5-2). Prior to launch, it is fueled from the Shuttle, using propellant transfer equipment on the SOC. For launch, the MOTV separates from the docking port and moves to a safe distance from the SOC before engine ignition. The first stage returns to the SOC before the second stage and is stored temporarily on the stage assembly strongback. After completion of the mission, the second stage and crew module returns to the SOC and either docks or is berthed by the manipulator to its port on the service module. The first stage is mated to the second using the manipulator, and the vehicle is then checked out in preparation for the next mission.

Co-orbiting satellites are serviced by the same facilities. If pressurized access to the interior is required, either the MOTV or the Shuttle docking port can be used, depending on availability.

1.6 DEVELOPMENT CONSIDERATIONS

A number of the elements of a Space Operations Center have functional relationships in common with elements planned for use with the Shuttle. For example, a SOC service module has certain functional similarities with the 25 kW power module currently planned to provide support services for science and applications free-flying platforms and other payloads. Even though general appearances would indicate significant differences in the two elements, such as the SOC service module's requirement for pressurization, they are functionally alike in many ways even though the quantitative values of most of the requirements are different. For instance, both require solar panels for electrical power, radiators, an attitude control system, a communication system, and docking ports. While it probably would not be cost-effective to force all the SOC design requirements on the 25 kW power module in order to have common use, it might be worthwhile to have power module design requirements which would allow for the subsequent accommodation of SOC requirements.

A large part of the SOC construction facility elements are already being developed for use with Shuttle payloads or are included in technology development programs. These elements include the Shuttle remote manipulator, beam builder, and construction fixtures. Mechanisms and operations for on-orbit assembly of IUS solid stages for an early Shuttle mission could also be components of an orbiting assembly and servicing facility which might be used by the Shuttle prior to the assembly of a SOC. The early consideration of SOC requirements in the development of various hardware elements for use with the Shuttle can maximize the evolutionary development of both SOC functional equipment and operational processes. Conceptually, proper planning and requirements definition for equipment for use in Shuttle utilization projects could produce elements which, with modifications, could be integrated with habitation modules to achieve a permanent, manned SOC. Even if components proved to not have high commonality, the development would still have evolutionary advantages for similar elements ultimately required for a SOC.

1.7 PROGRAMMATIC CONSIDERATIONS

Figure 1.7-1 shows estimated schedule requirements by "program year" for developing a SOC. The buildup shown in the schedule has the service and habitation modules being launched in the 8th and 9th program years, after which time the capability would exist to support a crew of 8 for extended periods of time without continuous attendance by the Shuttle. The flight support and space construction facilities would be added a year later. A significant point is that, if one were to assume that year 1 is 1979 and funded system analysis were to begin in 1980, the total SOC capability would not be achieved until 1988. This indicates a need for early initiation of at least the first phases of work on this concept. Needless to say, there could be many variations in the buildup strategy of such a program including early operational use of one habitation module manned only when the Shuttle is docked to it.

Table 1.7-1 shows estimated costs by program year for the development schedule shown in figure 1.7-1. The totals show estimates on the order of $2.1 billion for the permanently habitable 8-person "core" configuration, and $2.7 billion for the operational SOC with the construction and flight support facilities. These estimates do not include the cost of approximately 10 Shuttle launches needed to launch and supply the SOC during the two years required for its assembly, nor the cost of any materials which would be required for projects to be constructed. The first service module would cost about $700 million including DDT&E and the second about $250 million, or about a billion dollars for both. The two habitation modules are also estimated at about a billion dollars with the first one costing about $800 million including development costs. The flight support and construction facilities are estimated at about $300 million each, but it should be noted that these facilities are less understood and defined than the service and habitation modules, and, consequently, there is less confidence in their estimates. The peak funding required for any one year is about $800 million in the 7th year.

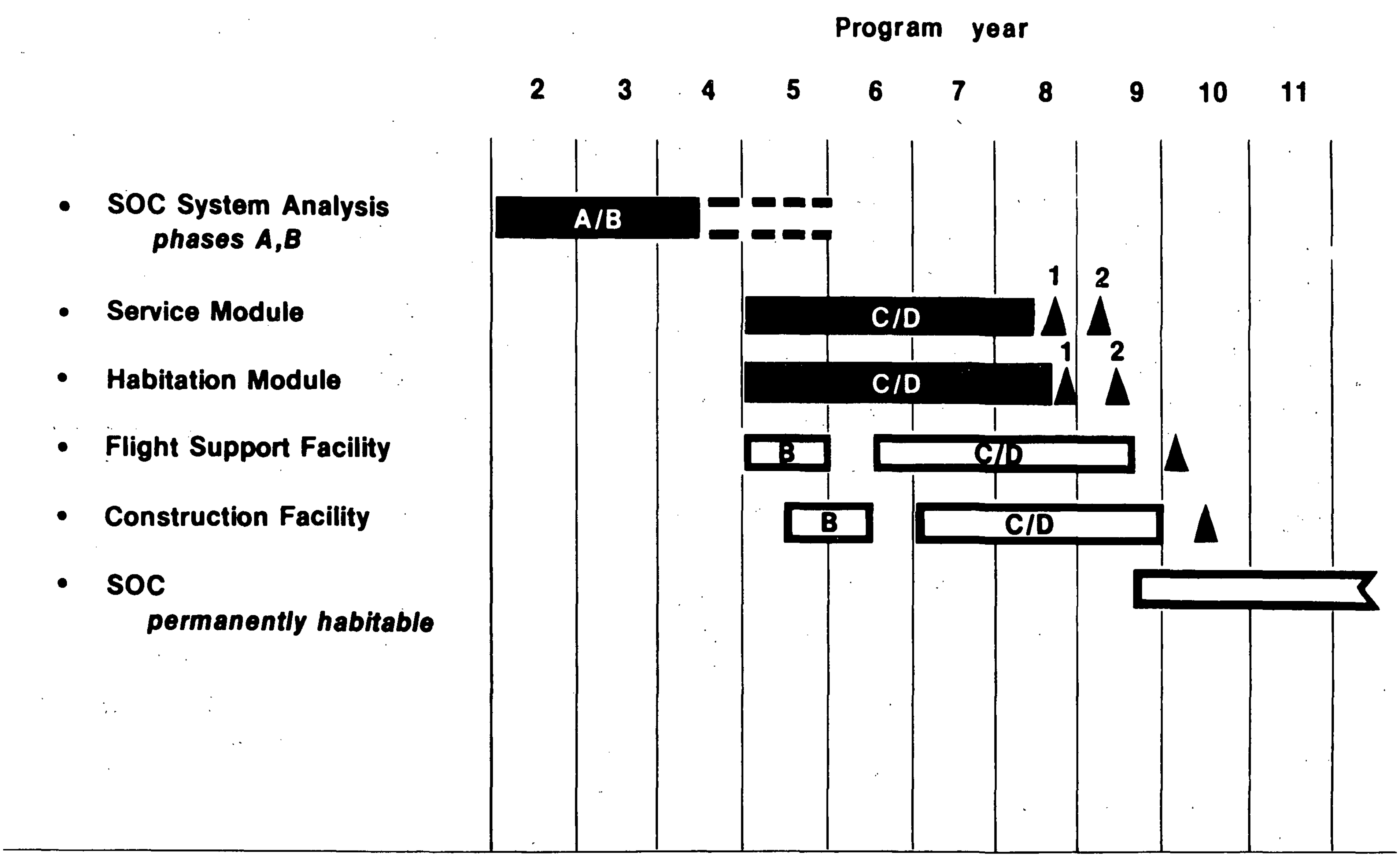


Figure 1.7-1 ESTIMATED DEVELOPMENT SCHEDULE BY PROGRAM YEAR

Table 1.7-1 COST ESTIMATES - $ MILLION BY PROGRAM YEAR

	Program year										
	2	3	4	5	6	7	8	9	10	11	
SOC System Analysis, Phases A,B	(.3)	2	10								12
Service Module											
1				109	191	241	137	50			728
2				28	62	65	46	47			248
Habitation Module											
1				117	238	264	129	36			784
2				21	55	67	39	8			190
Logistcs Module											
1				8	17	38	29	12			104
2					4	13	7	10			34
Subtotal											2100
Flight Support Facility				11	28	63	80	49	43		274
Construction Facility				10	28	63	91	73	61		326
Total	(.3)	2	10	304	623	814	558	285	104		2700
Number of Shuttle Launches							2	4	4		

1.8 CONCLUSIONS

The most reasonable next step in the evolution of manned space flight should soon be identified as a goal after Shuttle. The results of this study indicate that the Space Operations Center concept is a likely candidate for that goal since it appears to have a desirable combination of need, usefulness, scope, evolutionary development, and funding requirements. Further analysis of this concept should be made to substantiate this conclusion and, if still appropriate, consideration should be given to continuing or initiating those long lead-time technology areas which would support future implementation of the concept. In addition, the concept should be used as a focus for other current or planned projects which, with compatible requirements, could contribute to the evolution of the SOC and its operations. In a more general way, it would be desirable for future studies of geosynchronous and deep space missions to consider the implications of the potential availability of flight support facilities in low earth orbit.

2.0 INTRODUCTION

The Apollo Program established an extensive technological and operational base for manned space activities. The Skylab Program capitalized on the use of Apollo hardware to assess man's ability to live and work in space for long periods of time. The objective of the current Shuttle Program is to develop a low cost, partially reusable transportation system to go to and return from low earth orbit. The Shuttle will be used for transporting payloads, providing manned support for experiments, servicing and/or retrieval of free-flying satellites, the development of space construction techniques, and for the initial on-orbit assembly of certain deep space vehicles.

It is believed timely to identify the goal which would represent a logical next step in the evolution of manned space flight. Several factors indicate the timeliness of such an action. The shuttle is approaching operational status with initial flights scheduled for 1980; a continuity of research and development is necessary to maintain the U.S. leadership in manned space activities; significant advances in space activities inherently require long gestation and development periods; certain space applications now being identified will require manned operations beyond the capability of Shuttle transportation systems; a continuing program of technology development is much more effective if it has a long range focus; Shuttle operational developments will be enhanced if compatible with a longer term goal; and a goal is needed to maintain enthusiasm of the present participants in the space program and also to maintain the interest of future participants in our manned space program.

In relation to maintaining U.S. leadership in space it is constructive to look at the recent activities of the USSR. Beginning in 1971 that country has launched successfully six twenty-ton Salyut space stations. The Salyut-6 Space Station as of May 1979 had been successfully revisited seven times with the manned Soyuz spacecraft and six times with unmanned Progress supply spacecraft. Each of the latter carrying 5,000 lbs of cargo. The Soviets have also successfully completed missions lasting as much as 170 days with a crew of two and longer missions are predicted for the near future.

In order to stimulate interest in the identification of a next goal, a preliminary study was conducted at the Johnson Space Center during 1979. The objectives of the study were to consider possible goals in space, select the one which appeared most desirable, and develop a technical concept and framework for further study.

The Space Operations Center was selected as a candidate for the next goal in manned space flight. The Space Operations Center is a shuttle-serviced, permanent manned facility in near space to be used for operational support of space activities in the late 1980's and 1990's.

The present report documents the result of the preliminary study. It includes a discussion of the rationale for selecting the Space Operations Center concept, program objectives, a preliminary system and subsystem analysis, identification of key technical problems and limited programmatic information.

3.0 PROGRAM RATIONALE

What are the alternatives for a next goal? The utilization of Shuttle capabilities only might constitute such a goal, and it is not an insignificant one. The Shuttle will have considerable capabilities and it is certainly appropriate to exploit them and it is intended that such be done. Such a limited goal however, would not meet many of the objectives stated earlier. A permanent manned facility in low earth orbit is a second option. A more extensive option would involve a manned geosynchronous sortie capability, and a still more extensive capability would involve a permanent manned facility in geosynchronous orbit. Considering an even longer range goal, a manned lunar sortie capability or lunar base may be considered. Let us consider each of these options in turn.

The Shuttle utilization will evolve naturally. It requires no major new research and development thrust and it does not provide a clear focus as a future goal. A goal limited to Shuttle utilization may not support a national policy of sustaining leadership in space and it represents less than a desirable pace of advancement. On the other hand a permanent manned geosynchronous facility or lunar base would bypass desirable evolutionary steps of technology and operational development. Consequently the permanent manned facility in low earth orbit and/or a manned geosynchronous sortie capability, both appear to represent reasonable size technical and funding steps and both offer potentially useful applications.

The manned low earth orbit (LEO) facility would provide a form of consolidation of our ability to operate in near space, both from a transportation standpoint and a permanency consideration. On the other hand a manned geosynchronous sortie capability would be a transportation system primarily, with limited capability for operations at geosynchronous orbit. It would in fact be a low earth orbit to geosynchronous orbit shuttle. If we accept the premise that geosynchronous orbit is clearly a primary operational area in space in the coming decade, a permanent manned facility in low earth orbit still appears to be an attractive next step. It provides a more economical location for construction activities pertinent to the geosynchronous program and it also provides a staging base for the enhancement of geosynchronous and deep-space missions. This leads us to identify the objective of a permanent, manned low earth orbit facility. Such a facility would provide a capability for the space construction and checkout of large space structural systems. It would also provide a base from which the techniques necessary for this construction could be developed. The Space Operations Center in low earth orbit would provide a capability for the on-orbit assembly, launch, recovery and servicing of space vehicles. It would also provide the capability for tending co-orbiting free-flying satellites. A more general objective would involve the development of a permanent manned operation capability in space with reduced dependence on earth for control and for resupply. These objectives are discussed further in the following paragraphs.

The Shuttle System will be used in the 1980's to initiate space construction development activities. However, current studies would indicate that the Shuttle configuration and its on-orbit stay time is probably inadequate for the scope of construction projects required in the 90's. Such projects might include large solar arrays for power of the 200 kW range or large platforms for communications whose area might be as much as 4000 square meters, and large antennas for very high resolutions whose sizes might range from a hundred meters in diameter to larger sizes. The on-orbit assembly, launch, recovery, and servicing of space vehicles, has the potential for making higher energy missions and larger payloads possible, thereby effectively enhancing Shuttle performance. Secondly, on-orbit basing of reusable stages offers advantages for certain missions of a repetitive type. On-orbit rendezvous and recovery of planetary return payloads could provide a quarantine of return samples prior to their delivery to earth.

The Space Operations Center would provide a permanent manned operations capability in space with a reduced dependence on earth supply and earth control. Reduced dependence on earth resupply would include consideration of long-term power generation systems; the recycling of air and water; a degree of onboard health maintenance; and comprehensive emergency considerations, which in turn would involve a high degree of redundancy both in systems and in living quarters. In order to reduce dependence on earth monitoring and control the space system would have to provide a capability for increased systems monitoring; fault isolation and failure analysis, and the ability to replace failed equipments; onboard guidance and navigation; the ability to store and call up extensive sets of data to support the onboard control of the vehicle; and would require the onboard capability for mission and activity planning, much of which in the past has been carried out on the ground. The following sections of the report translates these general objectives into more quantitative or specific objectives and guidelines and proceeds to a preliminary system analysis of the concept.

4.0 SPACE OPERATIONS CENTER OBJECTIVES

4.1 SPACE CONSTRUCTION

Many of the space systems planned for the future are so large, massive and/or complex that placement in orbit can be accomplished only by construction in space. A major objective of the SOC will be to develop and implement the capability to perform such construction operations. This objective will be achieved in two broad phases. First, building on ground tests and component-level flight tests, a system-level space construction capability will be developed and verified by the construction on platform-type structures, including installation of subsystems. Following verification, the facility will be expanded and utilized to construct a variety of large operational space systems.

The first functional requirement of the facility is to support the engineering and development of space construction equipment and operational procedures. These include fabrication of members from raw stock, erection of structures from prefabricated components, deployment of preassembled, folded members, and assembly of these members with subsystem components to make up complete space systems. The space construction equipment will include holding and alignment fixtures, beam builders, manipulators, end effectors and remote work stations ("cherry pickers").

The second requirement is the construction of test systems for design verification. Such systems may be typified by the SPS Test Article shown in figure 4.1-1. This is a complete, independent spacecraft approximately 200m long. Its construction involves fabrication of triangular beams; connecting the beams to make a platform; installation of solar arrays, electrical conductors, and other subsystems; erection, installation, alignment and test of the microwave antenna; and installation of electric propulsion modules for orbital transfer. The overall construction sequence, as shown in figure 4.1-2, illustrates the basic concept of a fixed work station through which the work is moved for access. Previous studies have indicated that this approach allows a higher level of automation and crew utilization than the method in which the work is fixed and the crew and equipment move over it during construction.

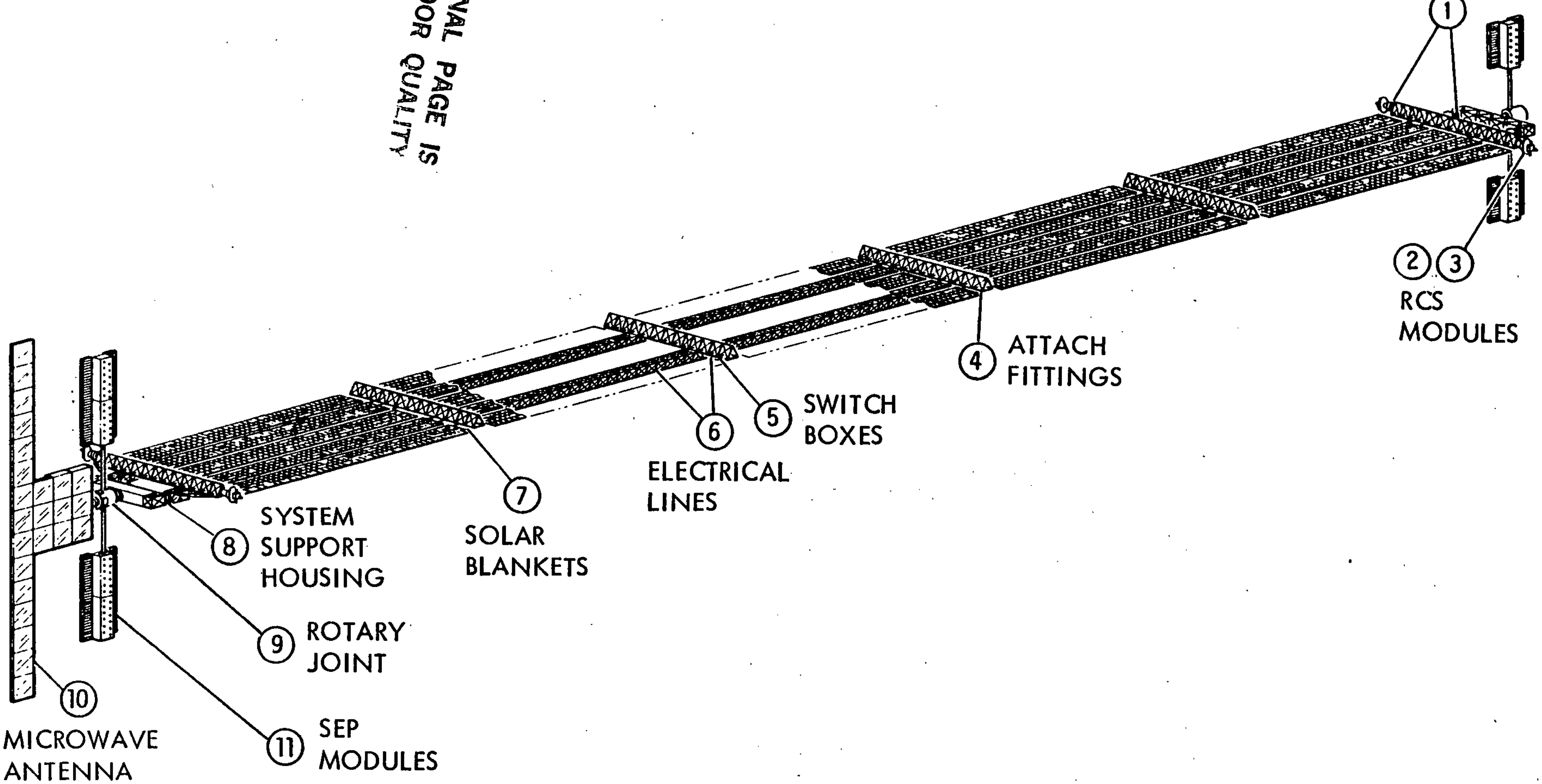


Figure 4.1-1. SPS Test Article Concept

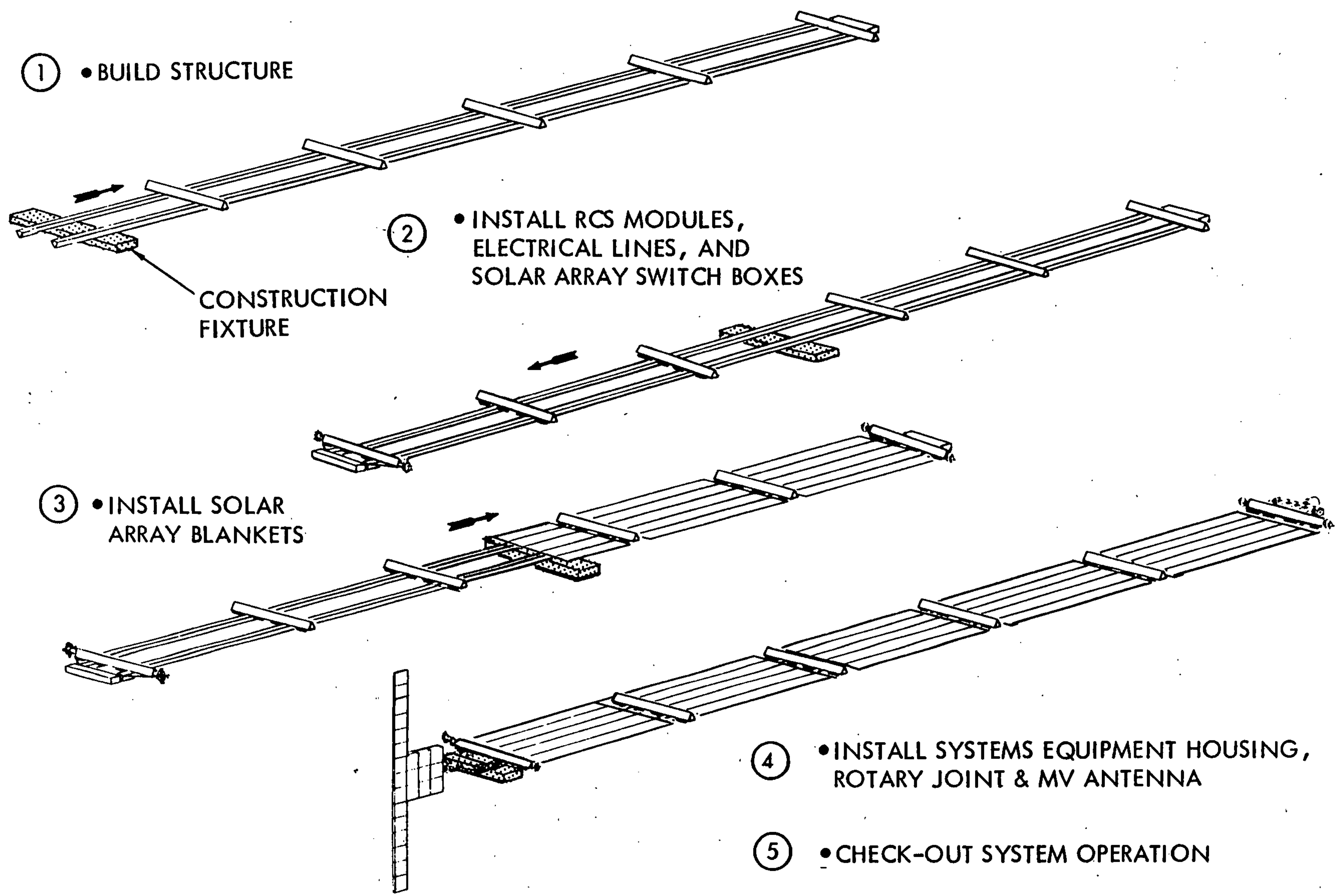


Figure 4.1-2. SPS Test Article Construction Sequence

The third functional requirement is the construction of large operational space systems for various applications, such as the advanced communications platform in figure 4.1-3. This capability differs little in principle from that in the preceding paragraph, but will require larger facilities capable of fabricating more complex structures, including the tri-beam illustrated and curved beams for large dish antennas, and installing larger and more massive subsystem components.

4.2 GEOSTATIONARY ORBIT AND PLANETARY MISSION SUPPORT

The availability of a SOC with the capability to assemble propulsion stages and to provide liquid propellant transfer and expendables greatly enhances the capabilities to operate in the geosynchronous and planetary mission regions, since the payload and dimensional constraints of a single Orbiter are removed and the energy requirements for achieving initial orbit are shifted from the individual mission vehicles to the Orbiter.

Utilization of geosynchronous space is increasing rapidly, and plans envision larger and more complex spacecraft in the future. These vehicles will require space construction, assembly, deployment, checkout and servicing. The accomplishment of these activities is enhanced by man's participation because of the complexity of the tasks and his ability to respond to unforeseen situations in real time. One of the primary limitations on the lifetime of existing geostationary satellites is the depletion of control propellants. Extension of their lifetimes by servicing is a cost effective alternative to replacement. Placing man in this environment will require development of manned orbital transfer vehicles (MOTV) as an extension of the present STS.

Availability of the SOC to serve as a MOTV base for maintenance and servicing widens the spectrum of potential MOTV concepts significantly. The potential for space basing of all MOTV hardware elements uncouples, to a great extent, the MOTV and Shuttle operations.

For purposes of this study, a two common stage, space based, all propulsive MOTV was postulated, so that representative handling, servicing and maintenance systems could be conceptualized. These elements are described in detail in Section 10.0 of this report.

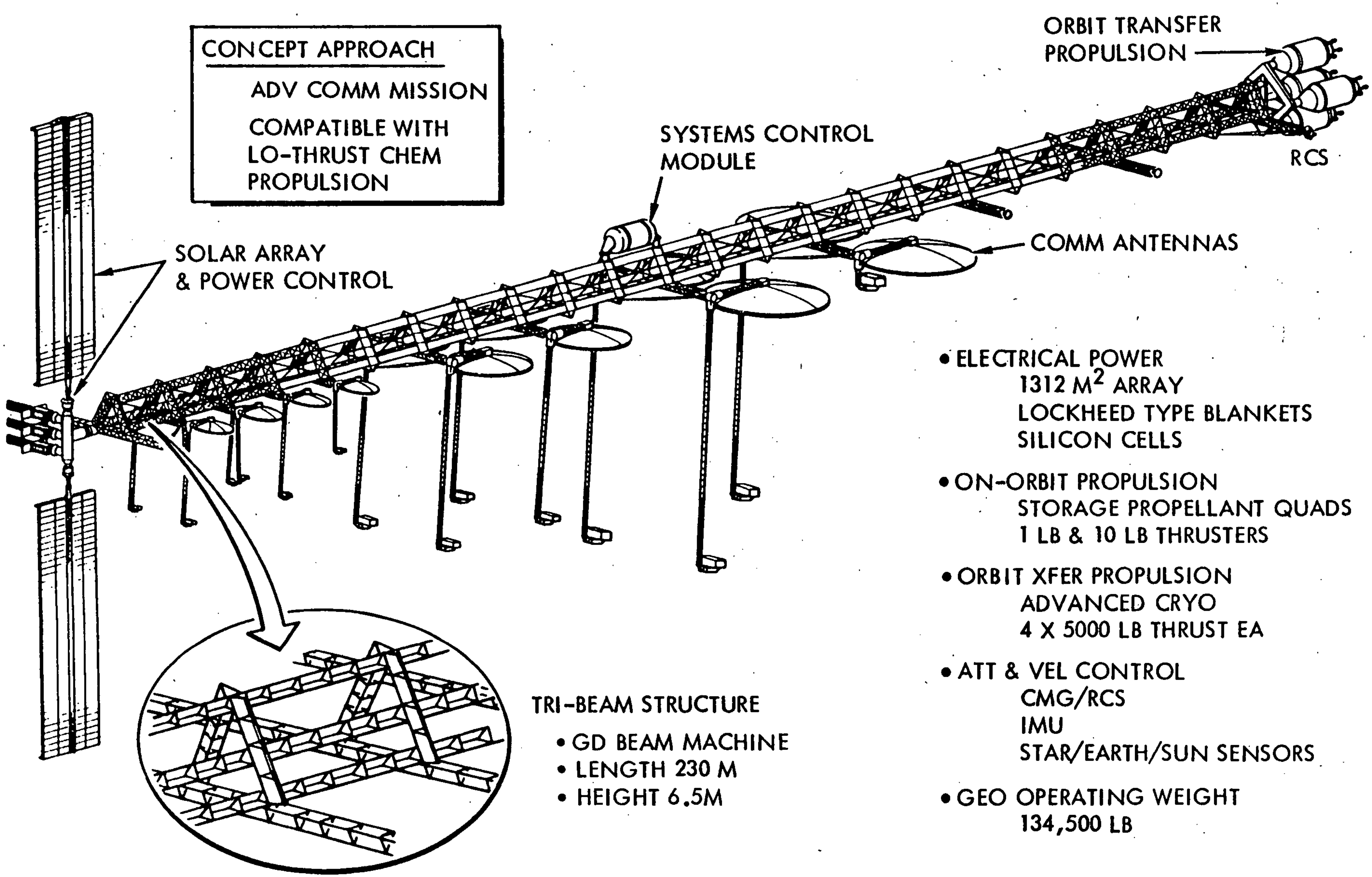


Figure 4.1-3. Communications Platform Concept

Planetary mission support offers the capability, utilizing the SOC, of virtually eliminating the present day payload constraints imposed on planetary spacecraft designs. Utilizing existing and planned propulsion stages such as Centaur, IUS stages and SEPS as building blocks, transportation systems can be tailored to specific missions with capabilities far above the capabilities existent with present ground launched boosters.

Specific functions provided include payload assembly, sample retrieval operations, launch support and orbital checkout. An example of payload assembly is the requirement, in a conceptual direct entry Mars sample return design, of a landing aeroshell decelerator which has larger diameter than Orbiter can accommodate. Assembly of several elements of the shell makes this mission mode a viable candidate for the proposed mission.

The retrieval of planetary samples returned to highly elliptical earth orbits is within the MOTV energy and lifetime capabilities.

Orbital payload checkout offers the opportunity to make a final assessment of spacecraft status after being subjected to the Earth launch environment prior to mission initiation.

Table 4.2-1 tabulates approved and proposed planetary missions through the end of the century, most of which are potential candidates for SOC support.

Figures 4.2-1 and 4.2-2 illustrate several of the potential building blocks which might be utilized in this activity. The graph in Figure 4.3-3 delineates the performance capabilities of several possible planetary propulsion systems.

4.3 FREE-FLYING SCIENCE AND APPLICATIONS SATELLITE TENDING

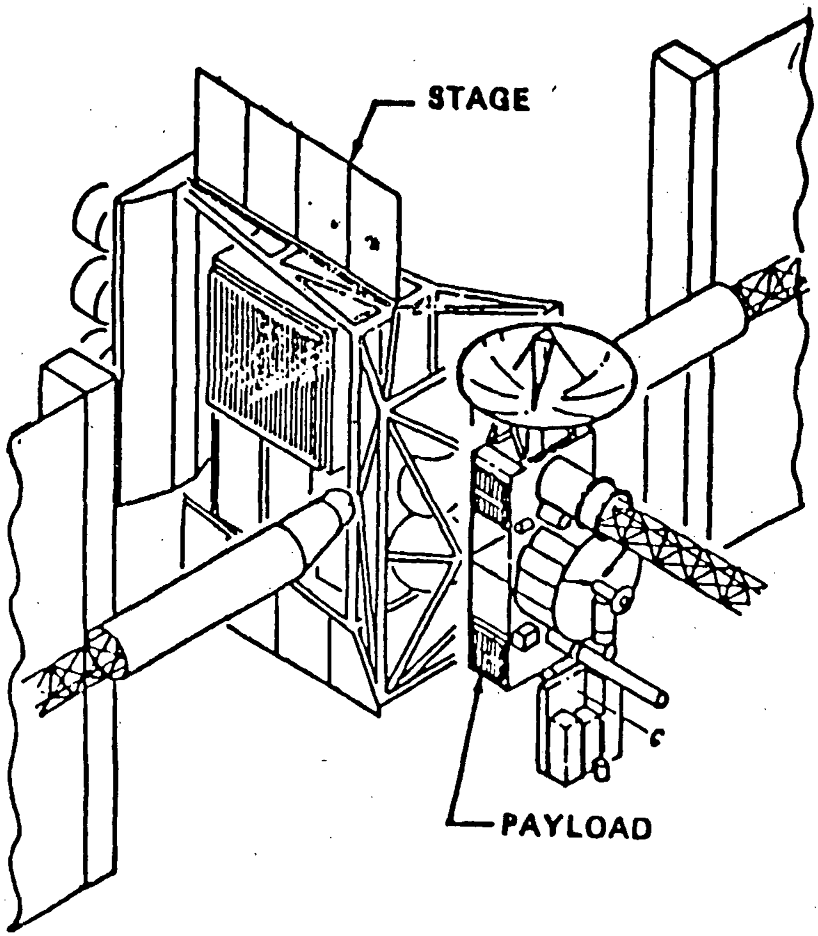
Some space operations, such as space construction, require the presence of man almost continuously for optimum results. Others, such as routine data collection, function well with no hands-on human contact at all. A third class operates best without human intervention or disturbance, but requires frequent servicing, adjustment, component replacement, etc. that can be managed more easily and economically by a human presence than by an automated machine, however sophisticated it may be. This class, which is the subject of this section, includes such operations as materials

TABLE 4.2-1 PLANETARY EXPLORATION STRATEGY

MISSION	NEW START	LAUNCH
VENUS ORBITER IMAGING RADAR (VOIR)	81	DEC 84
HALLEY COMET FLYBY/TEMPEL II RENDEZVOUS	82	JULY 85
SATURN ORBITER W/DUAL PROBE (SOP^2)	84	FEB 89
IO ORBITER/PLUTO FLYBY	86	OCT 90
URANUS ORBITER	86	DEC 91
NEPTUNE FLYBY	86	DEC 92
MARS SAMPLE RETURN #1	89	OCT 94
#2		NOV 96
#3		NOV 96
GALILEAN SATELLITE	93	TBD
ASTEROID MULTIPLE RENDEZVOUS	96	TBD

NOTE: CONCLUSIONS OF OSS PLANETARY STRATEGY CONFERENCE, APRIL 1979. FIRST THREE MISSIONS ARE IN FIVE YEAR PLAN; REMAINING MISSIONS ARE TO SCOPE THE PROGRAM AT AN ANNUAL FUNDING LEVEL OF $300 MILLION AND ARE LIKELY TO BE REVISED. INJECTED MASS, C_3 AND DLA DATA NOT YET AVAILABLE.

ADDITIONAL APPROVED MISSIONS: JUPITER ORBITER PROBE (GALILEO) - 1982
SOLAR OBSERVATORY - 1983



CHARACTERISTICS SUMMARY

SOLAR ARRAY (EOL PWR)	25 KW
ION THRUSTERS	8
FM POWER PROCESSORS	8
PROPELLANT	MERCURY
SPECIFIC IMPULSE	3000 SEC
THRUST	1 NEWTON
AVIONICS*	C&DH/GN&C

*NASA STANDARD SYSTEM (MMS)

INERT MASS - 1285 KG

MERCURY PROPELLANT - 2100 KG (MAX)

Figure 4.2-1. Current SEPS Concept

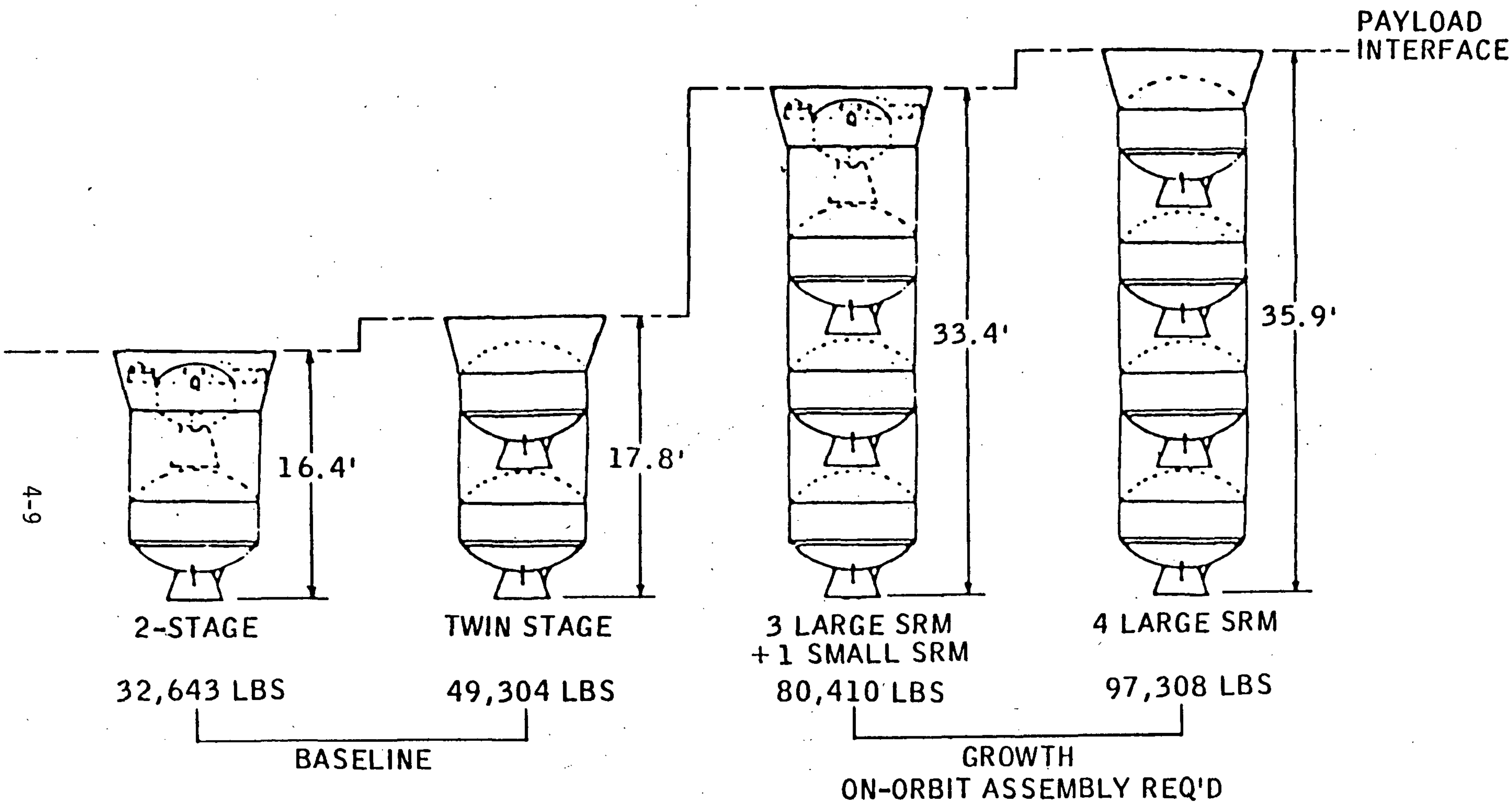


Figure 4.2-2. Solid IUS Configurations

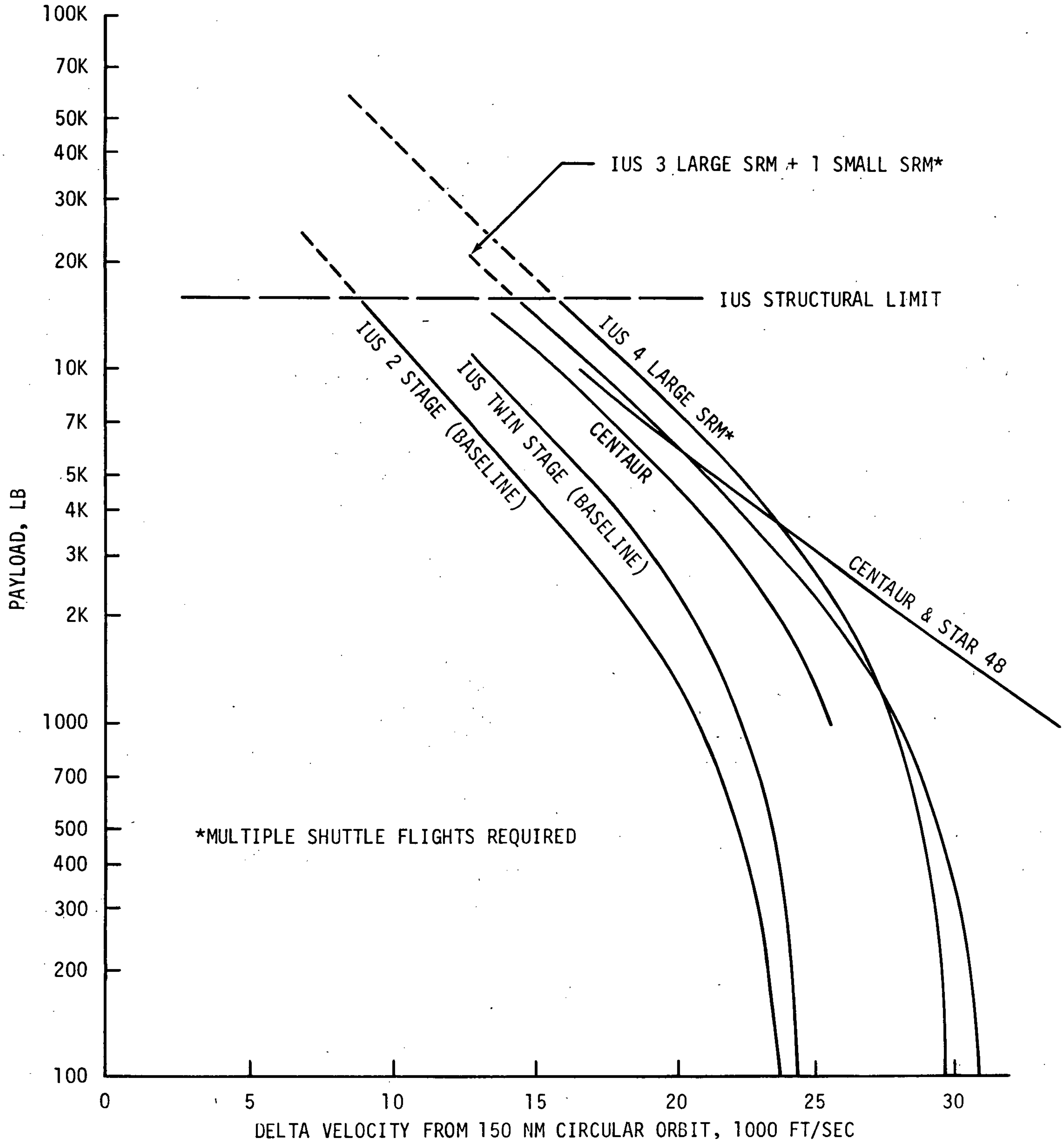


Figure 4.2-3 Stage Performance

processing, which requires extended periods of extremely low acceleration, and a large space telescope, which tolerates poorly the contamination associated with a human crew, but may need frequent instrument replacement, calibration, etc.

The SOC offers a unique opportunity to operate satellites of this kind in a co-orbiting mode, permitting them to operate at whatever distance may be required while being easily recalled to the SOC when necessary. The capabilities required for tending co-orbiting satellites are included within those necessary for support of a geosynchronous orbit transfer vehicle. These provisions include berthing facilities for orbiter payload bay-sized spacecraft, access to the interior and exterior of the serviced vehicle, docking controlled remotely from the SOC, and servicing and repair facilities. The two capabilities can therefore be developed concurrently with little additional cost except the satellites themselves.

4.4 AUTONOMOUS SPACE SYSTEM OPERATION

The SOC provides a significant opportunity to address the mission management and control requirements for long-term future manned space flight programs. The present mission management and control process is characterized by a people-intensive ground control operation involving significant supporting ground information and control facilities and a tightly-integrated ground/flight crew operation. The extensive information requirements associated with a ground-centered flight control operation places significant data transmission bandwidth requirements on the flight vehicle. Although these requirements are well within existing near-earth mission capabilities, future manned missions could be faced with significant wideband data transmission requirements not presently realizable. The time-delay factor associated with planetary distances, as well as unavailability of quick return-to-earth for geosynchronous or planetary distances, suggest a long-term requirement for onboard mission-management capability.

A principal objective in the SOC program is the development and implementation of significant capabilities for autonomous space system operation. The principal challenge in this respect will be the definition and implementation of computer aids required to permit effective daily mission management and control by a comparatively small flight crew.

The absence of ascent and deorbit/return-to-earth requirements for SOC, as well as the limited requirements for on-orbit maneuvering and attitude control, suggest that autonomous GN&C operations will be relatively straightforward. A potential exception is the on-orbit stabilization associated with a highly flexible vehicle structure.

Onboard vehicle system monitoring, fault isolation and replacement/repair is considered to be a reasonably attainable objective for the initial SOC flight period. This capability might require augmentation with an "extraordinary problem" troubleshooting capability resident on the ground and provided to SOC on an on-call basis.

Mission flight planning and control will likely have a ground element responsible for longer-term strategic-level planning, with the management of day-to-day mission operations in response to the strategic plan a function of the flight system.

A major new function related to long-duration flight operations is the information storage and retrieval capability associated with such functions as inventories, resupply, consumables management, maintenance and other procedures, data retrieval, activities scheduling, and perhaps crew entertainment. This requirement may face a technology barrier associated with availability of flight-qualified large-capacity mass memory systems. In such an eventuality, an appropriate initial concept might consist of large mass storage systems resident in ground systems and immediately accessible by SOC personnel through TDRSS.

In summary, the principal activity in developing an autonomous space system capability will concentrate on minimizing and perhaps eliminating the people-intensive operation associated with current mission operations concepts. The initial placement of certain computer storage and retrieval functions in ground-based systems should be considered as an architectural alternative in the face of significant technological barriers to the implementation of onboard mass memory capabilities.

4.5 SUBSYSTEMS INTEGRATION OPTIMIZATION

A completely autonomous SOC would ideally require no resupply of any kind. In practice, this ideal cannot be achieved within the foreseeable future, but it can still serve as a goal toward which to work.

The most progress in this area has been in environmental control and life support (EC/LS) where water and carbon dioxide reclamation systems are well advanced. These systems will be incorporated into the SOC at the outset. Other candidates for further subsystem integration are reaction control, which can potentially use EC/LS waste products, and electrical energy storage, which could be combined with EC/LS water electrolysis cells.

Other possibilities, farther in the future but still within the capability of the SOC, include direct conversion of solar energy into food by onboard hydroponic gardens.

The SOC offers an excellent test bed for these and other concepts by virtue of its continuous operation, modular construction which permits the replacement of entire modules if necessary, and its open-ended configuration which allows great flexibility in arrangement and type of modules.

4.6 LONG-DURATION LIVING AND WORKING IN SPACE

4.6.1 Background

The SOC will afford the opportunity for workers to perform a wide variety of beneficial activities over a long period of time. Present knowledge gained from previous flight programs provides a high level of confidence that men can live comfortably and work affectively in the null-gravity environment for periods of time which probably exceed three months. This appears to be possible despite the fact that the null-gravity environment is foreign to the phylogenetic history of development of human organ systems. It is indeed fortuitous that the environmental factors that have influenced so powerfully the anatomic and functional characteristics of organ systems have also influenced certain systems to acquire the capability to accommodate or eventually to adapt to a wide range of environmental stresses. Thus is is not surprising that changes occur in the performance of body systems in null-gravity, nor is it surprising that the accommodative processes enable the individual to perform well in what might otherwise be a threatening setting.

4.6.2 Cardiovascular Deconditioning

We have learned that the null-gravity environment contributes to redistribution of the labile body fluids. Such fluid shifts trigger reflex responses which serve to adjust total fluid volume. The influx of blood to regions of high compliance triggers a response in volume-sensing regions in the heart and central vessels, with the results that neurohormonal influences on the kidney cause a loss of water and salts, and a reduction in total circulating blood volume. Such reflex accommodations were developed to account for naturally occurring temporal changes in body water, position and activity. The physiological consequences of having triggered the blood volume control reflexes in null-gravity results in an inappropriate response because the evolutionary history of the system development cannot account for lack of gravity. So long as the individual remains in the gravity-free state, the accommodated processes appear to interfere minimally with survival or performance. The inappropriateness of the accommodations to zero gravity become evident when the individual returns to earth to find that the force of gravity reestablishes hydrostatic columns at a time when total circulating blood volume is depleted. Refilling the dependent regions of the lower limbs and abdomen from a diminished total reservoir results in a relatively inadequate volume for circulation to the heart and for perfusion of the vital organs. The processes leading to such orthostatic hypotension, or the deficiency of volume for tissue perfusion, lend themselves to certain counteractive measures. Countermeasures include (1) application of pressure on the lower limbs and abdomen to reduce the volume available into which blood can pool, thus conserving the reduced blood volume, or (2) drinking excess water and salt while pharmacologically inhibiting water and salt loss by way of the kidneys.

4.6.3 Depletion of Bone Salts and Muscle Mass

The release from gravity reverses the physiological mechanisms that serve to build bones and strong muscles. Bone calcium is lost from the skeleton to the plasma and thence from the body via wastes. Muscles lose some strength as structural materials in muscle cells are lost from the muscles of the body. The anti-gravity or postural muscles are especially affected. There is no evidence now that the loss of bone calcium diminishes or terminates in weightless exposures lasting as long as three months. Much research on the problem of osteoporosis of space flight remains to be done. At present, the countermeasures used include provision of adequate bone replacement salts in the diet along with muscular exercise to attempt to simulate the forces on bones and muscles that would have been provided by gravity. Muscular exercise appears to be beneficial in moderating the loss of muscle strength.

4.6.4 Neurosensory Disturbances

For reasons as yet unexplained, the sensory systems affected by pressure, acceleration, position and visual patterning appear to lose the fine tuning of their normal integrated interplay. Sensory confusion occurs below the level of consciousness and the conflict of incoming information may give way to disorder. The body and brain respond primitively, and space orientation sickness may result. The disturbance appears early in the exposure to null-gravity. Stomach awareness, malaise and vomiting can occur. The symptoms appear to wane as exposure continues, and in the experiences during Skylab, the problems of orientation and "space motion sickness" virtually disappeared with the passage of time. The most effective countermeasure presently available appears to be the application of pharmacological agents which dull the acuteness of the symptoms without impairing performance. Much more research must be done to understand the processes involved in this malady and to develop more effective countermeasures.

4.6.5 A Generalization

Bodily responses to exposure to null-gravity appear to occur according to a scheme related to the physical characteristics of the systems. Reactions involving consciousness and the higher levels of subcortical reflexes appear to accommodate most rapidly. Disorders of orientation occur very early, and fortuitously appear to return to a normal operating mode within hours or in a few days. Disturbances in bone and muscle appear less rapidly, reflecting the relative sluggishness of biochemical changes at the cellular level. An interesting relation can be drawn between the rate of onset during exposure to weightlessness and the rate of recovery upon return to Earth. It appears that the rapid onset of cardiovascular and neurological disturbance is mirrored in rapid recovery. Similarly, the slower onset of disturbances at the cellular level is associated with a slower recovery rate. However, the observed changes all are considered to operate within the predictable range of physiological performance. All changes observed have been shown to be reversible. These observations combine to encourage the lengthening of null-gravity exposure, and a reasonable lengthening is believed to be 120 days.

4.6.6 Objectives

The objectives of the SOC Health Maintenance Facility are three-fold: (1) to provide services and equipment to assure continuing good health and productivity of human participants in the SOC, (2) to provide the opportunity through the use of biomedical measurement systems to continue to expand the acquisition of data relating to the responses of human organ systems in the null-gravity environment, and (3) to develop measures which counteract the adverse physiological changes.

As the activities associated with assembly and operation of the SOC accelerate and the personnel involved increase in number, the requirement for a comprehensive health care facility will be well established. Minor illnesses and injuries can be expected to occur as the complexity of operational procedures increases. Although rescue-to-Earth measures would be in order for serious injuries or illnesses requiring interventions not feasible in the SOC, an onboard treatment facility would enhance the effectiveness of crew stay time.

The Health Maintenance Facility will serve an important additional function by providing for the use of analytical and diagnostic equipment to acquire data on the status of crew health. Although not designated as a research facility, the acquisition of data relating to health and physiological functions becomes a valuable adjunct to understanding responses of crewmen at work in null-gravity environment. As experience and opportunities permit, growth of medical investigative procedures will undoubtedly occur. For the near future, however, maintenance of crew health will remain of primary importance in the operation of the SOC.

5.0 SPACE OPERATIONS CENTER DESCRIPTION

5.1 SYSTEM GUIDELINES

Several basic guidelines were established at the beginning of the study:

1. The SOC shall be capable of operating indefinitely with resupply, on-orbit refurbishment and orbit maintenance.

2. The SOC shall be nominally manned, but capable of unmanned operation.

3. Continuous attendance at the SOC by an orbiter shall not be necessary.

4. Either habitation module shall be capable of supporting the entire crew for 90 days in an emergency.

5. The orbit inclination shall be 28.5°.

6. The orbit altitude shall be optimized for Shuttle visits and orbit maintenance.

7. "Extreme" requirements for pointing, contamination-free environment and near-zero gravity shall not be imposed on the SOC but satisfied by free-flyers if necessary.

8. The SOC capabilities are to be developed incrementally.

9. A growth potential shall be maintained at all stages of buildup.

In addition to these general guidelines, some more specific concept guidelines were adopted:

1. The SOC shall be built up of Shuttle-launched modules.

2. Compatibility with the 25 kW Power Module shall be maintained as far as is practical.

3. Multiple docking ports shall be provided for the Orbiter with access for buildup and resupply.

4. Multiple berthing ports shall be provided for modules and free-flying experiments.

5. The SOC shall incorporate an onboard maintenance capability.

6. Shirtsleeve transfer between modules shall be provided.

7. Limited ground monitoring shall be required, with autonomous operations as a goal.

5.2 SYSTEM CAPABILITY

The capabilities of the SOC fall into two major categories, viz., internal subsystems such as electrical power and life support, and operational systems such as space construction. The requirements listed here represent the best current understanding of the SOC. As such, they are subject to change with further study; however, major alterations are not anticipated.

5.2.1 Subsystems

Electrical Power: Both 28V DC and 115V, three-phase, 400 Hz will be available. A continuous power level of 35 kW has been used for initial planning purposes, pending in-depth analysis of requirements.

Life Support: The cabin atmosphere will be maintained at 14.7 psia with a temperature between 70 and 80F and a dew point between 40 and 60F. Maximum CO_2 pressure under nominal conditions will be 3.8 mm Hg. Minimum O_2 partial pressure will be 3.2 psia. The system will be configured so that the loss of any one module will not impair the ability of the crew to survive for 90 days before rescue. The system will support up to two two-man EVA's per week. Water will be supplied for drinking, food preparation, hand washing and bathing.

Thermal Control: Each module will reject its own thermal loads. Coolant transfer from one module to another will be avoided.

Avionics: Attitude hold within 5° will be sufficient for most SOC requirements. $\pm 0.5°$ will be maintained for docking and assembly.

The system will provide onboard position determination, thrust commands for orbit maintenance and CMG desaturation and attitude control. The data management system will serve all SOC subsystems plus the operational systems and experiments.

Communications and Tracking: Two-way voice, text and graphics plus down-link telemetry and TV and up-link commands will be provided from earth via TDRSS. Other communication links include two-way voice and tracking from the orbiter; two-way voice and EKG from EVA astronauts; voice, data and TV from free-flyers and voice and commands to free-flyers from the SOC. Internal distribution within the SOC will include audio, data and TV.

Reaction Control: The system will provide impulse for orbit maintenance, CMG desaturation and back-up attitude control.

5.2.2 Operational Systems

Space Construction: In the early phase of SOC buildup, the construction system will evaluate various construction techniques and will fabricate experimental planar platform structures up to about 10 m wide and 200 m long, including subsystem installation and system checkout. Large parabolic reflectors can also be fabricated.

Launch and Recovery: The SOC will support the assembly, checkout, launch and recovery of unmanned planetary vehicles, planetary sample return vehicles, and manned geosynchronous spacecraft. In the early phase, the SOC will evaluate techniques for assembly, fueling, launch and recovery. It will assemble Shuttle-launched propulsion stages and payloads and checkout and launch the assembled vehicles. It will incorporate docking facilities for recoverable stages, provisions for refueling them from the Orbiter, a pressurized docking port for shirt-sleeve crew transfer to a manned module, and facilities for on-orbit maintenance of OTV's.

Health Maintenance: The SOC will include facilities for monitoring the health of the crew, and for collecting clinical data for continuing analysis of the effects of space on man. These facilities will provide for diagnosis and treatment, including minor surgery, environmental monitoring, and exercise and physical fitness.

5.3 CONFIGURATION DESCRIPTION

A configuration of the SOC has been conceptually designed to indicate feasibility of the SOC concept and its ability to accommodate all necessary functions and mission operations. Numerous in-house and contracted studies of space stations, orbital service modules, and power modules for a wide variety of missions, based on utilizing the Shuttle, have contributed greatly toward the configuration design described herein; these prior efforts are gratefully acknowledged.

The present configuration is in no way intended to represent a final or optimum arrangement. It exists solely as a means of identifying configurational problems and determining whether feasible solutions to these problems exist.

5.3.1 Basic Configuration

The SOC is shown in figure 5.3-1 in its initial, fully-manned configuration, without its externally attached mission facilities. It consists of five separately launched modules -- launched in the order described.

5.3.1.1 Service Module - The service module interconnects all modules and provides a pressurized passageway, plus the services of an airlock, electrical power, guidance, navigation, attitude control and communications. The service module is composed of two identical, separately launched halves. Each half is capable of performing (at a reduced level in some cases) all functions of the complete service module in the event of a total loss of the other half. Eight peripheral berthing ports and two end docking ports are provided. Two large solar arrays are mounted on each side of the service module on long booms. A two-axis gimbal at the outboard end of each boom provides for pointing of the arrays toward the sun (the boom does not rotate). Also symmetrically mounted to either side of the service module on the boom are radiator panels, omni antennas and steerable dish antennas, providing these subsystems with an excellent location with respect to minimizing obstruction to their fields-of-view, etc., by the SOC configuration. Reaction control thrusters are also mounted on the boom as shown in the figure. It is recognized that the

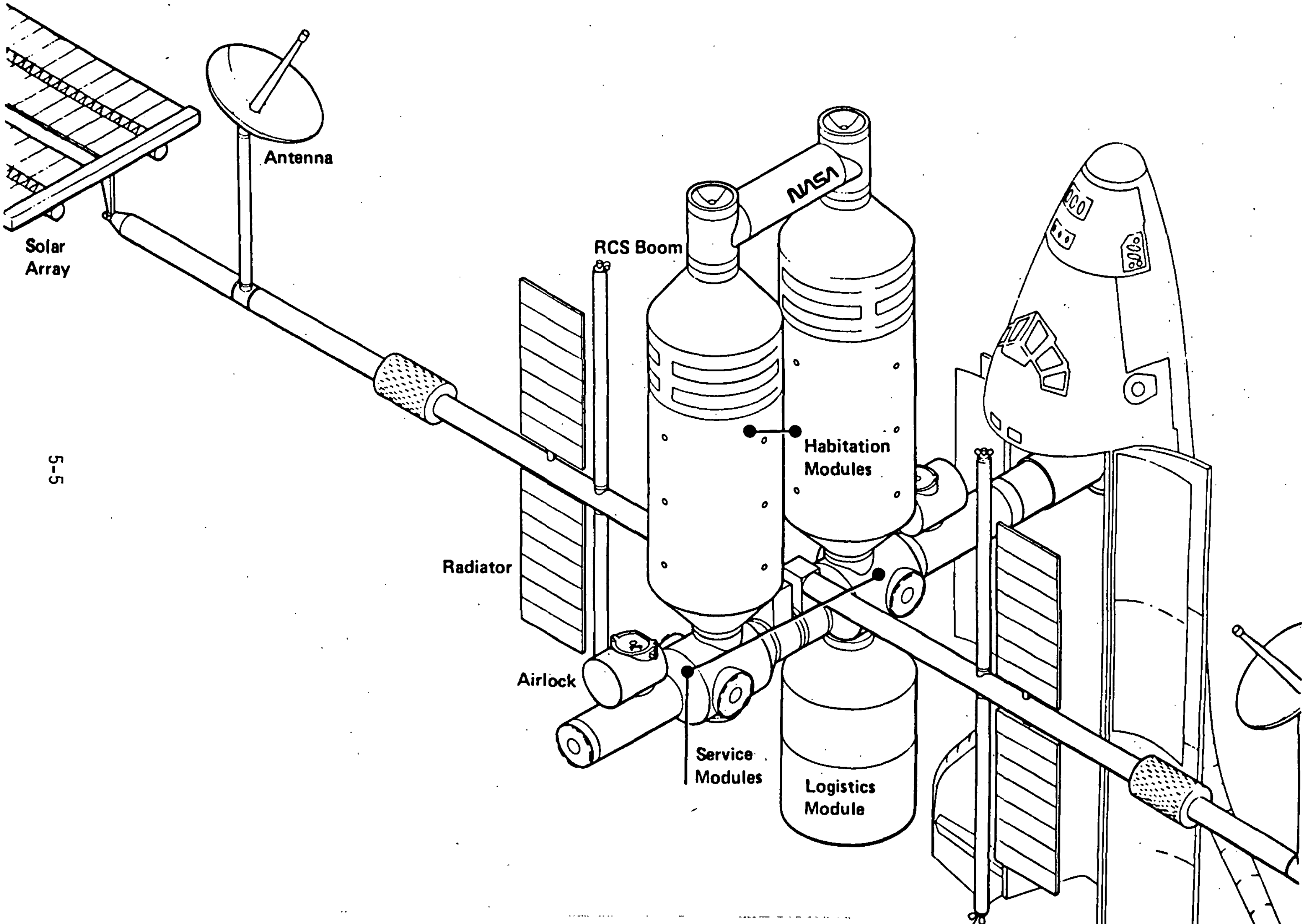


Figure 5.3-1. Space Operations Center

stiffness of this RCS mount concept is an issue, and they may be better accommodated with their own mounting booms, having additional struts (a tripod, for example). However, folding for launch stowage is better accommodated by this arrangement, and it should be noted that the attitude control system (primarily control by CMG's) must be designed to be adaptive with natural frequencies of components on the order of .01 Hz (solar arrays, construction projects, etc.). The service module, alone and unmanned in orbit, is an independent, self-sufficient spacecraft capable of being monitored and commanded from the ground.

5.3.1.2 Habitation Modules - Two separately launched, basically identical cylindrical modules each provide living accommodations for a crew of four, and a SOC control center. One habitation module contains a health maintenance facility, and the other contains experiment/lab provisions in place of the health maintenance facility, except that it provides stowage of essential medical equipment in case the other module is rendered uninhabitable. Each module contains a complete ECLSS as well as certain avionics, etc. (described in Section 9.0).

5.3.1.3 Logistics Module - Resupply provisions and additional equipment are provided to the SOC at regular intervals with the logistics module, which is transported by the Shuttle. Two logistics modules must be manufactured so that the "empty" module is replaced by a "full" module and returned to earth on a single Shuttle flight. The logistics module consists structurally of one "deck" of a habitation module (pressurized) plus a "skirt" section (unpressurized) for cargo that would logically be required external to the SOC. The logistics module replacement procedure involves two peripheral ports on the service module. When the logistics module shown in the figure is replaced, the replacement is berthed to the adjacent port on the solar array side of the service module; thus, the orbiter can receive the empty module in the same location in its payload bay as previously occupied by the full module.

5.3.1.4 Tunnel - For maximum crew safety plus added convenience, an interconnecting tunnel is installed between the habitation modules opposite to the service module. The Orbiter may also be docked to the indicated port provided by this tunnel installation, as a backup to the primary docking port at the end of the service module. It is envisioned that the habitation module interconnecting tunnel would be transported to the SOC, along with the initial logistics module, on the fifth Shuttle/SOC flight. The interconnecting tunnel would be installed utilizing the Orbiter's remote manipulator system (RMS) with the Orbiter station-keeping to the SOC in the appropriate location.

5.3.2 Basic Configuration with Mission Facilities

Figure 5.3-2 shows the basic SOC with an operational construction facility and a manned orbital transfer vehicle support facility installed (these facilities, and others, are described in Section 10). Under construction is a platform of a size on the order of 10m wide x 200m long. The construction facility is docked to the end port of the service module. This arrangement provides that there is no inherent restriction on the construction project or construction facility configuration imposed by the SOC configuration. The long, slender platform is logically constructed so that its longitudinal axis is in the orbit plane and oriented to the SOC such that the SOC solar array boom is perpendicular to the orbit plane (POP). The SOC flight orientation is earth-oriented, with the minimum moment of inertia axis of the total system along the local vertical. The platform under construction being the dominant contributor to the system moment of inertia as it nears completion, pitch attitude is allowed to follow the motion of the platform in the facility. The axis of maximum moment of inertia is POP, providing inherent stability. If the construction project configuration were a cross or disc of a size and mass that also dominated the system inertia properties, it would be constructed with the plane of the cross or disc located normal to the service module longitudinal axis, and the SOC flight orientation would be changed so that the solar array boom was in the orbit plane and the SOC was inertially fixed, in an attitude favoring full illumination of the solar arrays. The solar array's two-axis gimbal system accommodates either flight orientation, having one axis parallel to the boom centerline (capable of continuous rotation), and the other axis located outboard of

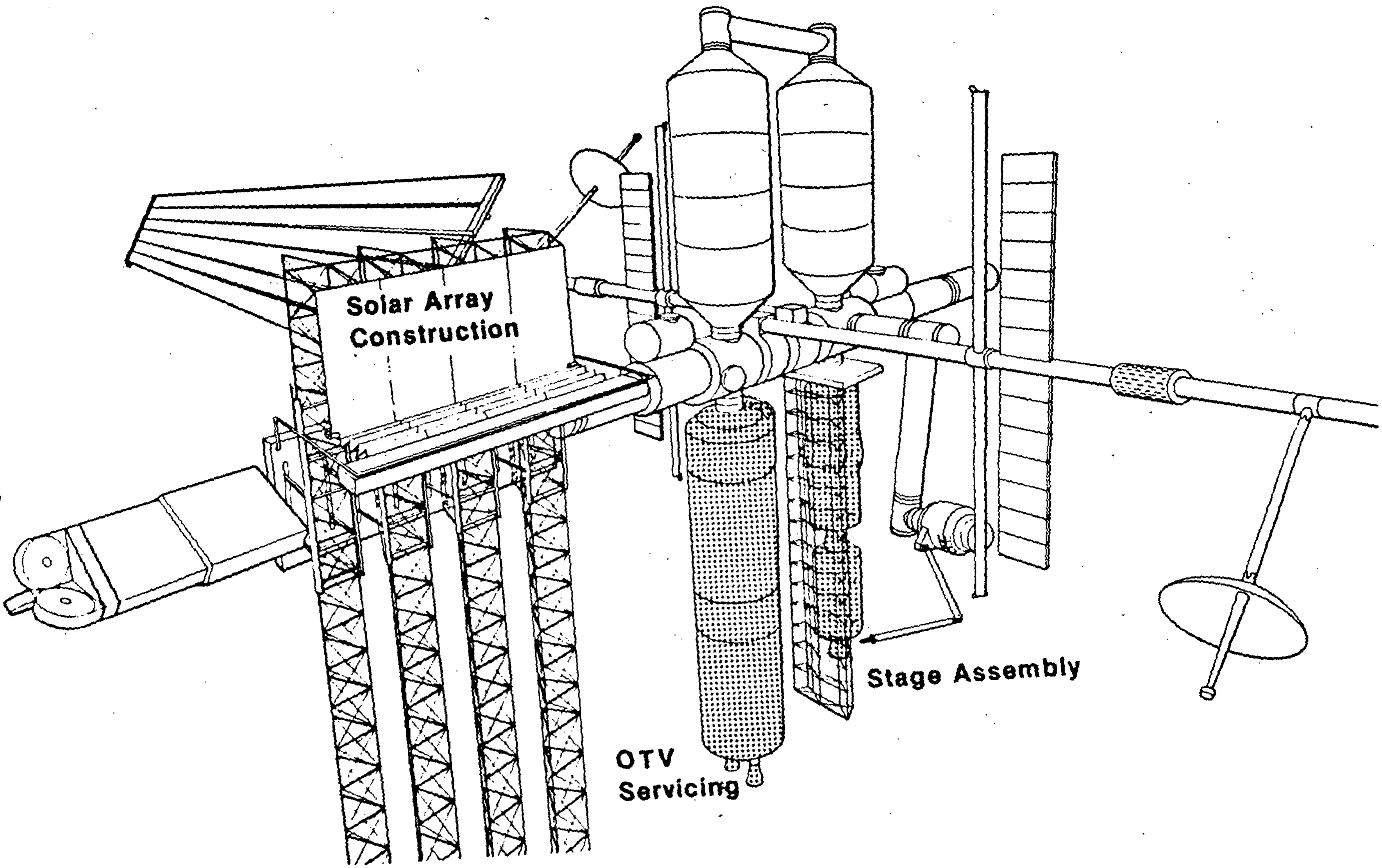


Figure 5.3-2. Space Operations Center With Construction And Flight Support Facilities

the first axis and arranged perpendicular to the boom and in the plane of the array blankets (capable of a maximum of ±90° rotation). The SOC configuration and flight orientation capabilities are, therefore, designed such that bias aerodynamic and gravity gradient torques are eliminated or minimized (reducing RCS propellant requirements relative to CMG desaturation).

Provisions for orbital launch vehicle stage assembly and manned orbital transfer vehicle support are located under the service module opposite the habitation modules. This location and arrangement minimizes perturbations to the SOC principal axes. For example, as the construction project configuration changed during its construction, the pitch attitude of the SOC could be modified to allow bias gravity gradient torque (i.e., accumulated angular momentum in the CMG's) to counteract bias aerodynamic torque -- when integrated through a complete orbital cycle. This can be accomplished by appropriate control system software. By locating all significant mass elements in the orbit plane, large attitude excursions occur primarily about the pitch axis, which can most easily accommodate them. Because of the size and mass of the SOC, and the extreme variations in these properties resulting from its variety of missions, failure to heed the points just discussed would result in the necessity to transport large quantities of RCS propellants via the Shuttle, or operate in flight attitudes where it was impossible to obtain the desired electrical power from the solar arrays.

Both the construction and stage assembly facilities are supported by an Orbiter-type RMS attached to a control cab. The cab is mounted on a movable, pressurized arm which permits shirtsleeve access to the control cab and, by repositioning the cab, effectively extends the reach of the RMS. The latter feature enables a single RMS to fulfil all presently identified manipulation requirements of the SOC. A manned remote work station (MRWS) can be mounted at the end of the RMS and positioned as required for support of construction, inspection and maintenance operations.

5.3.3 Service Module Design

The service module consists of two identical halves berthed end to end. The evolution of this concept is discussed in section 5.3.5.

The basic arrangement provides pressurized internal space for certain subsystems and crew passageways, and external, unpressurized areas for installation of subsystems (figure 5.3-3). The figure indicates external equipment racks as an open structure; however, this was done only to emphasize the point. This area would be completely covered with an exterior structural skin/meteoroid bumper/and, possibly, radiators integrated with the meteoroid bumper.

The resulting basic SOC configuration is shown in side view in figure 5.3-4. The system provides maximum redundancy of all functions, including two airlocks. The required Orbiter docking extension is integral with the service module; the habitation modules are close together, minimizing the interconnecting tunnel length; there is adequate area available for subsystem installation; and the length of Orbiter payload bay occupied during launch allows ample room for OMS kit installation, etc. Instead of making each half of the service module identical, there may be variations that better accommodate other configuration objectives without significantly altering the intended principles of the concept.

The pressurized structure of each half (figure 5.3-3) consists of two 60-inch diameter cylinders, a 100-inch diameter cylinder, two cone frustums (identical), and six berthing/docking ports which are identical except for energy absorption capability compatible with the Orbiter's mass properties for those ports where the Orbiter is required to dock. The external, unpressurized structure consists of modular frames and longerons, and outer skin panels. The airlock is identical to the Orbiter airlock and all hatches are identical to the Orbiter airlock and cabin aft bulkhead hatches. All hatches open inward, toward the primary, pressurized volume. Port sizes are 40-inch diameter, "D" shaped (same as Orbiter), to allow the hatch to be removed through the port it covers. The same hatch/port design would be used throughout the SOC. One of the major "drivers" sizing the service module pressurized structure is providing space for "open" hatch stowage that doesn't block the crew passageway or cover adjacent ports.

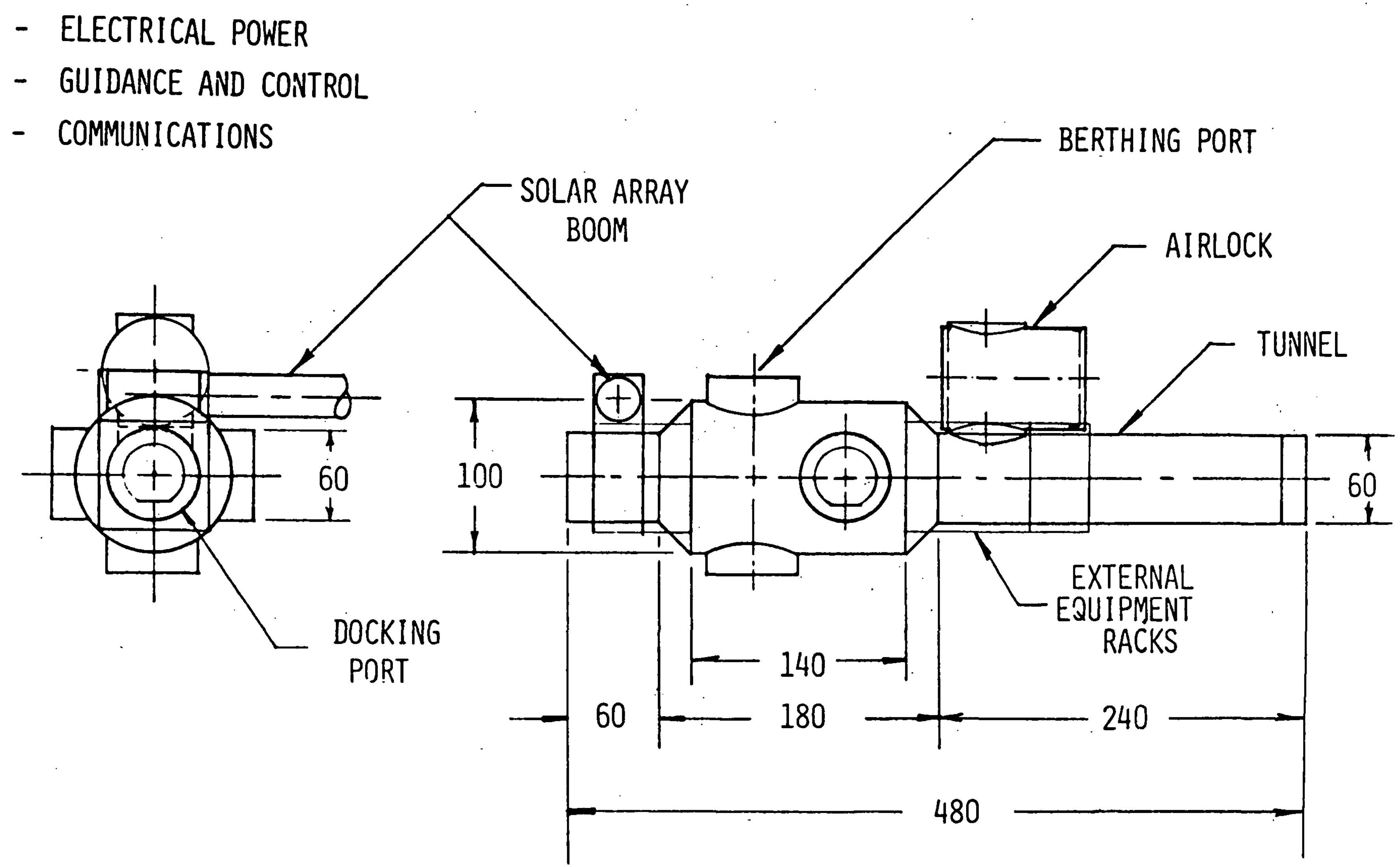


Figure 5.3-3. Service Module

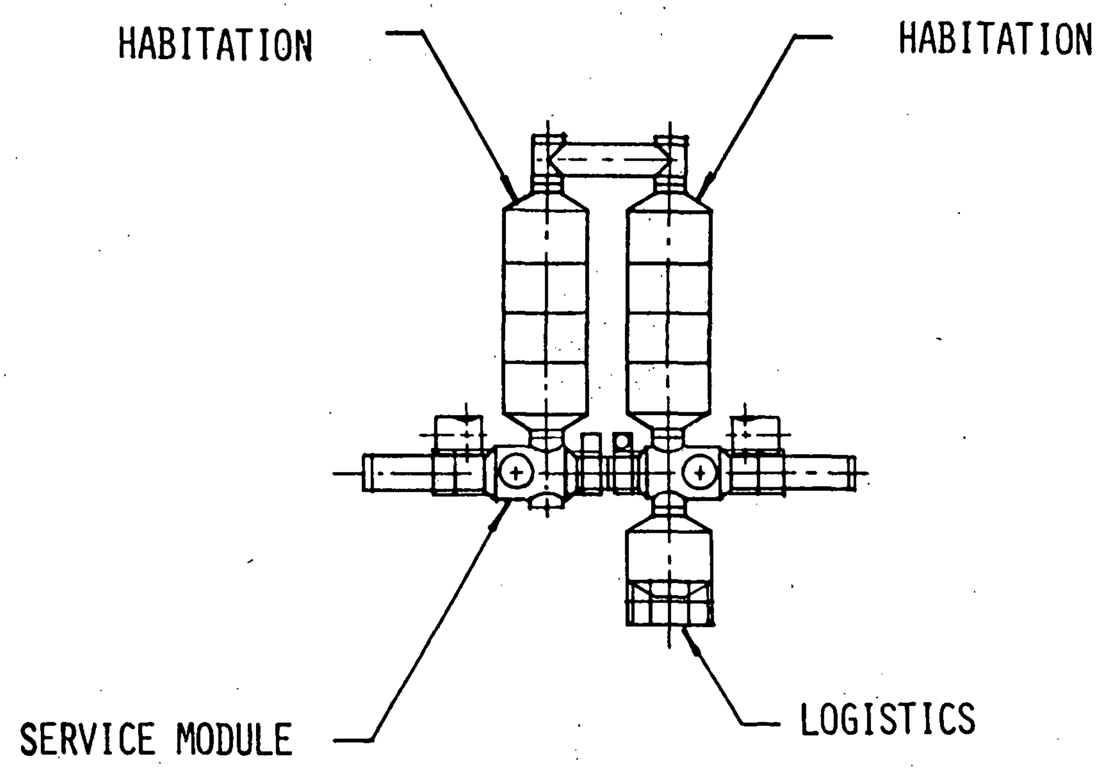


Figure 5.3-4. SOC Configuration (Dual Service Module)

5.3.4 Habitation Module Design

A concept for the habitation module structural configuration and interior arrangement is shown in figure 5.3-5. The module is 40 feet long and 14 feet in diameter (outside). Allowing for external meteoroid bumper and thermal insulation, the inside diameter of the cylindrical shell is approximately 160 inches (13 feet - 4 inches). The ends are cone-knuckle configurations, requiring no "kick" frame at the transition of cylinder to cone frustum. Two massive bulkheads provide structural support for, basically, all internal equipment, subsystems and furnishings. The four trunnions attaching the module to the Orbiter and its longerons are located at these bulkheads (two trunnions at each), and the keel attachment is located at one bulkhead. These bulkheads may be identical in design (at some weight penalty), and serve as the "floors" of the four deck module. A center bulkhead (thinner and lighter) serves as a ceiling for each of the two center decks, and stabilizes the center portion of the cylindrical shell. Two of the decks are "upside down" relative to the other two. This is of no consequence in orbit, but of some consideration relative to internal equipment installation during manufacturing. A 40-inch diameter (minimum) central, clear passageway is provided longitudinally through the module, and two adjacent triangular cross section through-ways carry all longitudinal runs of wiring, tubes and ducts.

Deck A is at the service module end and contains primary subsystems (engine room concept) and the control center (for the module and SOC). Pressure suit drying and stowage is also in the "engine room." Deck B contains the bathroom, and the health maintenance facility for habitation module no. 1. Hab module no. 2 has the health maintenance facility replaced with experimental lab/shop equipment and stowage for emergency medical equipment, but is the same otherwise. Deck C provides an identical private "stateroom" for each of the crew of four. Deck D contains the wardroom, which provides for food preparation and eating, rest and relaxation, entertainment, and games and exercise.

No internal equipment or subsystem item is attached to the pressure vessel wall, all items being supported by the two floor bulkheads, the center ceiling bulkhead, and/or internal partition walls. The two floor

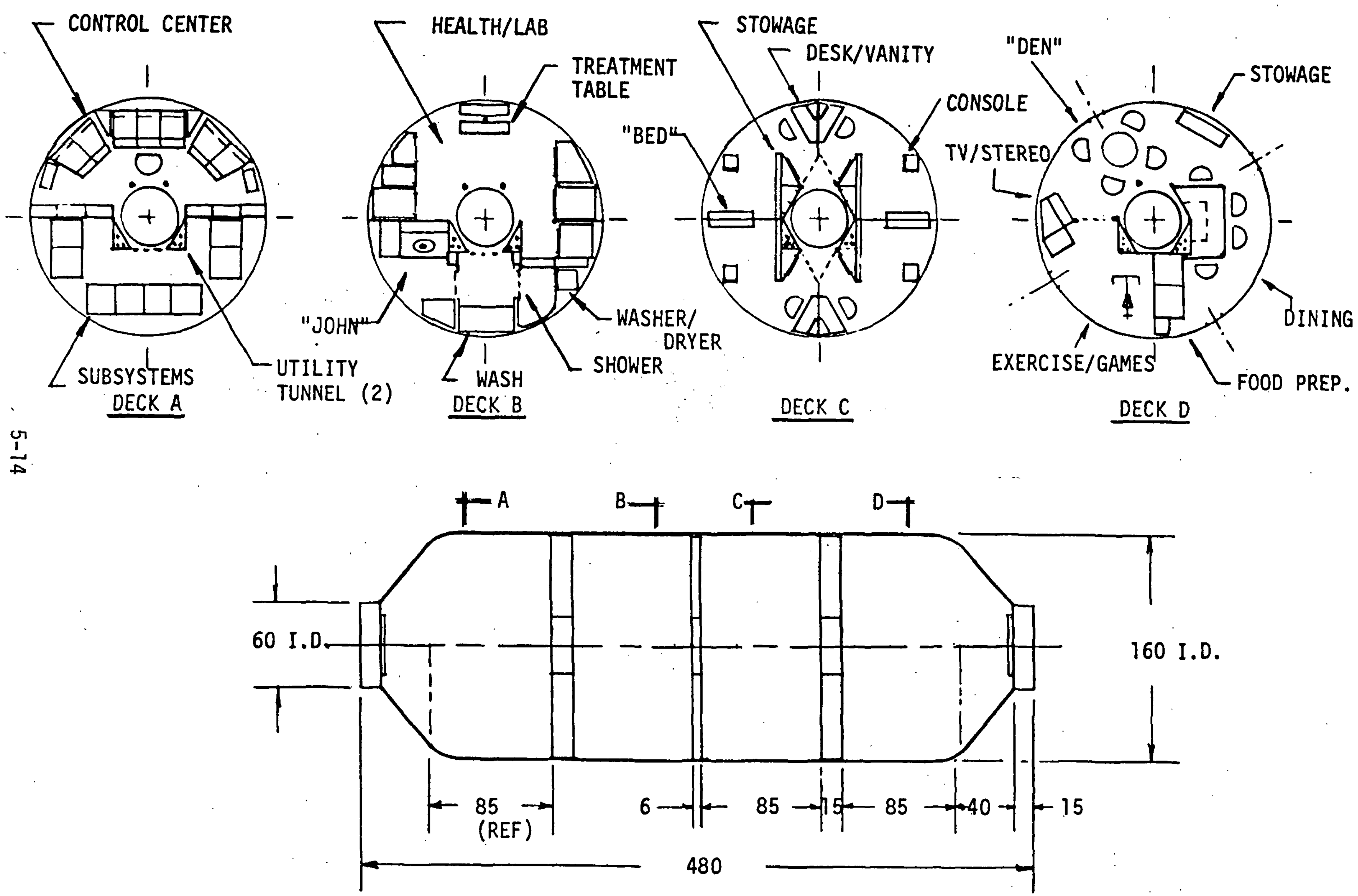


Figure 5.3-5. Habitation Module Configuration

bulkheads may be structurally interconnected by a transverse partition of decks B and C. Internal bracing may be provided to stabilize equipment against launch vibration, this bracing to be removed during "make ready" operations in orbit (and returned to earth for use on the next habitation module). All equipment is modular and sized so that any subassembly can be removed from the module through the normal ports and passageways after assembly is complete or on-orbit. In the event that the pressure vessel is punctured (such as by a meteoroid) on-orbit, the majority of the module outer shell area is directly accessible for application of a patch. In case of equipment blocking access, that item can be readily removed or moved. For example, a large control console assembly may be moved radially inward about one foot and allow access for patch installation. These concepts are not only compatible with on-orbit service and replacement of failed equipment subassemblies, but should also enhance manufacturing and allow the entire interior of the module to be thoroughly cleaned occasionally. It is envisioned that almost all equipment would be installed during manufacturing to the two primary bulkheads, and then the center cylindrical section and the two ends would be added.

The interior layout of the module, as indicated in figure 3.5-5, was an attempt to heed not only basic functional requirements, but fundamental architectural principles as well. The interior volume is very small (relatively to current U.S. living standards), so an attempt was made to influence the crew's perception of the interior space. The cone-knuckle end design was chosen to eliminate the need for a "kick" frame or bulkhead at the cylinder-cone intersection, and thus allow the compartments at either end to have more than a flat ceiling seven feet from the floor. This provides a distance from the floor to the hatches at the berthing ports of approximately 10 feet. A portion of this "extra" conical volume would be left open and a portion cut off from view by a lowered ceiling over part of the area (with some stowage volume for provisions above it). "Cabinets" for both functional subsystems and stowed provisions and partition walls are deliberately arranged to enhance the variety of the space and block the crew's visibility of the total space from most vantage points. Thus, there is essentially no place in the wardroom from where a crewman can view the entire space from that location -- the space will always continue around the corner, above the ceiling, down the center passageway, on the other side of a cabinet, etc. Therefore, the space will appear to be much larger than it actually is. When the crewman is in his (or her) private stateroom (which has less volume than most walk-in closets), in his bed (sleep restraint), the console which is located above the bed will block his view of a portion of the wall. He cannot see the entry door, nor all of the desk/vanity, nor all of the area where the desk/vanity is located. (The console provides communications, data, alarm, music, television, lighting, etc.) If he is at the desk, with the entry door open, the passageway volume, which extends the length of the module, becomes part of the space he occupies. If the entry door were closed, the vanity mirror (logically as large as feasible) could not reflect all of the stateroom space -- the view is blocked by the triangular stowage peninsula and the corner of the large stowage "wall" adjacent to the bed. Thus, the stateroom is arranged to increase its apparent size (and more nearly be analagous to a coffin with the lid open, rather than closed). Similar treatment of the health maintenance facility/lab and the control center is envisioned. It is anticipated that the module interior design would include "expert" attention to all details affecting habitability, including all surface materials, upholstery, colors, textures, lighting, reflectivity and transmission of sound, etc., as well as the basic architectural arrangement and subsystems.

5.3.5 Configuration Development

The configuration described in the preceding sections represents the results of extensive, if not exhaustive, layout studies. The objective of this section is to summarize those studies and the way in which they led to the present configuration concept.

An initial arrangement is shown in figure 5.3-6. It includes a central core, two habitation modules, two experiment modules and a construction module with two large cranes. The solar arrays are arranged so as to minimize the variation in SOC moments of inertia as the arrays track

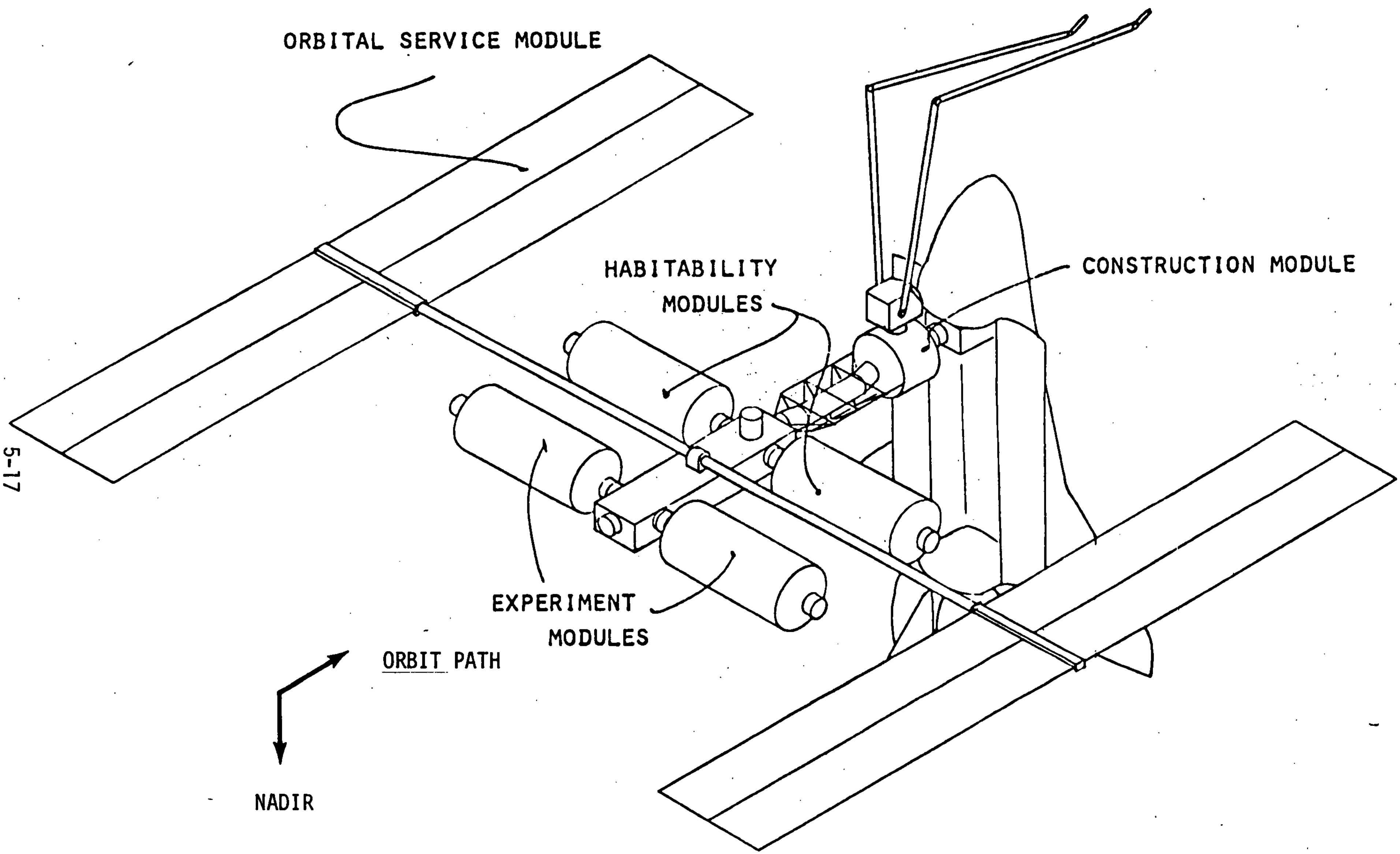


Figure 5.3-6. SOC - Initial Concept

the sun. The experiment modules are perpendicular to the orbit plane (POP) for optimum earth viewing and to permit the addition of a derotated (inertially stabilized) platform for astronomical instruments if such instruments should become a requirement. The construction module is at one end of the core to minimize possible constraints on the size of constructed objects. It includes external storage space for materials, tools, etc. The core has internal tunnels to connect the modules with minimum pressurized volume, and an airlock near one end for EVA.

The moments of inertia of this concept, however, are such that the attitude is unstable due to gravity gradient torques. The second configuration, in figure 5.3-7, eliminated this undesirable situation by placing the four side modules in the orbit plane. Continuous earth viewing is still available from the ends of two modules. A derotated platform for astronomy is less simple, but since no requirement for such a platform had been defined, its retention offered no advantage.

The core module, or service module, was originally conceived as an unpressurized box structure with internal tunnels for crew movement. Equipment not requiring pressurization was mounted outside the tunnels. This was changed to make the tunnels the primary structure (figure 5.3-8) with external equipment installation as before. The tunnels were enlarged in the berthing port areas to allow adequate space for hatch opening.

Attention was next directed to the support of operational activities, viz., construction and vehicle assembly and servicing operations. The large pressurized construction module was replaced by a handling fixture and beam builder (figure 5.3-9). The end mounting was retained to minimize dimensional constraints on constructed articles. The crane was scaled down (by cost considerations) to a duplicate of the Orbiter RMS and mounted, with cab, on the side of the service module for better visibility of construction operations and for improved reach to the far side of the construction fixture.

Vehicle assembly and servicing imposes two sets of requirements: one for multi-stage solid boosters and another for a manned orbit transfer vehicle (MOTV). Solid booster assembly was approached as shown in figure 5.3-10. As they are brought by the Orbiter, stages and payloads are

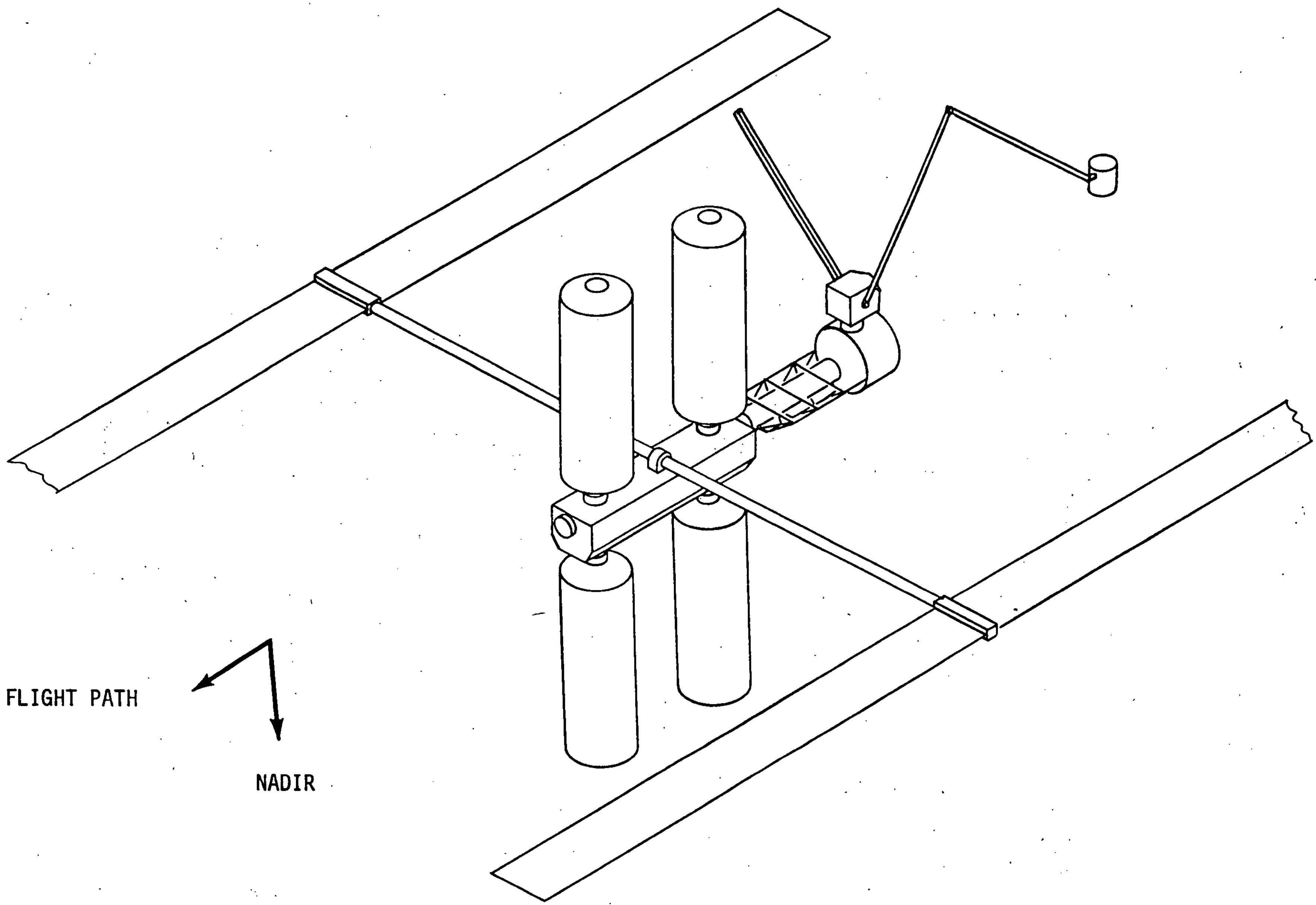


Figure 5.3-7. SOC - Modules In Orbit Plane

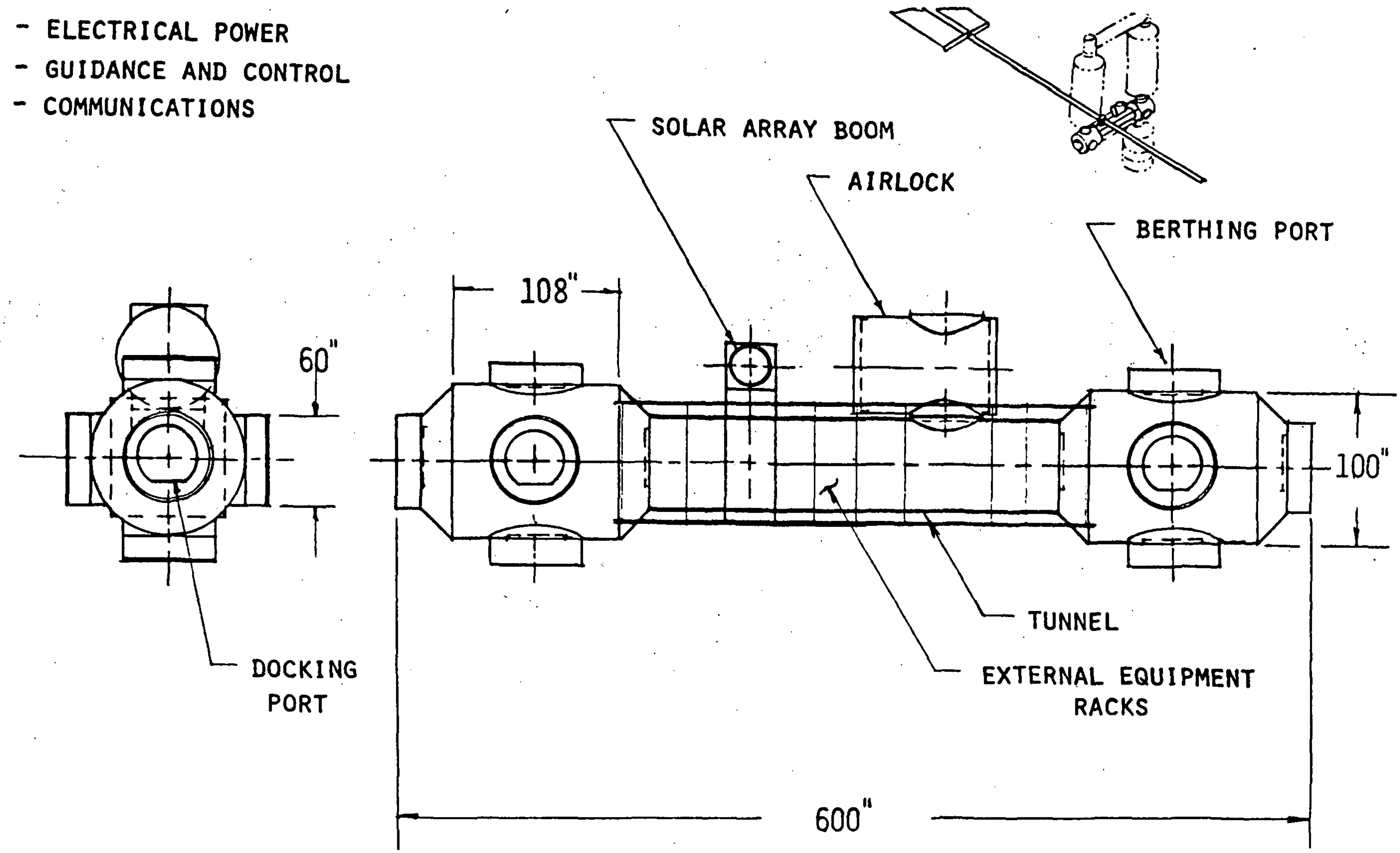


Figure 5.3-8. Service Module External Configuration

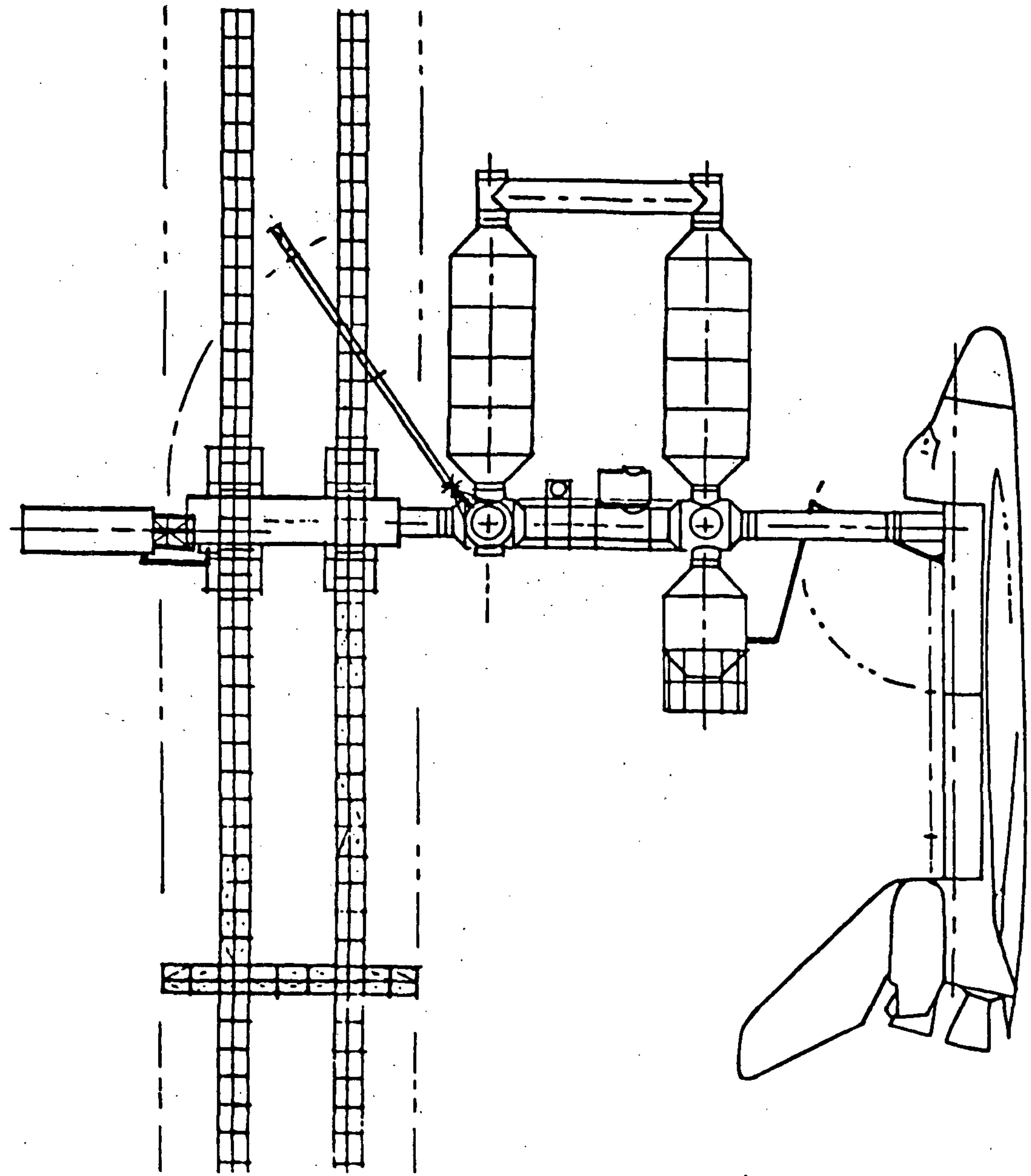


Figure 5.3-9. Platform Construction

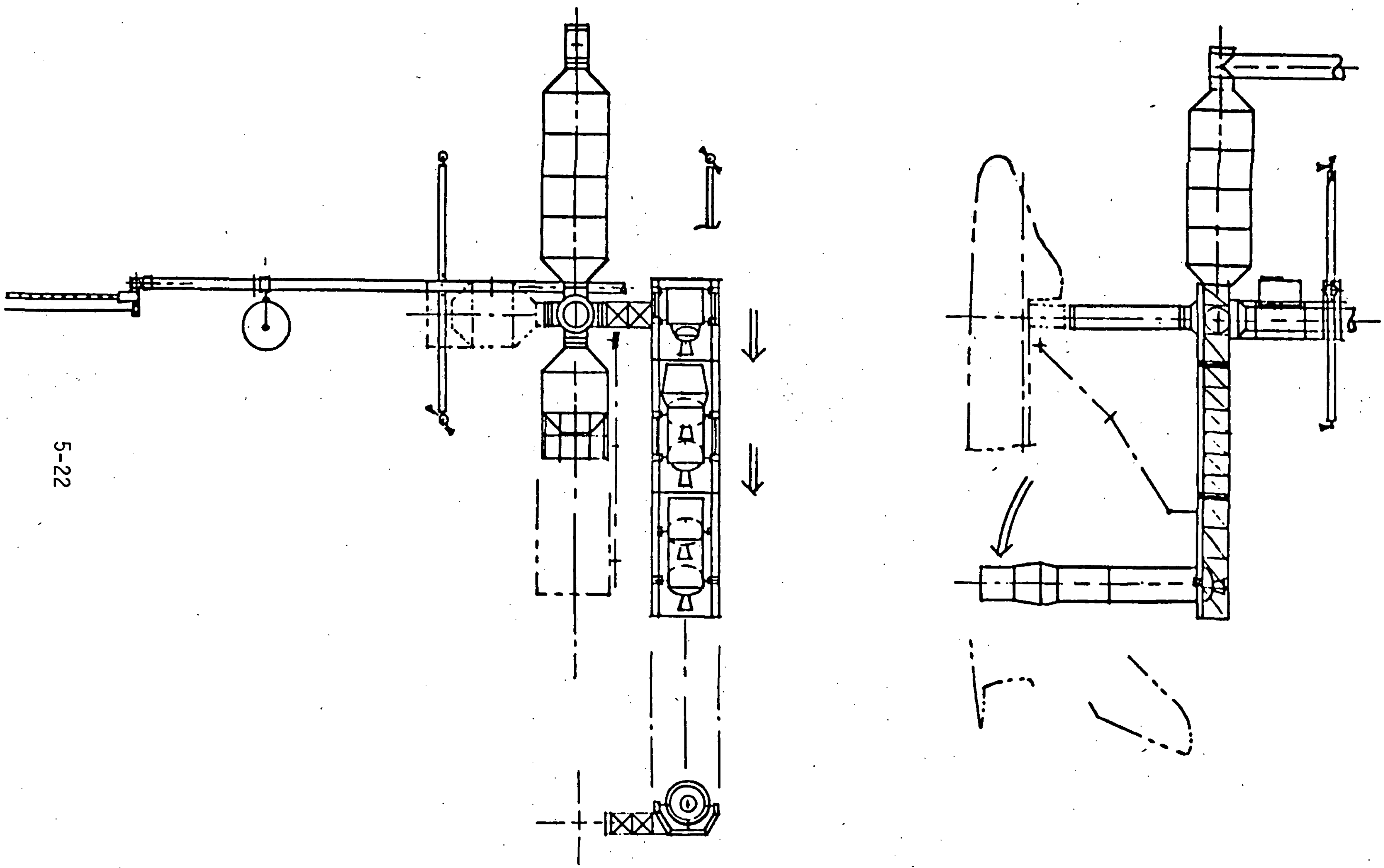


Figure 5.3-10. Planetary Vehicle Assembly

placed in appropriate locations on a strongback attached to one side of the SOC. When all components are in place, movable mounts join the stages. The completed vehicle is rotated out of the strongback and separated for launch.

MOTV assembly and retrieval are illustrated in figure 5.3-11. The first stage is retrieved first and must be stored until return of the second stage and crew module. This was accomplished by capturing the first stage with a small manipulator, which then swings it out of the way. The second stage and crew module docks to a fixture at the end of a pressurized tunnel. The end of the tunnel is then rotated to position the second stage above the first stage, which is positioned and mated to the second stage by the manipulator. The entire MOTV handling system is located on the side of the SOC opposite the solid booster assembly system. This location leaves the end of the service module open for Orbiter docking while minimizing RMS reach requirements for delivery of solid or liquid vehicle stages to the SOC.

Except for the small manipulator handling the MOTV first stage, most of the manipulation burden of the stage assembly facility must be done by the Orbiter RMS. In normal operations, this need not be a problem, but little flexibility is left for contingency situations or future operational requirements not presently envisioned. In addition, the asymmetrical arrangement destroys the orthogonality between the orbit plane and the SOC principal axes of inertia, placing an extra load on the attitude control system when equal masses are not present on both sides. To avoid both of these problems, the MOTV and solid stage assembly locations were moved to locations "under" the service module and the manipulator and control cab were placed on a movable, pressurized boom on the side of the service module (figure 5.3-12). Some imbalance still exists, but to a much smaller degree than with the side-mounted assembly facility. This location permits the manipulator to serve both the construction and the assembly facilities.

The service module presented several problems. First, for altitudes above about 200 nautical miles, additional OMS tanks in the payload bay will be required. Allowing for a docking module at the forward end of the bay

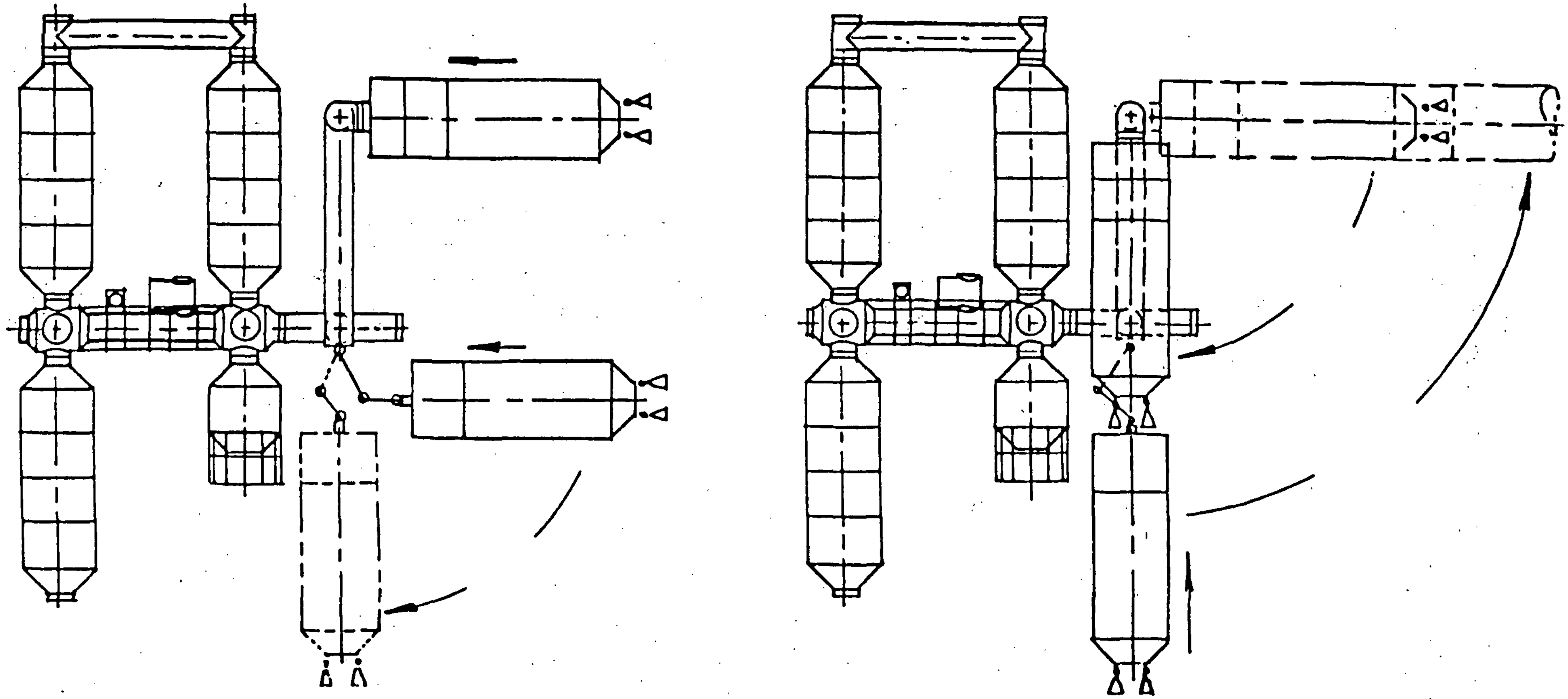


Figure 5.3-11. OTV Retrieval And Assembly

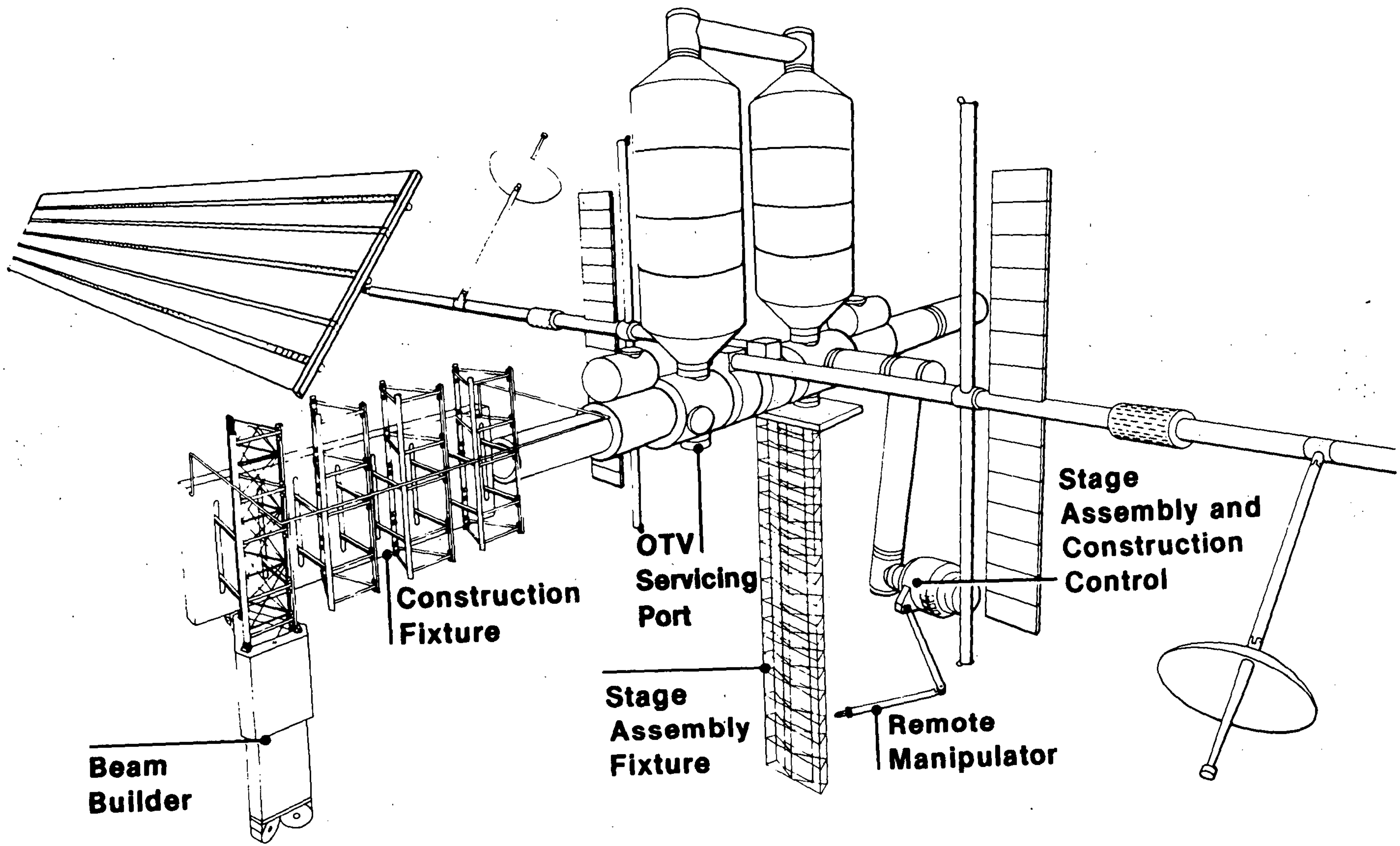


Figure 5.3-12. SOC - Current Configuration

and for reasonable extraction clearances, maximum payload length is about 40 feet, while the service module was 50 feet long. Second, an Orbiter docking port must be about 25 feet away from any part of the SOC that would be "above" and parallel to the Orbiter payload bay. With the other modules near the ends of the service module, a docking extension (figure 5.3-13a) would be required for delivery of other modules. This extension would require an additional launch unless it could be combined with the tunnel. Third, the requirement for 90-day survival of the loss of any one module makes the service module an unacceptable single failure point since all critical systems except life support are located there. All these difficulties were circumvented by the present configuration (figures 5.3-3 and 5.3-13b)) in which the service module consists of two identical halves. Section 5.3.3 discusses the service module in detail.

5.4 OPERATIONAL ORBIT CONSIDERATIONS

The selection of an operational altitude for the SOC is a very important factor, particularly in terms of overall long range operations. Specifically, some of the factors to be considered are: aerodynamic forces and torques, gravity gradient torques, altitude decay rates, types of missions that will use the center as a base, and the launch transportation system available for earth to SOC flights. Qualitatively, disturbances due to aerodynamics and gravity gradients decrease with increasing orbital altitude, thus resulting in lower fuel requirements. Likewise, orbital decay rates decrease with increase in orbital altitude which means that the number of refueling flights for orbit maintenance decreases and consequently that in the event of some SOC failure more time is available for repairs. Not all considerations point towards a higher orbital altitude for SOC operations. Given a particular launch system, trade-offs between number of flights to deliver payload weight to orbit and orbital altitude indicate that lower orbital altitudes require fewer flights resulting in lower cost per pound delivered. Operations at low orbital altitudes, while they are cost effective based on number of launches to deliver a given payload, have the disadvantage that decay rates, aerodynamic torques,

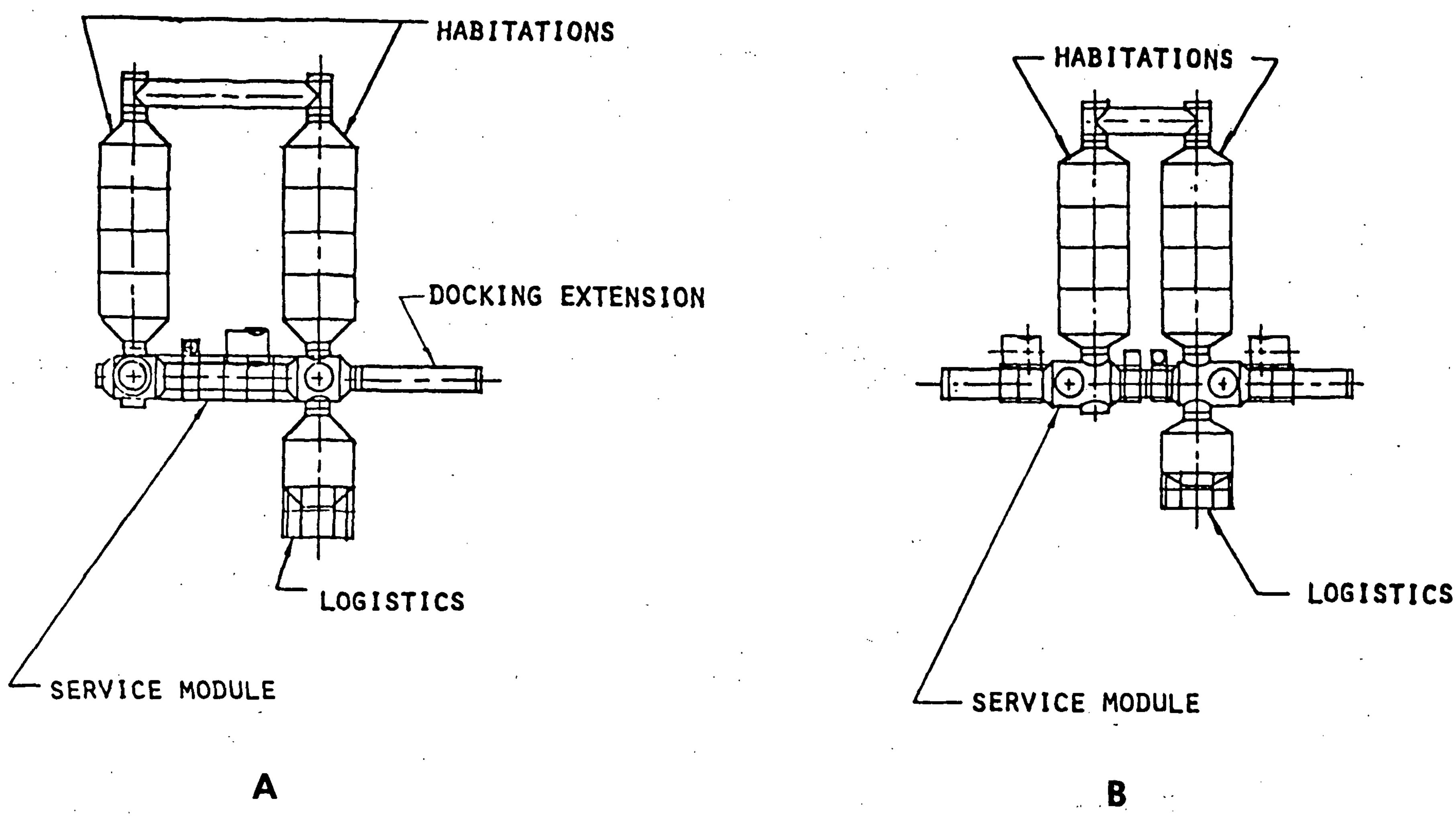


Figure 5.3-13. Service Module Configuration Effects

and attitude control torques are significantly higher. This indicates that more frequent fuel resupply launches are required which off-sets the cost effectiveness of the low altitudes. Based on data available at this time, it seems appropriate to recommend an operational altitude of 265 n.mi. This altitude is a compromise between the low altitude desirability based on number of launches to deliver a payload and the high altitudes which are optimum from the standpoint of aerodynamic and gravity gradient disturbances.

5.5 BUILDUP AND USE PLAN

This section provides a reference buildup and use schedule for the SOC. First, it outlines the overall use of the station from the initial launches in program year 8 through the early construction work starting in year 11 (figure 5.5-1). Then, the early construction work (represented by the blocked area in figure 5.5-1) will be discussed as a more detailed example of SOC activities.

The flight program begins with launch and unmanned docking of the service modules. Assuming that initially a single Shuttle is devoted to SOC activities and can be launched on one to two month centers, the first habitation module is then launched early in program year 9. The habitation module is berthed to the service modules, its interfaces connected (e.g., power, atmosphere, communications, and instrumentation) and the modules activated and thoroughly checked out. After about a weeks' stay the crew returns to Earth. Then the second habitation module is launched, its interfaces made, and the new module activated and checked out. The Shuttle then returns to Earth while leaving a four-man crew onboard the SOC. At this point, long duration assessments of man's ability to live and work in space can begin.

Assuming a schedule of three months for Shuttle revisits, crew changes, and logistics resupply, the first revisit would occur in year 9 and continue periodically thereafter. As much as possible, these flights would be incorporated in flights for other purposes.

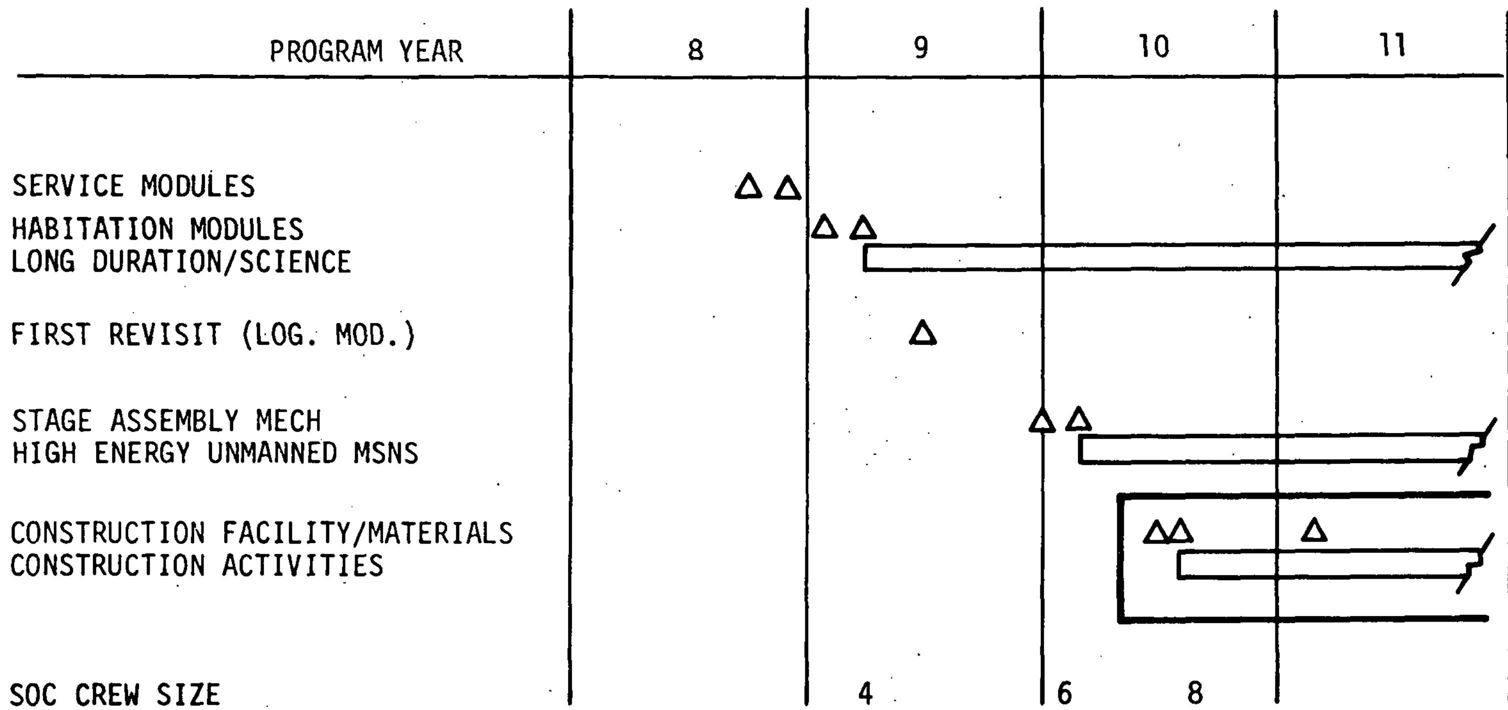


Figure 5.5-1. SOC Reference Build-Up And Use Schedule

Early in year 10, the stage assembly capability for unmanned high energy GEO and planetary missions would be added and the crew size increased to six. About six months later, construction facilities would be launched and the construction work described in Section 4.2 would begin. The crew size is increased to eight.

Thus, after three of four years, the SOC is conducting several major kinds of work. It serves as a station for assessing man's long duration capabilities to work and live in space, it assembles unmanned high energy GEO and planetary vehicles, and it is engaged in construction of large space satellites.

Figure 5.5-2 presents a matrix of estimated numbers of Shuttle flights by both year and function to accomplish the first three years of the SOC flight program.

As a more detailed example of SOC activities, figure 5.5-3 illustrates the early construction work. Following the launch of construction equipment, a six-month test and verification period is begun. Note 1 on the figure lists many of the kinds of functions needed to accomplish major construction tasks. Most of these functions will have been exercised in Shuttle sortie flights prior to the SOC. However, with the SOC, they can now be integrated and conducted with actual equipment that can be used for large-scale construction. This will verify and establish experience in both techniques and equipment.

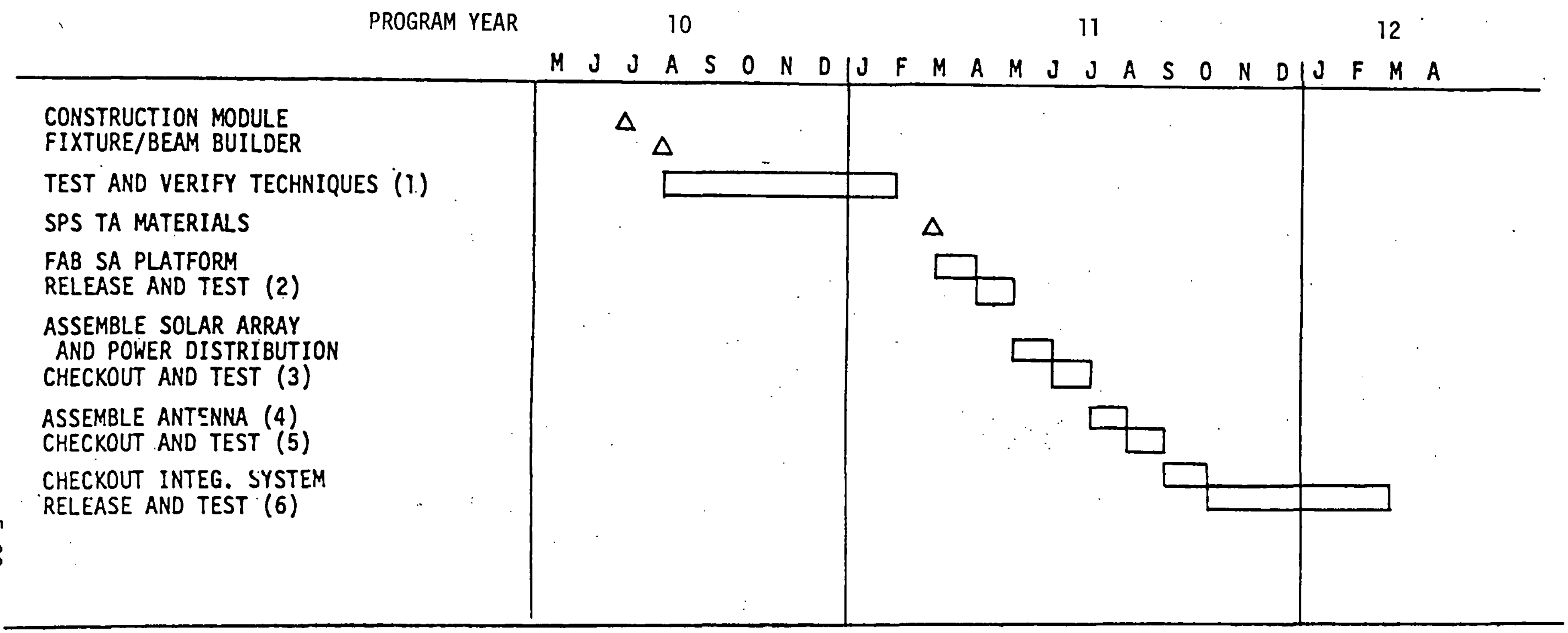
Following this verification period, the first large construction job will be to manufacture a 250 kW SPS test article. This is accomplished in three distinct steps: the fabrication of the solar array platform structure, the assembling of the solar arrays and power distribution, and the assembling of the microwave antenna. At each step the system is thoroughly checked out. Finally, the total integrated system is flown in a test program with a beam mapping satellite. The total set of activities associated with the test article illustrates the value of a permanently manned facility. It is difficult to envision how this work could be done effectively using only Shuttle sortie flights.

PROGRAM YEAR	8	9	10	11	TOTAL
BASIC SOC MODULES (SERVICE & HAB.)	2	2			4
LOGISTIC/REVISITS*		2	2 + (2)	4	8 + (2)
CONSTRUCTION EQUIPMENT			2		2
CONSTRUCTION MATERIALS				1	1
DEPOT HARDWARE			2		2
UNMANNED OTV STAGES/PROP**			4	4	8
TOTAL	2	4	10	9	25

* NUMBER OF FLIGHTS IN PARENTHESES DONE IN CONJUNCTION WITH FLIGHTS FOR OTHER PURPOSES

** ASSUMES TWO GEO/PLANETARY FLIGHTS/YEAR

FIGURE 5.5-2 MATRIX OF SHUTTLE USES



NOTES:

(1) BEAM MAKING
ERECTING/DEPLOYING
POSITIONING/BERTHING/ALIGNING/MOVING
JOINING/ASSEMBLING/FASTENING
ELECTRICAL AND FLUID CONNECTIONS
EVA WORK
LIGHTING
CHECKOUT DEVICES
EQUIPMENT MAINTENANCE
TIMELINING

(2) STRUCTURAL DYNAMICS
MECHANICAL ALIGNMENT
THERMAL STABILITY

(3) COLLECTOR OUTPUT VOLT, POWER, EFF. AS FUNCTIONS OF TEMPERATURE, ORIENT-VERIFY
MAINTENANCE PROCEDURES

(4) DEPLOY STRUCTURE
INSTALL POWER DISTRIBUTION
INSTALL ANTENNA PANELS

(5) EFFICIENCY, LEAKAGE
ALIGNMENT, CALIBRATION

(6) MICROWAVE XMISSION AND PHASE CONTROL
RFI EFFECTS
SPACE PLASMA EFFECTS
END-TO-END FUNCTIONAL VERIFICATION

FIGURE 5.5-3. SOC EARLY CONSTRUCTION ACTIVITIES

6.0 DEVELOPMENT PLANNING

The development of the SOC is based upon a foundation which is provided by previous space flight programs culminating in the Skylab and Shuttle programs. In particular, Skylab provides the basis for confidence in projecting the capability of man to function for long durations in zero-G flight. There is also a data base for long duration flight systems. The design requirement for Shuttle Orbiter systems is 100 missions of fourteen days each which amounts to nearly four years of flight time. These systems are designed and verified for that life assuming the replacement and maintenance of the systems components as required.

The development of the SOC would proceed with an operational analysis study of the program's long-term goals. This analysis would define the requirements for the design of the SOC configuration, the systems performance capacity, and the SOC functional capability. Following this, phased studies can be initiated to conceptualize the SOC in preparation for the final phases to design and to produce the hardware for flight. A schedule for this development is shown in figure 6.1. The operational analysis study of the SOC would be performed initially. Concept and preliminary design studies for the habitable module and service module would be initiated subsequently. Detailed design and hardware production would start three years after initiation of systems analysis. After three and one-half years for production and integrated testing and six months for delivery and checkout at the launch site, the service module and habitable module would be launched to establish the initial operating capability of the SOC. The remaining facets of the SOC are scheduled for specific desired operational dates. The critical part of the schedule is the three and one-half years for production of the service and habitation modules. The time estimated is based on a comparison with the Skylab production schedule. A brief examination of the projected time needed for each subsystem of the SOC verifies this except for the time estimated for the software development. Further study will be done to explore the possibility of reducing the software requirements for the initial flight of the SOC to bring that subsystem in line with the overall schedule.

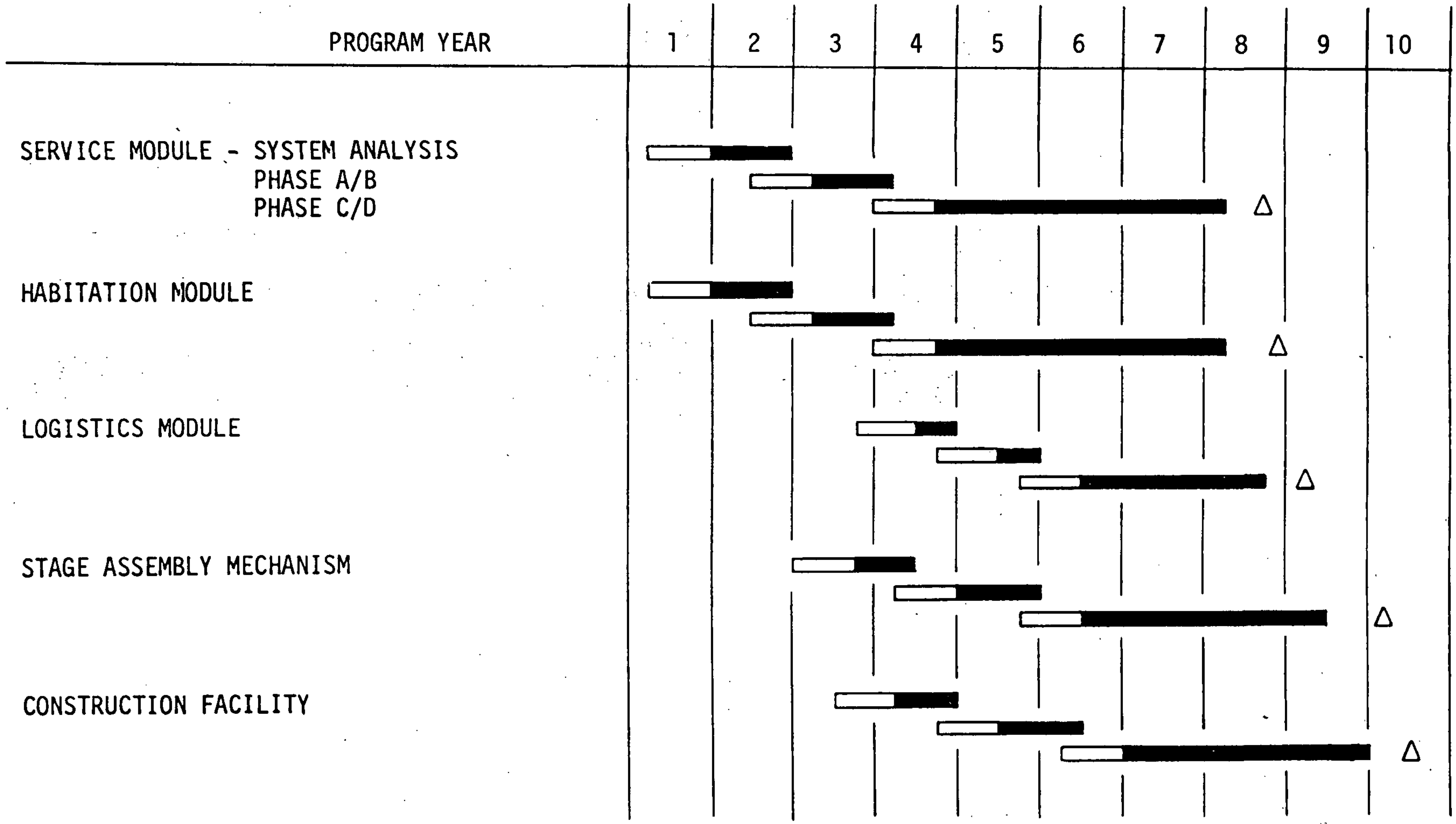


Figure 6.1 Space Operations Center Schedule

7.0 SPACE OPERATIONS CENTER COST ESTIMATE

7.1 PURPOSE

The purpose of this section is to present a total program cost estimate for the SOC. The work breakdown structure (WBS) used for this estimate forms figure 7.1. It should be noted that the estimate includes all program cost elements, not just those related to the space facility. All NASA in-house activities are included, as well as launch facility costs and overall management costs. Table 7.2 contains cost summary for the SOC.

7.2 GROUNDRULES AND ASSUMPTIONS

A. FY78 $ in millions.

B. 90% learning.

C. Projects phased such that design inheritance is possible.

D. NASA in-house organization and functions similar to today

   (1) No substantial data base
   (2) Testing by NASA instead of contractors where possible

E. Two production lines.

F. Each module assumes its own management and integration cost.

7.3 APPROACH

7.3.1 Space Facility

Costs were estimated at the subsystem level, or lower, and accumulated by module. Standard aerospace cost estimating relationships were generally used for the estimate except for data/communications for which the RCA PRICE model was used. The first module requiring a WBS element was charged with the DDT&E and TFU of that element. Following modules benefitted. In addition it was assumed that there was some design

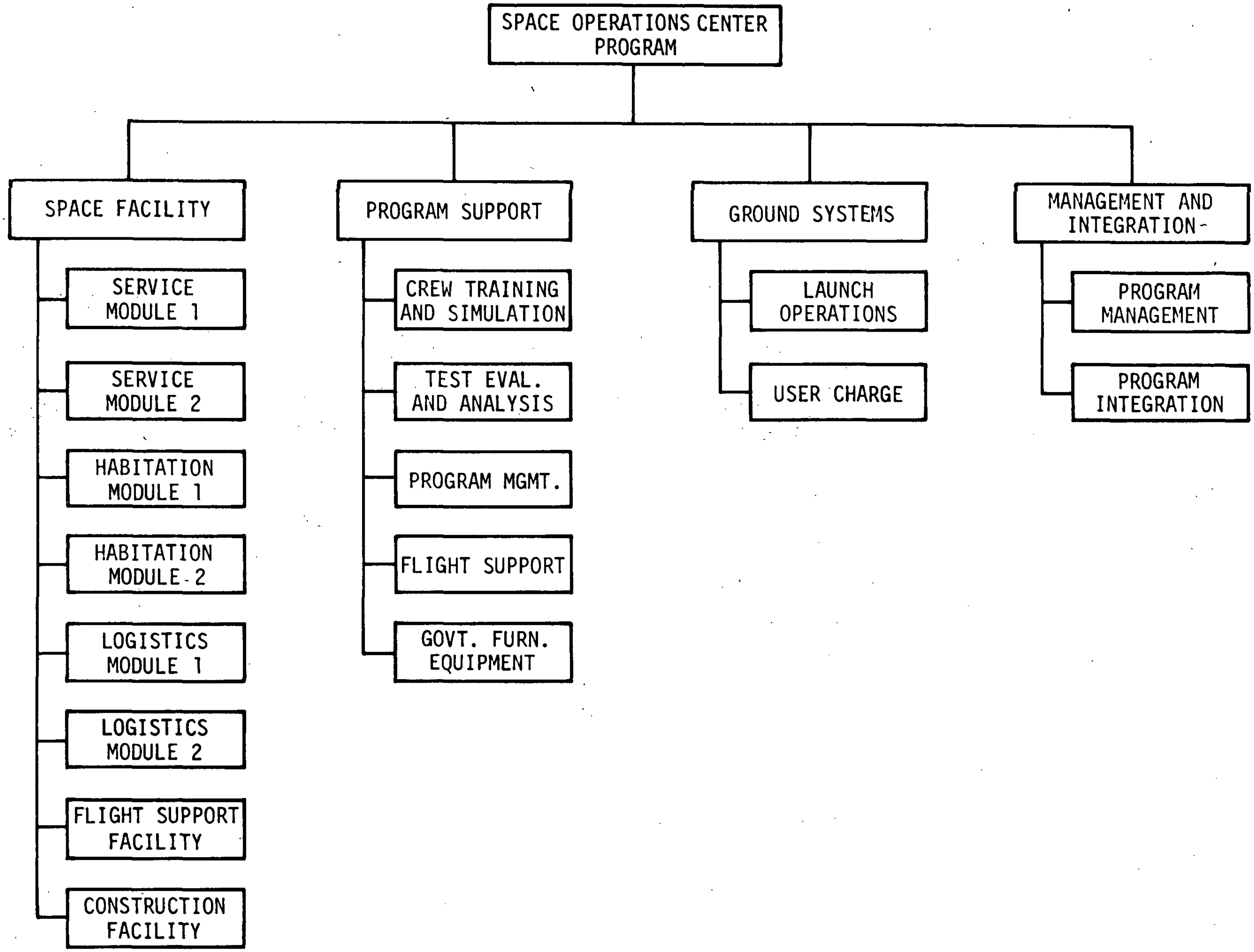


Figure 7.1. Space Operations Center Cost Work Breakdown Structure

TABLE 7.2
SPACE OPERATIONS CENTER
SUMMARY OF TOTAL COSTS
78 $'s in Millions

PROGRAM YEAR	2	3	4	5	6	7	8	9	10	TOTAL
PHASE A, B	(.3)	2	10							12
SERVICE MODULE										
1				61	142	197	106	33		539
2				22	40	46	35	27		170
HAB. MODULE										
1				71	176	213	102	24		584
2				13	34	49	27	4		127
LOGISTICS MODULE										
1				5	11	29	21	8		74
2					3	10	6	5		24
CONSTR. FACILITY				10	10	50	70	50	28	218
L&R SVC. FACILITY				10	10	50	60	30	16	176
SUBTOTAL	(.3)	2	10	192	426	644	427	181	44	1924
PROGRAM SUPPORT				100	172	145	111	86	38	654
PROGRAM INTEGRATION				10	10	10	10	10	20	70
SPECIAL HANDLING EQUIP				2	15	15	10	8	3	52
TOTAL	(.3)	2	10	304	623	814	558	285	104	2700

inheritance in the case of later structures since all of the major structures were aluminum and were constrained in size and shape by the 15 x 60 Orbiter payload bay. Tables 7.3-7.8 provide subsystem level costs for each module.

7.3.2 Program Support

As mentioned earlier, the assumption was made that there would be no substantial DTMO base; consequently, the SOC program would assume the cost of most in-house activities. Table 7.9 contains the "grassroots" estimate developed for SOC program support.

7.3.3 Ground Systems

This WBS element consists of launch operations, the largest single item of which is a second line of Ground Support Equipment.

7.3.4 Management and Integration (M&I)

It was assumed that 100 people would be required for the first year and 200 people for each year afterward. An annual off-site rate of $50,000 was used to calculate cost.

TABLE 7.3
SPACE OPERATIONS CENTER
SUMMARY OF PROJECT COST
- SERVICE MODULE
FY 78 $ IN MILLIONS

	DDT&E PROD. SM 1	SM2	TOTAL
STRUCTURE	76	9	85
TOOLING	14	-0-	14
ELECTRICAL POWER	78	46	124
ECLSS	1	1	2
RCS	58	11	69
THERMAL CONTROL	7	-0-	7
SG&C	87	11	98
COMM/DATA	28	17	45
DOCKING	12	4	16
HATCH	5	2	7
AIRLOCK	5	2	7
SOFTWARE	24	4	28
HARDWARE SUBTOTAL	395	107	502
SPARES (15%)	17	17	34
INTEG., ASSY., & C/O	16	16	32
PROJECT MANAGEMENT	13	3	16
SYST ENGR & INTEG	36	9	45
SYSTEM TEST	27	8	35
GSE	36	9	45
LOGISTICS	4	1	5
SUBTOTAL	544	170	714
PROGRAM SUPPORT AND INTEGRATION	184	78	
TOTAL	728	248	976

C-2

TABLE 7.4

SPACE OPERATIONS CENTER
SUMMARY OF PROJECT COST
HABITATION MODULE #1
FY 78 $ IN MILLIONS

WBS ELEMENT	DDT&E	PROD	TOTAL
STRUCTURE	43	11	54
TOOLING	1	3	4
ELECTRICAL POWER	0	3	3
ECLSS	170	27	197
RCS	0	0	0
THERMAL CONTROL	0	0+	0+
SGN&C	20	4	24
COMM/DATA	44	16	60
DOCKING	0	0	0
SOFTWARE	90	8	98
HARDWARE SUBTOTAL	368	72	440
SPARES (15%)	0	11	11
INTEG., ASSY., & C/O	0	11	11
PROJECT MANAGEMENT	11	2	13
SYST ENGR & INTEG	33	6	39
SYSTEM TEST	26	5	31
GSE	33	6	39
LOGISTICS	4	1	5
SUBTOTAL	475	114	589
PROGRAM SUPPORT AND INTEGRATION			195
TOTAL			784

TABLE 7.5

SPACE OPERATIONS CENTER
SUMMARY OF PROJECT COST
HABITATION MODULE #2
FY 78 $ IN MILLIONS

WBS ELEMENT	DDT&E	PROD	TOTAL
STRUCTURE	0	10	10
TOOLING	0	0	0
ELECTRICAL POWER	0	3	3
ECLSS	0	24	24
RCS	0	-	-
THERMAL CONTROL	0+	0+	0+
SGN&C	0	0	0
COMM/DATA	0	7	7
DOCKING	0	0	0
TUNNEL	3	5	8
SOFTWARE	30	3	33
HARDWARE SUBTOTAL	33	52	85
SPARES (15%)	0	8	8
INTEG., ASSY., & C/O	0	8	8
PROJECT MANAGEMENT	1	2	3
SYST ENGR & INTEG	3	5	8
SYSTEMS TEST	2	4	6
GSE	3	5	8
LOGISTICS	0+	1	1
SUBTOTAL	42	85	127
PROGRAM SUPPORT AND INTEG.			63
TOTAL			190

TABLE 7.6

SPACE OPERATIONS CENTER
SUMMARY OF PROJECT COSTS
LOGISTICS MODULE
FY 78 $ IN MILLIONS

	DDT&E PROD. LOG. #1	LOGISTICS MOD. #2	TOTAL
STRUCTURE	36	7	43
TOOLING	1	1	2
ELECTRICAL POWER	3	3	6
ECLSS	1	1	2
RCS	0	0	0
THERMAL CONTROL	13	3	16
SGN&C	0	0	0
COMM/DATA	0	0	0
DOCKING	0	0	0
HARDWARE SUBTOTAL	54	15	69
SPARES (15%)	3	3	6
INTEG., ASSY., & C/O	3	2	5
PROJECT MANAGEMENT	2	1	3
SYST ENGR & INTEG	4	1	5
SYSTEM TEST	4	1	5
GSE	4	1	5
LOGISTICS	0	0	0
SUBTOTAL	74	24	98
PROGRAM SUPPORT AND INTEGRATION	30	10	
TOTAL	104	34	138

TABLE 7.7
SPACE OPERATIONS CENTER
SUMMARY OF PROJECT COST
SPACE CONSTRUCTION FACILITY
FY 78 $ IN MILLIONS

WBS ELEMENT	DDT&E	PROD	TOTAL
POWER DISTRIBUTION	0	3	3
RCS	0	-	-
COMM/DATA	0	2+	2+
SOFTWARE	12	2	14
DOCKING	0	2	2
MRWS	23	3	26
BEAM BUILDER	16	4	20
JIG	12	2	14
RMS ARM	6	10	16
RMS CAB	36	22	58
RMS ATTACH STRUCTURE	5	1	6
HARDWARE SUBTOTAL	110	51	161
SPARES	0	7	7
INTEG., ASSY., & C/O	0	8	8
PROJECT MANAGEMENT	3	1	4
SYST ENGR & INTEG	9	4	13
SYSTEM TEST	7	3	10
GSE	9	4	13
LOGISTICS	1	1	2
SUBTOTAL	139	79	218
PROGRAM SUPPORT AND INTEGRATION			108
TOTAL			326

TABLE 7.8
LAUNCH RETRIEVAL AND SERVICING FACILITY
SUMMARY OF COSTS - 78 $ IN MILLIONS

	DDT&E	PROD	TOTAL
STAGE ASSEMBLY MECHANISM	36	45	81
STRUCTURE	25	7	32
RMS	6	8	14
CAB	3	22	25
MRWS	2	3	5
DOCKING/BERTHING	0	3	3
POWER DISTRIBUTION	0	1	1
ECLS	0	1	1
PROPELLANT TRANSFER FACILITY	37	5	42
AVIONICS	30	4	34
PUMP	3	0+	3
LINES	4	1	5
SPARES	0	8	8
INTEG, ASSY & CHECKOUT	0	8	8
PROJECT MANAGEMENT	2	2	4
SYSTEMS ENGINEERING & INTEGRATION	7	4	11
SYSTEM TEST	5	4	9
GSE	7	4	11
LOGISTICS	1	1	2
SUBTOTAL	95	81	176
PROGRAM SUPPORT AND INTEGRATION			98
TOTAL			274

TABLE 7.9
SPACE OPERATIONS CENTER
PROGRAM SUPPORT
FY 78 $ IN MILLIONS

PROGRAM YEAR	5	6	7	8	9	10	TOTAL
CREW TRAINING & SIMULATION	25	46	44	23	11	6	155
- HAB & SM TRAINER	10	26	26	11			73
- FAB & ASSY TRAINER	7	4	5				16
- MMU TRAINER	3	4	3				10
- CREW PROCEDURES DEVELOPMENT	-	6	5	6	5	3	25
- SIMULATOR OPERATION & SUST. SUPPORT	5	6	5	6	6	3	31
TEST, EVALUATION & ANALYSIS	17	45	55	54	43	16	230
- ENGINEERING VERIFICATION LABORATORY	6	21	35	36	26	6	130
- SUPPORTING DEVELOPMENT	4	5	4	4	4	2	23
- SAFETY, RELIABILITY & QUALITY ASSURANCE	1	3	2	2	2	1	11
- MATERIALS QUALIFICATION	1	5	4	3	3	2	18
- LABORATORY SUPPORT	1	5	4	3	2	1	16
- TEST CHAMBER SUPPORT	1	1	1	1	1	1	6
- IN-LINE TASKS	3	5	5	5	5	3	26
PROGRAM MANAGEMENT	4	3	3	2	2	2	16
FLIGHT SUPPORT	38	49	30	32	30	15	194
- MISSION CONTROL CENTER MODS & OPS	18	21	6	6	6	1	59
- DATA REDUCTION CENTER MODS & OPS	1	4	3	3	3	1	15
- MISSION PLANNING (FOD)	2	3	3	3	2	1	14
- FLIGHT PLANNING	4	4	4	4	4	2	22
- CENTRAL ENGR ANAL & PLNG COMP FAC (BLD 12)	6	6	6	6	6	3	33
- GROUND SOFTWARE	7	10	9	9	9	7	51
GOVERNMENT FURNISHED EQUIPMENT	16	29	13				58
- EXTRAVEHICULAR MOBILITY UNIT	10	22	10				42
- PORTABLE O_2 SYSTEM	2	2	1				5
- CAMERAS	2	2	1				5
- CREW PROVISIONING & EQUIPMENT	2	2	1				5
- RADIATION MONITORING EQUIPMENT		1					1
TOTAL	100	172	145	111	86	38	654

8.0 COMPARISON WITH 25 KW POWER MODULE

The original concept of the service module (SM) was a single structural entity, with power, control and communications gear, providing access to the other modules of the SOC. It is not difficult to conceive of an accident to the SM that would cause the loss of all access as well as some critical subsystems. In addition, the SM was the heaviest single module based on initial estimates and was uncomfortably close to the Shuttle capability. Accordingly, some attention was devoted to building and launching the SM in two halves.

The preliminary configuration is shown in figure 8.0-1. Subsystems are divided between the two identical halves with interconnections as necessary. Since the subsystems had been planned for extensive redundancy, this approach does not greatly increase total subsystem weight. The solar array boom extends on one side of the SM and supports half of the total array area. When the two halves are joined (figure 8.0-2), the array booms extend on both sides of the completed SM.

This configuration offers complete isolation for the two halves of each subsystem in the SM, as well as maintaining the pressure integrity of half the SM in the event of a puncture or other damage. It also greatly reduces the maximum weight per launch, and keeps each module short enough to fit in the Shuttle payload bay with a docking module and an OMS kit.

The revised configuration parallels closely the size and functions of the 25 kW power module (PM) under study as a free-flying support module for various science and applications payloads. A comparison of the two modules was made to determine whether a common design might be developed to satisfy both applications.

The system requirements comparison is summarized in table 8.0-1. The major differences are the lack of pressurization in the PM, the very large software requirements of the SM, the second degree of freedom in the SM solar array, the 115V, three-phase SM electrical bus, and the significantly greater communications and data handling requirements of the SM. The SM requirements are more severe in every case except pointing accuracy, and even this can be easily accommodated by the SM control system. It appears

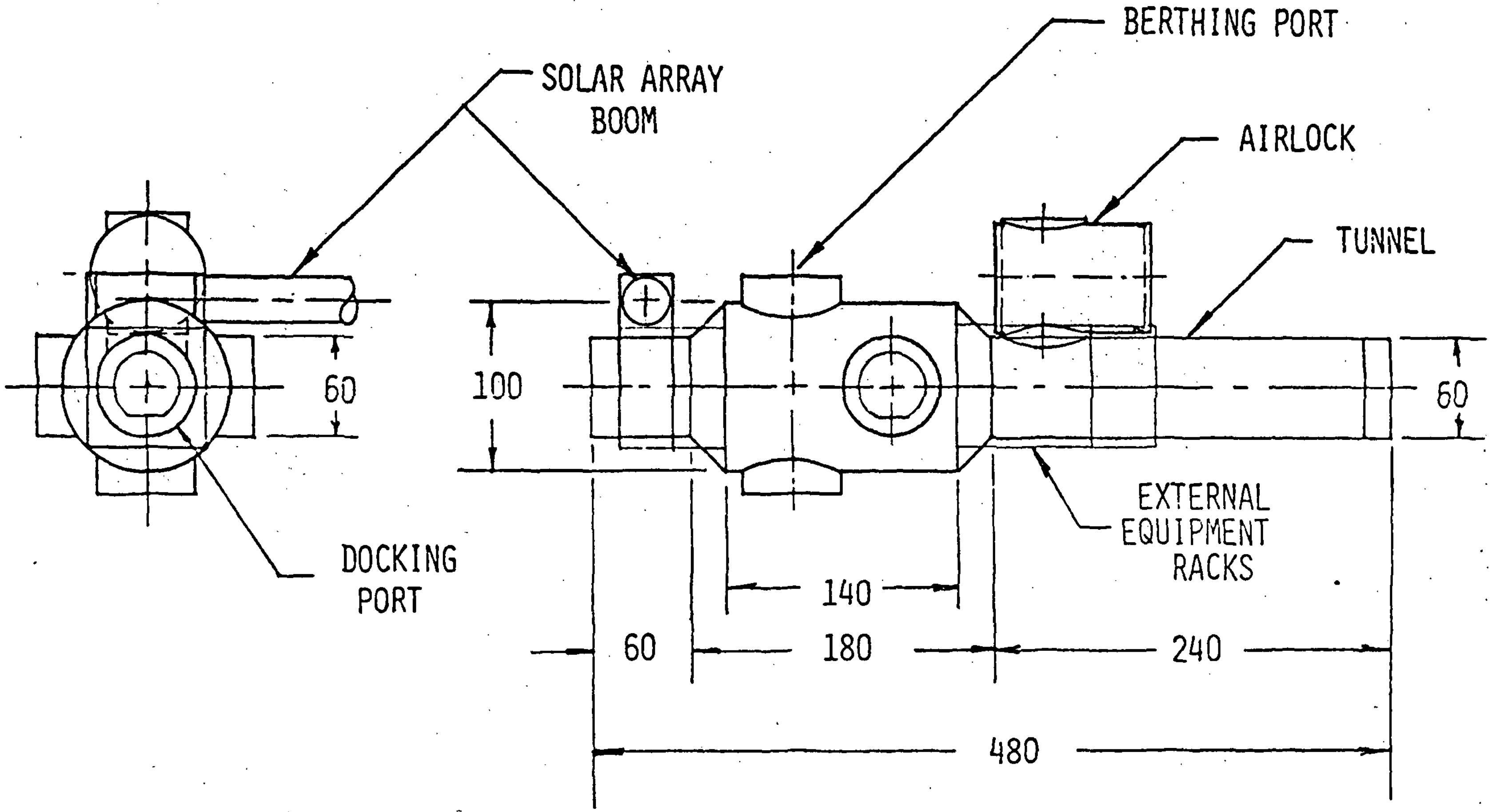
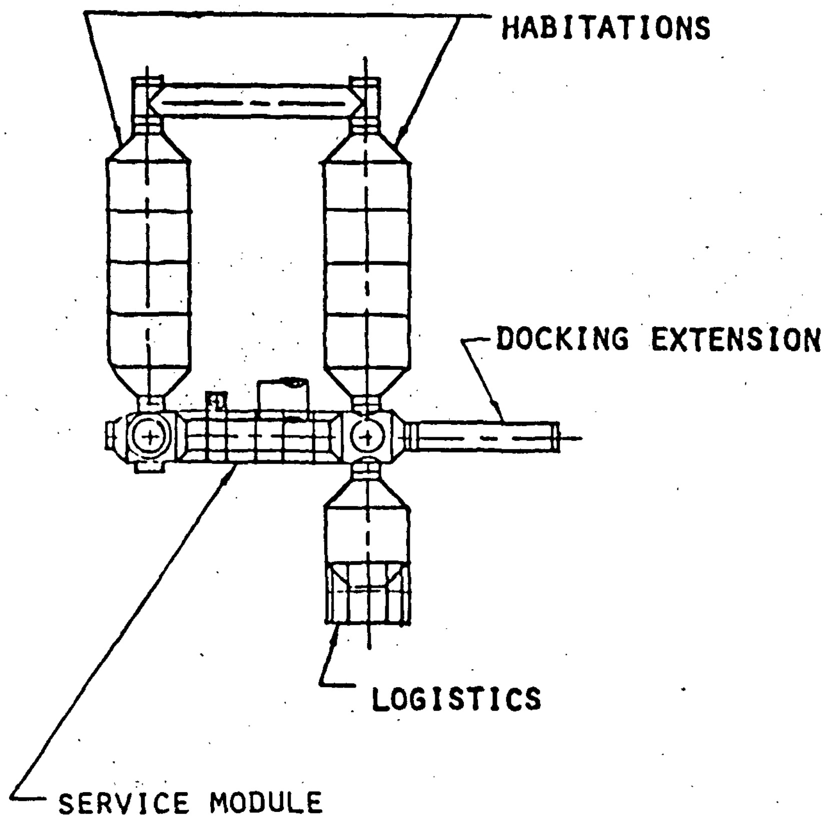
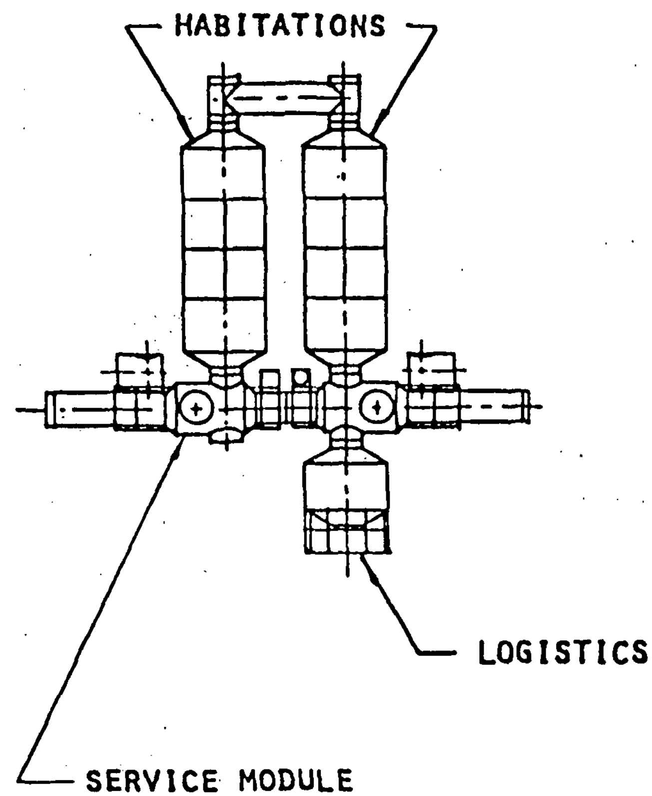


Figure 8.0-1. Service Module



SINGLE SERVICE MODULE



DUAL SERVICE MODULES

Figure 8.0-2. Service Module Configuration Effects

Table 8.0-1. System Requirements

SOC SM	25 kW PM
STRUCTURES	
- 10 DOCKING/BERTHING PORTS	- 2 DOCKING PORTS AND GROUND ACCESS HATCH
- PRESSURIZED TRANSFER WITHIN SM	- UNPRESSURIZED
- AIRLOCK	
AVIONICS/SOFTWARE	
- POINTING $\pm 5°$	- POINTING $\pm 0.5°$
- MOMENTS OF INERTIA 6 TO 10 MILLION SLUG-FT^2	- MOMENTS OF INERTIA 0.1 TO 0.3 MILLION SLUG-FT^2
- 6 IMPROVED SKYLAB CMG'S	- 3 SKYLAB CMG'S
- SOFTWARE (GN&C, CONTROL, DISPLAY, INTERFACE, CHECKOUT & FAULT ISOLATION, DATA MANAGEMENT, ETC.)	
REACTION CONTROL	
- CMG DESATURATION	- ORBIT MAINTENANCE
- ORBIT MAINTENANCE	

Table 8.0-1. System Requirements (Cont.)

SOC SM	25 kW PM
ELECTRICAL POWER	
- CONTINUOUS OUTPUT 35 kW (EOL)	- CONTINUOUS OUTPUT 25 kW PLUS 2 kW FOR INTERNAL SYSTEMS (EOL)
- 28V DC	- 30 V DC
- 115 V, 3 PHASE, 400 Hz	
- 2 D.O.F. SOLAR ARRAY (CONTINUOUS AND ± 52°)	- 1 D.O.F. SOLAR ARRAY (± 180°)
THERMAL CONTROL	
- 18 kW FROM SM	- 9 kW FROM PM - 12 kW FROM USER
- 700 FT^2 DOUBLE-SURFACE RADIATORS	- FOUR ORBITER DOUBLE-SURFACE RADIATORS (~ 650 FT^2)

Table 8.0-1. System Requirements (Concl.)

COMMUNICATIONS AND DATA HANDLING

SOC SM*	25 kW PM
- TDRSS COMMANDS (UPLINK) TELEMETRY (DOWNLINK) TELEVISION (DOWNLINK) VOICE (2-WAY) TEXT AND GRAPHICS (2-WAY)	- TDRSS (STDN BACK-UP) OR ORBITER COMMANDS (UPLINK) - 1 KBPS TELEMETRY (DOWNLINK) - 4 KBPS
- ORBITER VOICE (2-WAY) TRACKING	
- FREE FLYERS COMMANDS (FROM SOC) TELEMETRY (TO SOC) VOICE (2-WAY) TV (TO SOC)	
- EVA VOICE (2-WAY) EKG	
- INTERNAL DISTRIBUTION DATA TV AUDIO	- INTERNAL DISTRIBUTION DATA

*SOME COMMUNICATIONS COMPONENTS MAY BE IN OTHER MODULES feasible in principle, therefore, to utilize one-half of the SM as a PM by removing any components that are not needed for the PM mission.

Conversion of a SM to a PM is less attractive in practice than in principle, however. The solar array installation would not be usable in its SM form because of the large aerodynamic torques that would result from the asymmetry. The solar array mount would consequently have to be reconfigured for the PM application. Within each half of the SM, critical subsystem redundancy is required only for the brief period (one or two months) before the attachment of the second half. The PM, on the other hand, must be able to survive for extended periods and would require a different redundancy/back-up philosophy. Some PM missions may involve orientations not applicable to the SOC; there may as a result be a requirement for additional sensor locations and/or types. There could also be configurational incompatibilities for some PM missions, although none has been identified.

This is not to say that such a conversion is impractical, or that a common module or partially common modules could not fulfil both missions. However, if any degree of dual usage is desired, it is clear that such a requirement must be considered from the outset in the design process.

9.0 SUBSYSTEM DESCRIPTIONS

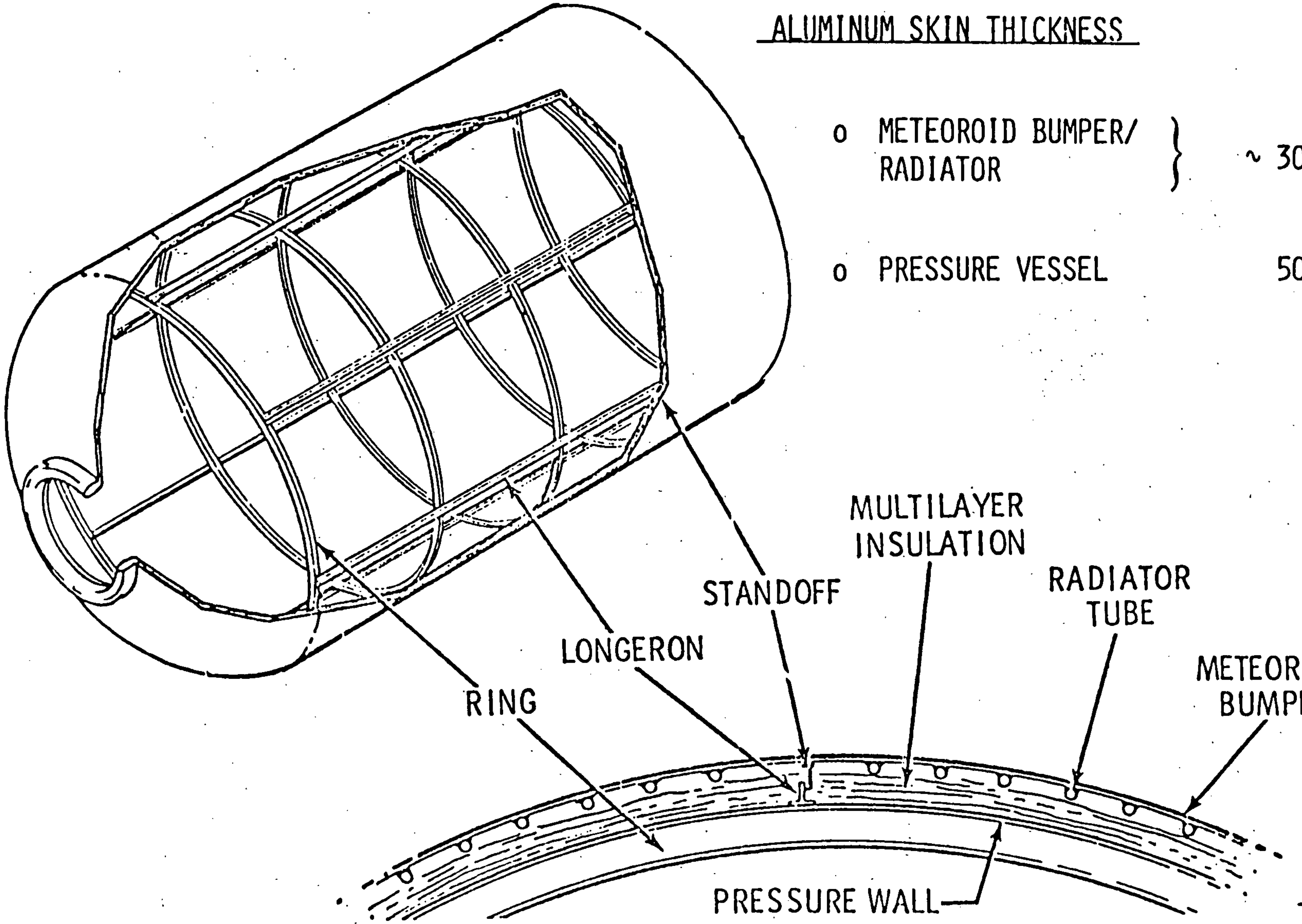
This section presents results and configurations obtained in the SOC initial design effort.

Subsystem design approach, technology requirements, potential alternatives and means of comparison will be addressed. Most elements of the SOC will draw heavily on Skylab, Shuttle and PEP hardware; however, advantages will be demonstrated in new technology systems where applicable, e.g., nickel hydrogen batteries. Cost items were presented in Section 7 and in general will not be addressed on a subsystem basis.

9.1 STRUCTURES

Consideration of the structural characteristics of the SOC draws heavily on experience gained through manned spacecraft programs and previous space station studies (e.g., reference 9-1). The SOC structure has the obvious requirements of pressure integrity for pressurized modules, external and internal load capability and adequate stiffness for control and operations. There are no structural requirements which would affect the overall rationale for the SOC. Also, structural life is not a significant issue for habitability or service modules since the dominant loading is experienced as a result of launch (or landing) accelerations. Structural loads associated with on-orbit operation are characteristically low in this relatively benign environment. Stiffness adequate for attitude control and operation is much more significant to structural design than operational loads.

A representative structural configuration for an SOC habitation module shown in figure 9.1-1 consists of a pressure vessel with internal rings, external longerons and a combination meteroid bumper-radiator (see Section 9.3) set off from the pressure vessel. With a high strength, weldable aluminum such as 2219 and a 15-foot diameter vessel at 15 psia pressure, the minimum (no factor-of-safety) monocoque skin thickness is about 20 mils. When a reasonable factor-of-safety is applied the required skin thickness is less than typical micrometeoroid and radiation protection



ALUMINUM SKIN THICKNESS

- METEOROID BUMPER/ RADIATOR — ~ 30 MIL
- PRESSURE VESSEL — 50 MIL

Figure 9.1-1. Representative Structural Configuration For Habitation Module requirements. These requirements, plus a minimum gauge of 80 mils for welding point toward the use of a lower performance more workable aluminum such as 6061. It may be cost effective to even take a weight penalty in the pressure vessel skin to reduce fabrication costs.

The habitation and service modules are felt to be state-of-the-art aluminum structures which would not require any technology development for design, engineering and fabrication. The structures associated with the SOC facilities are not as well defined, however; it is possible that these structures could benefit from technology development activities. The options are somewhat open depending on the desired capability of in-space activities. For example, if it was desirable to take advantage of the benign load environment in space for fabrication of high performance, precision structures, then the technology development associated with the construction facility would be required. In contrast, a relatively low technology construction facility could build large but not necessarily high performance or high precision structures.

The design and development philosophy recommended for the habitation, logistics and service module structures is a low cost approach of simplicity with a strong front end design effort that produces firm specifications and straightforward interface control requirements. It might then be possible to pursue fabrication through a fixed price contract. The structures could be made in a modular fashion using common tooling and jigs for the components. The secondary structure could be made as kits for interchangability and flexibility in the internal configuration.

Based on previous studies, the structure weight of a habitation module is estimated to be about 15% of the total module weight. This is about equally divided between secondary structure and prime structure. Since the major loads are associated with launch (or landing), the secondary structure requirements can be held to a minimum by configuring the module for launch (or landing) or by the use of "shipping" supports. Operational configuring of the internal systems would then be performed in orbit.

The SOC facilities design and development is a considerably different process from the habitation, service and logistic modules. Here there is more of a tradeoff between an extensive front end design effort and the learning experience of space operation. For example, in the consideration of the construction processes, the design and engineering effort without any flight experience would be considerably more extensive than a design and engineering effort which had the benefit of key flight experiments.

A preliminary assessment of the dynamics and control associated with the SOC identified three distinct phases and related issues. The first phase is that of SOC assembly. Flight experience with the Orbiter RMS will be of great benefit to the engineering and development of operational procedures for the SOC assembly. In addition, evaluation of this phase will be of considerable benefit to the design of the Orbiter docking system. Although we have flight experience with manned spacecraft docking, the Orbiter/SOC system presents greater moments of inertia about the docking interface and potentially the need for greater attenuation of flexible body dynamics. This phase of the SOC dynamics and control requires more detailed design definition for assessment.

The second phase of dynamics and control issues is associated with the stiffness characteristics of a fixed geometry SOC or SOC/Orbiter configuration. Preliminary calculation of the stiffness characteristics of SOC components and interfaces have been made. Some representative lowest order component dynamic frequencies are illustrated in figure 9.1-2. Although the major mass components will probably have frequencies in the order of from 1 to 10 Hz there can be components and overall system modes with frequencies in the order of .1 Hz. Consultation with our control experts has indicated that classical frequency separation between attitude control forcing function frequencies and these dynamic frequencies can probably be achieved with CMG's. It is also felt that RCS operation could achieve an adequate frequency separation for modes of 1 Hz or greater; however, separation from modes of the order of .1 Hz will require a more detailed investigation.

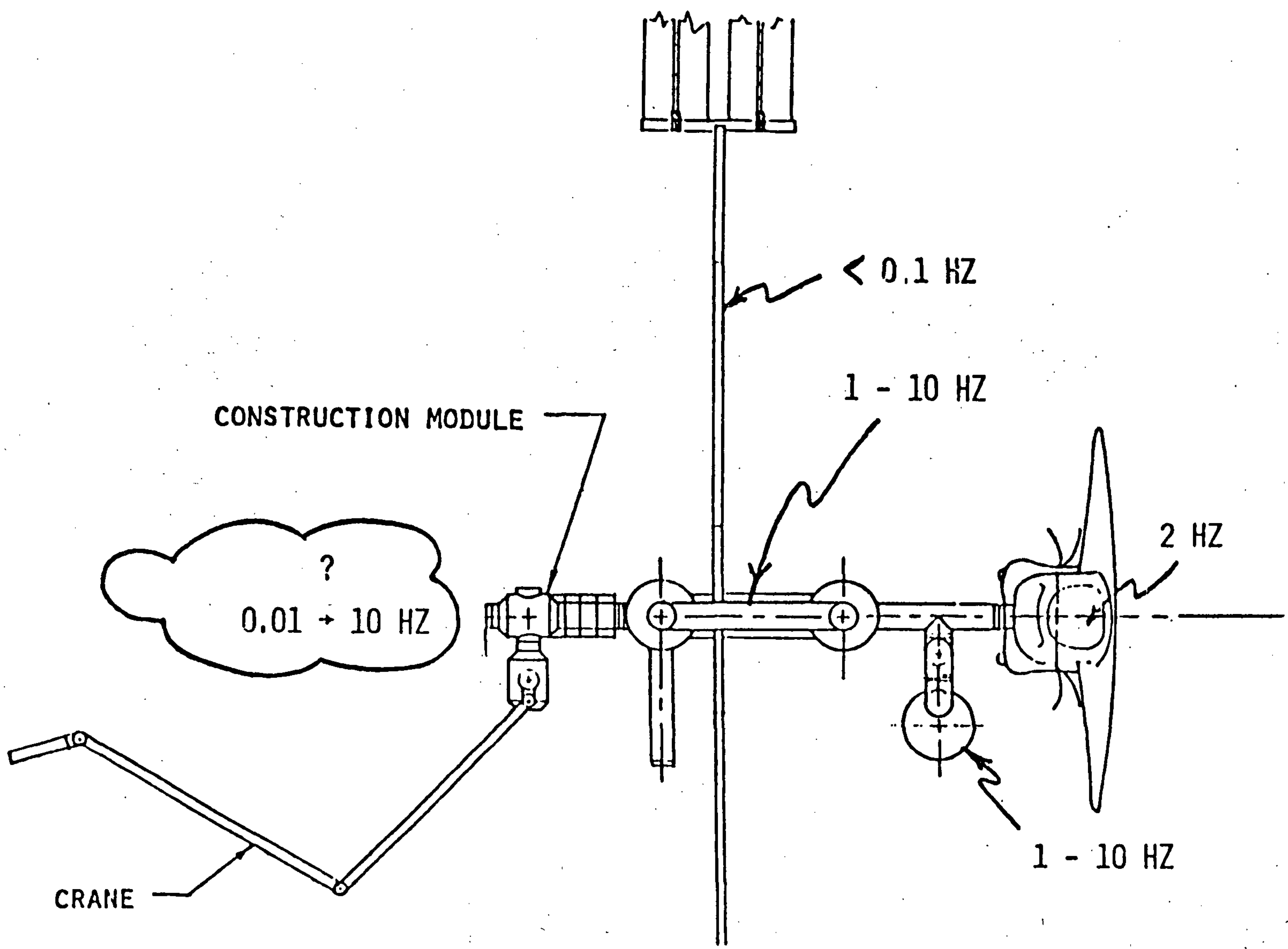


Figure 9.1-2. Preliminary Lowest Order Frequencies of SOC Components

The third phase of dynamics and control interactions associated with the SOC involves the routine movement of significant amounts of mass. Relative accelerations can be held to reasonable limits to limit transient forces and torques. However, referrring to figure 9.1-2, relative velocities parallel to the axis of the service module or parallel to the Orbiter axis produce coriolis accelerations or relative forces and torques. Neglecting the application of control torques, these motions represent potential changes in the moment of inertia for a fixed angular momentum. The net effect is to alter the angular velocity just as an ice skater extending or retracting her arms. The torque required to maintain a fixed attitude or given angular velocity while translating significant masses along these axis can dominate the control torque requirements (3×10^4 ft-#-sec for the movement of 10^4#, 300 ft through the construction facility). It is not clear that a fixed attitude or equivalent constraint is required; however, attitude control of an SOC will have to contend with the effects of variable geometry.

There is one other aspect of the SOC dynamics, and that is the potential for repetitive operations other than attitude control which might occur at frequencies within the range of the structural dynamic modes (e.g., repetitive construction operations like a beam builder operation). Although these would require assessment it is highly probable that the amount of dynamic energy available could be handled with moderate damping.

9.2 LIFE SUPPORT

9.2.1 Requirements and Assumptions

The requirements and assumptions which guided the ECLSS concept selection and sizing are as follows:

1. Two habitability modules in the SOC.
2. Crew size is eight men.
3. A resupply interval of 90 days sizes waste tanks and expendables.
4. A four-man ECLSS will be located in each habitability module.

5. Each four-man ECLSS will have eight-man off-design emergency capability for 90 days duration.

6. The ECLSS is maintainable. Launch weights and resupply weights contain an estimate for spares and expendable components, i.e., filters, chemical beds.

7. Twelve lbs. of atmospheric (air) leakage per day at 14.7 psia cabin pressure.

8. Initial pressurization requirements of SOC not included in ECLSS estimate.

9. Ten airlock operations per week with expendables minimized by pumpdown to 1 psia before dumping overboard.

10. Airlock volume is 130 ft^3.

11. Volume of SOC is 22,000 ft^3.

12. Nominal cabin parameters:

    70 - 80°F

    14.7 psia

    40 - 60°F dew point

    3.2 psia O_2

    3.8 mmHg CO_2

13. Nominal crewman mass balance as given on Table 9.2-1.

9.2.2 System Description

The ECLSS is a regenerative concept which minimizes the crew consumable expendables required for resupply.

The ECLSS functional schematic and mass balances are shown on figure 9.2-1. All values are in lbs. per day for an eight-man crew. The estimated weights, volumes, power and resupply weights are shown on Table 9.2-2. The subsystem concepts employed are as follows:

O_2 supply	Liquid water electrolysis
Urine Recovery	Vapor Compression Distillation
Wash Water Recovery	Hyperfiltration
Humidity Control	Condensing Heat Exchanger
CO_2 Collection	Electrochemical Concentrator
CO_2 Reduction	Sabatier Reactor
N_2 Supply	Hydrazine Dissociation

All metabolic water and oxygen requirements are regenerated by the closed cycle system. The only crew consumable expendable required for resupply is wet food (1.1 lb/man-day). Resupply of hydrazine will be required to meet cabin leakage requirements. Also some expendable ECLSS filters and chemical beds will require resupply. The total amount of food resupply is estimated at 1773 lb. The resupply requirement for the other expendables (hydrazine, filters, beds) is estimated at 1630 lbs.

The system is configured so that the reclaimed urine will be used only for oxygen production and not for drinking water. The mass balance shows that surplus reclaimed water will be available over and above that required for metabolic oxygen, cabin oxygen leakage and system oxygen process requirements. This excess water is potentially available for other system requirements, i.e., EMU recharge, supplemental cooling. This surplus water could also be considered as contingency to meet increased cabin leakage or to be used for emergency drinking water. The surplus of 5.3 lbs per day could provide the additional makeup oxygen required by a total SOC atmosphere leakage of 31.6 lb/day.

The drinking water requirement is met from three sources: (1) metabolic water vapor, (2) CO_2 concentrator process water vapor, and (3) CO_2 reduction process water. The metabolic water vapor is made up from lung latent loss and evaporation from the skin. Water vapor is a by-product from the electrochemical concentrator that removes the CO_2 from the atmosphere (fuel cell type of operation). In the CO_2 reduction process,

Table 9.2-1

NOMINAL CREWMAN MASS BALANCE[1]

(lbm/man-day)

INPUT				OUTPUT			
A. Solids			1.36				0.24
Food		1.36		Urine		0.13	
Oxygen	0.44			Feces		0.07	
Hydrogen	0.08						
Carbon	0.60			*Sweat		0.04	
Other	0.24						
B. Liquids (water)			9.86				8.62
Drink		5.18		Urine		4.4	
Added to Food		1.58		Latent		4.02	
Cold	0.79			Sweat	2.02		
Hot	0.79			**Insensible	2.00		
Contained in Food		1.10		Total Recoverable		8.42	
				Feces		0.20	
C. Gases			1.84				2.20
Oxygen		1.84		Carbon Dioxide		2.20	
TOTAL			11.06	TOTAL			11.06

1 Assumes metabolic rate = 11,200 Btu/man-day (2822 Kcal/man-day) and RQ = 0.87.

* One percent of latent (Bioastronautics Data Book, NASA SP-3006, p. 225).

** Composed of lung latent loss (10 percent of total metabolic rate) plus skin diffusion (~ 40 Btu/hr).

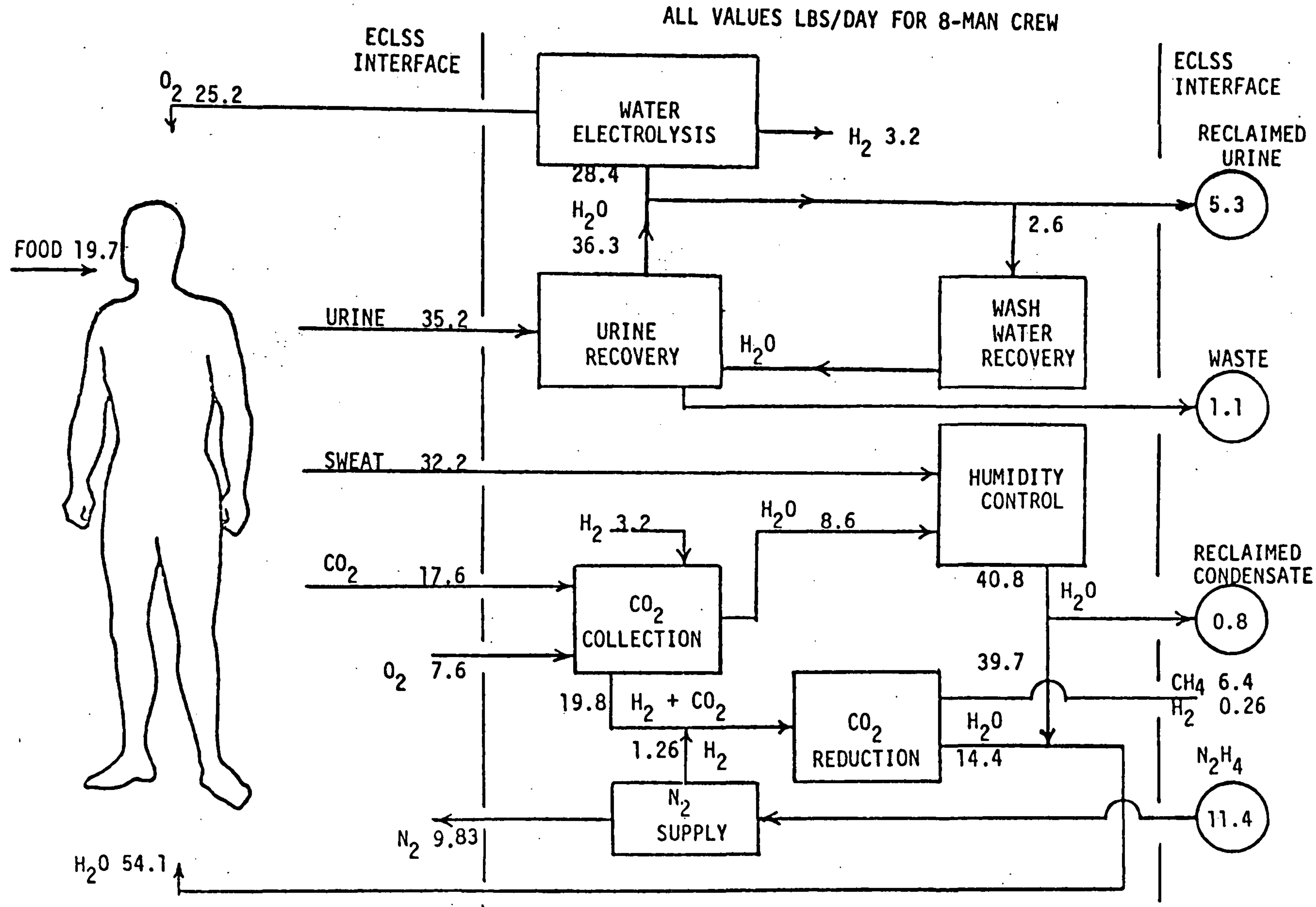


Figure 9.2-1. ECLSS Functional Schematic And Mass Balance

Table 9.2-2

WEIGHT, VOLUME, POWER, AND RESUPPLY WT.

ATMOSPHERIC REVITALIZATION

	WT, lb	Vol, ft^3	Power, Watts		Resupply lbs
O_2 produced by water electrolysis	345	11	2830		15
CO_2 removed by electrochemical cells	225	9	250		15
CO_2 Reduction	195	21	100		15
Humidity Control	105	6	390		
Temperature Control	150	8	260		___
SUBTOTAL	1020	55	3830		45

WATER RECOVERY

	Wt, lb	Vol, ft^3	Power, Watts		Resupply lbs
Vapor Compression Distillation (2-4 Man Units)	1067	72	210		120
Condensate Multifiltration	193	16	---		100
Hyperfiltration	1005	88	280	Peak	
			300	Avg	
Water Quality Monitor (2 units)	200	4	40		100
SUBTOTAL	2455	180	550		320

TOTAL ECLSS*

	Wt, lb	Vol, ft^3	Power, Watts	Resupply lbs
Air Revitalization	1020	55	3830	45
Water Recovery	2455	180	550	320
N_2 Storage (for 12 lb/day leakage)	1600	17	150	1270
	5075	252	4530	1635

*Does not include thermal loop

water along with methane as a by-product is produced by passing the hydrogen and CO_2 over a catalyst at an elevated temperature (600°F). With a hydrogen-rich process supply, the reaction can be operated at maximum efficiency ($\approx$90%) with only a small amount of CO_2 and water vapor in the by-product (methane) stream. Dissociation of hydrazine provides the extra hydrogen needed to obtain the maximum amount of water from the CO_2 reduction process, as well as nitrogen for cabin leakage and airlock operations without the complexity of long term cryogenic nitrogen storage or the extra weight of high pressure nitrogen gas storage.

The requirement of 90-day emergency duration for eight men can be accommodated by either of the four-man nominal design life support systems. By locating one in each habitation module, a failure and isolation of either habitation module can be accomplished with the crew supported by the remaining life support system for the duration of the emergency. Some supplemental sparing, especially of expendables, may be required. These requirements will be defined by a failure modes and effects analysis at the system level and as the overall SOC contingency philosophy becomes better defined. One emergency operational mode which was considered was to allow the SOC cabin to bleed down, i.e., no nitrogen makeup. The cabin pressure vs. time relationship is shown in figure 9.2-2. At the assumed leak rate of 12 lbs/day, the cabin pressure does not reach 8 psia until the 88th day. This demonstrates that the large cabin volume has the potential for providing contingency atmosphere for an extended period of time even after expendables are depleted. Oxygen usage is driven by metabolic consumption, not leakage, and must be supplied to the cabin during this decreasing cabin pressure. However, beginning at approximately 20 days, the oxygen pressure must be controlled to the decreasing maximum as shown on figure 9.2-2 to prevent excessive oxygen enrichment.

As shown on figure 9.2-3, the cabin volume provides a more limited contingency for CO_2 removal and oxygen supply. Without CO_2 removal, the CO_2 level will reach the upper limits of the emergency operations band in about 2 1/2 days. Without oxygen makeup the oxygen partial pressure will reach the lower emergency level in approximately ten days.

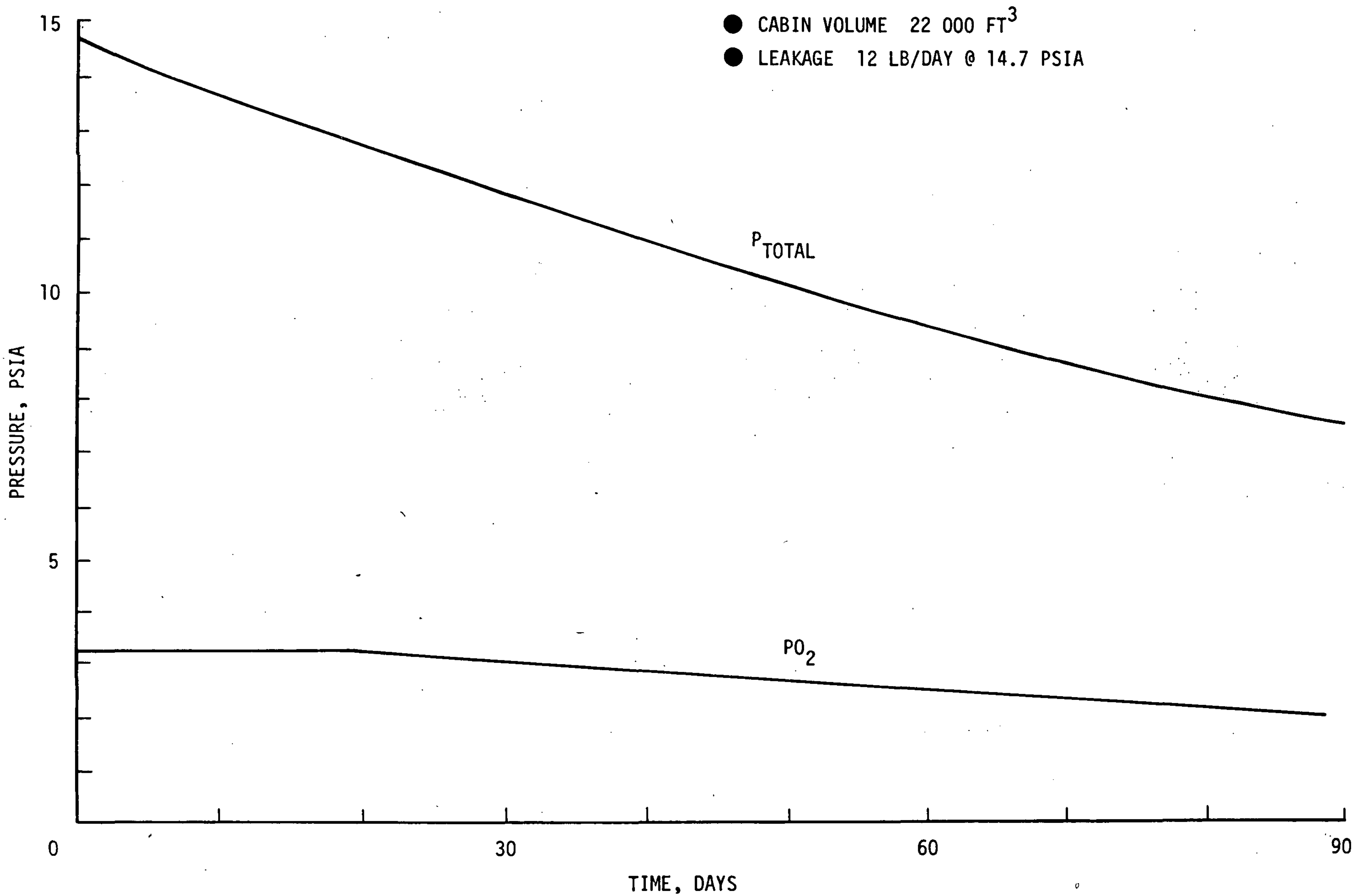


Figure 9.2-2. Cabin Total Pressure Delay Without Nitrogen Makeup

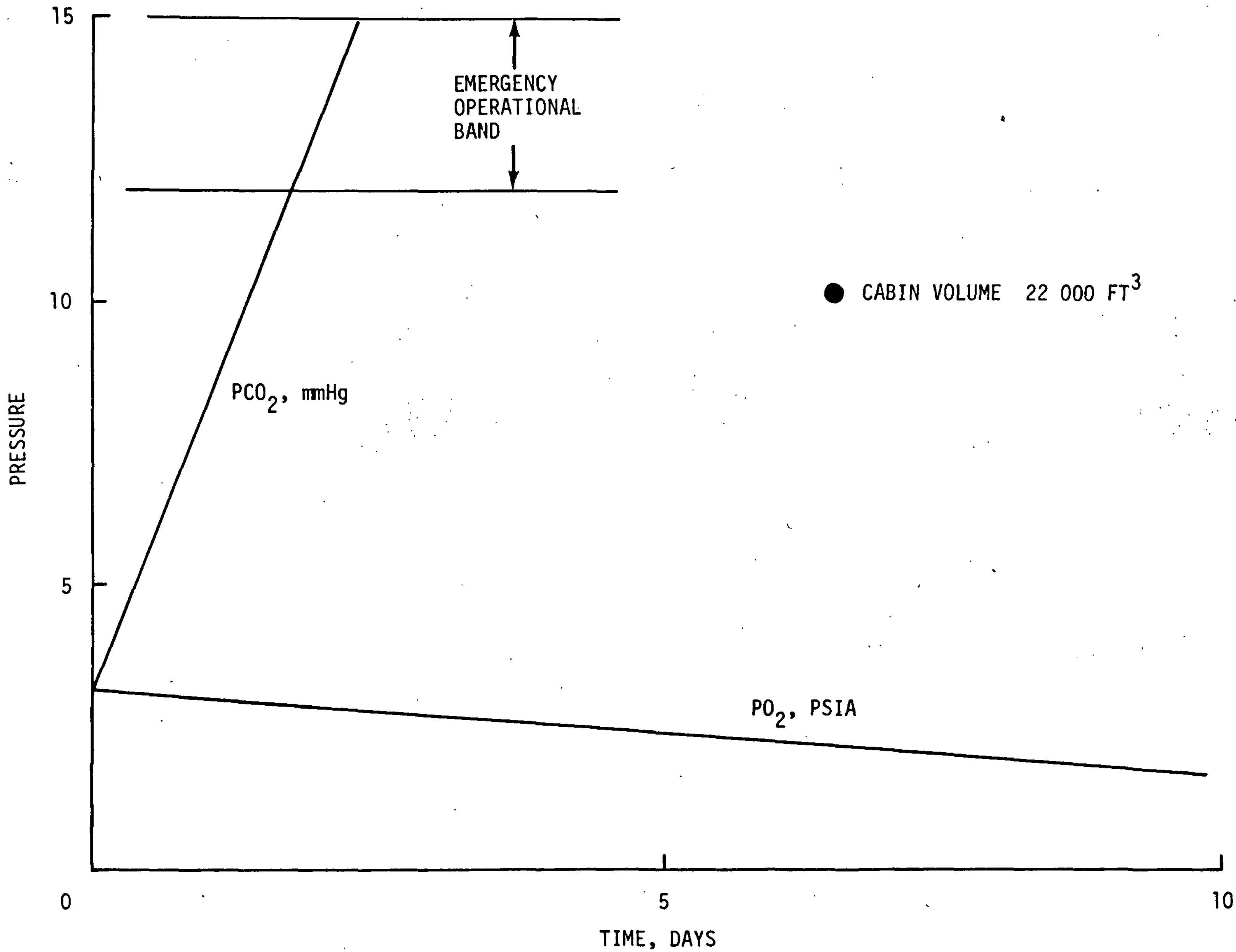


Figure 9.2-3. CO_2 Buildup and O_2 Decay With Loss Of ECLSS

9.2.3 Development Status

Briefly, the development status is that the first generation prototype has been delivered and tested for 1700 + hours (264 hours integrated system testing) and the second generation prototype has been partially delivered and tested (1800 + hours). The total test time in hours on each subsystem concept is summarized below.

	First Prototype	Second Prototype	Total
Urine Recovery	420	748	1168
Water Electrolysis	465*	1091	1534*
Electrochemical CO_2 Removal	452*	--	452*
CO_2 Reduction	385*	--	385*

*Included is 264 hours of integrated testing.

The CO_2 removal subsystem has been delivered and testing is expected to be completed by fall 1979. The CO_2 reduction subsystem is due to be delivered December 1979. Testing is expected to be completed in early 1980. Integrated systems testing is expected to begin mid to late 1980.

Following completion of integrated systems testing, any refurbishment or design modification identified as necessary will be implemented. Following these modifications the system will be installed in the 20-foot chamber in building 7 for final systems testing prior to manned testing.

This defines the basic development program that is being pursued with the end objective being able to enter a flight development program with a high degree of confidence.

9.3 THERMAL CONTROL

9.3.1 System Requirements and Groundrules

The basic functions of the SOC thermal control system are to (1) provide temperature control for the SOC's atmosphere and electrical equipment and (2) collect, transport, and reject all waste heat generated within all segments of the SOC.

The groundrules defined for the design of the system are listed below:

1. All SOC elements require temperatures in the +40° to +120°F range. This is the generally accepted range for manned spacecraft operations.

2. The service module waste heat load is expected to vary from 2 kW in a powered-down, semi-quiescent mode to as much as 18 kW during initial full capability operation. This load is primarily due to the heat from the electrical power conditioning equipment, but also includes some of the SOC subsystem loads as well. (The exact location of all subsystems has not been defined as of this writing.)

3. The waste heat loads originating in any other single module (habitation, life science, logistics, etc.) will not exceed the 4 to 10 kW range in the early life of the SOC.

4. Any proposed SOC thermal control system should utilize existing thermal control technology to the broadest extent possible.

5. Any growth version of the basic SOC will maintain the compatibility between electrical power and heat rejection available on orbit. In other words, any increase in the power generating capability of the SOC should be capable of being matched by an increase in the heat rejection capability of the thermal control system.

9.3.2 System Description

The primary objective in designing the SOC thermal control system was to avoid the necessity of making fluid connections during the buildup phase of the center by having no fluid lines cross the interfaces between the various modules. For this reason, the baseline design chosen was to have an independent thermal control system for each individual module. This means that all waste heat generated in any module will be rejected by the thermal control system of that module, and no fluid lines connecting various modules will be required. Baselining independent systems also made each system a size that would allow extensive use of existing Orbiter fluid loop components, such as pumps, heat exchangers, accumulators and valves. The three types of radiator systems baselined are shown in figure 9.3-1. The habitation module radiator system is typical of any large cylindrical module that will be used on the SOC. The service module radiators are unique to that module only. The experiment module system is typical of a system that could be used on any small module with little external surface area available. A more detailed description of each system is presented below.

9.3.3 Cylindrical Module System

Radiator systems for spacecraft can be integral with the exterior surface or they can be separate structures deployed away from the spacecraft. Radiators integral with the existing surface are usually preferable to deployed radiators due to simpler design, lower weight, and less cost. However, if the spacecraft does not possess the required amount of area to reject all of its waste heat at its operating temperature, a deployed radiator design must be used to provide the required amount of area.

The standard cylindrical module (14' diameter x 40' length) has an abundant amount of surface area to be utilized for rejecting its waste heat. For example, with the maximum expected module heat load of 10 kW and the maximum expected radiator environment (effective sink temperature = 0°F), 15.5 feet of the module's length (682 ft^2 area) is required. Since the module design already calls for a thin sheet of metal to completely surround the pressure shell to provide protection from the meteoroid environment, it is suggested that the entire module surface be utilized as radiator area. This would result in the radiator serving the dual purpose of radiator and meteoroid shield, as shown in figure 9.3-2. The extruded aluminum flow tubes extending circumferentially around the module would provide structural stiffness to the aluminum meteoroid shield serving as the radiator fin. Covering the entire module surface with the combination radiator/meteoroid shield design provides several other advantages:

o It eliminates the need for two different meteoroid shield designs, one integral with radiators and one without,

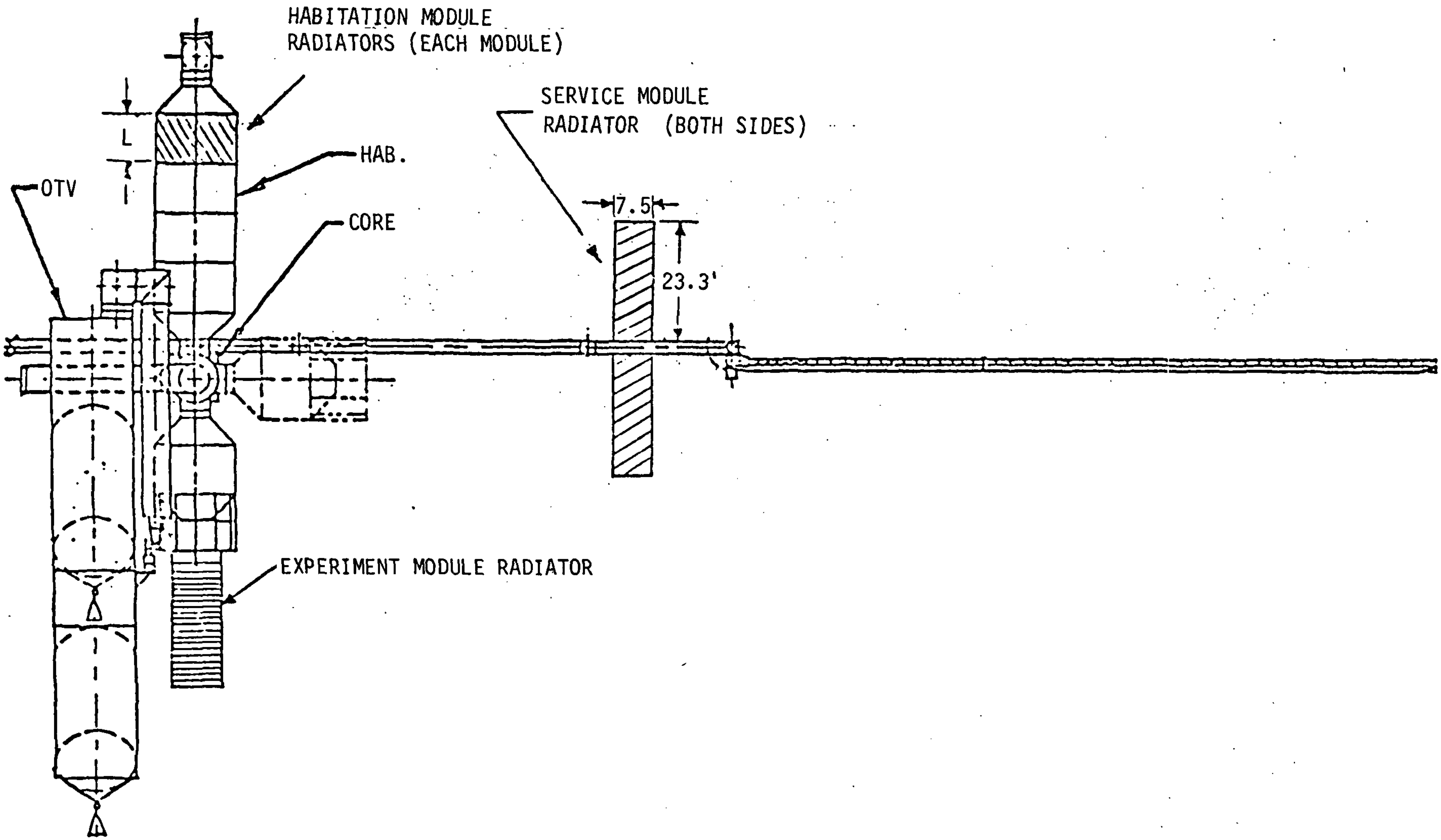


Figure 9.3-1. Radiator Locations

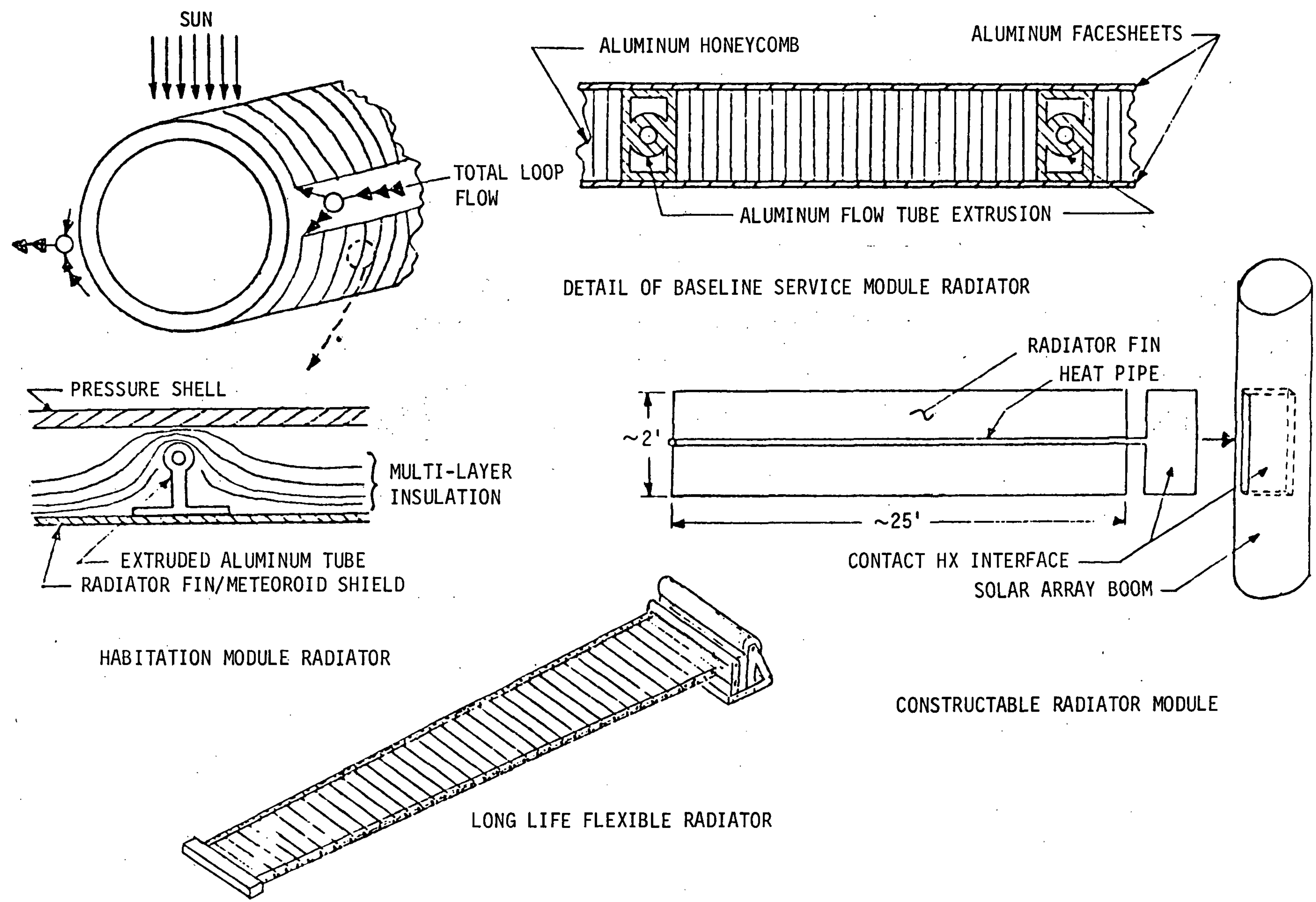


Figure 9.3-2. Radiator Design Concepts

o For initial operation, complete redundancy in module radiator area is provided, and

o Capability for 100% growth in module's heat rejection capacity is provided.

Inherent in the cylindrical shape of the module is the fact that one half is always facing the sun. Since the portion facing the sun is constantly changing, the design includes the use of an Apollo-type flow proportioning valve that biases most of the flow away from the hot side of the vehicle and toward the cold side, thus maximizing favorable environment effects.

The baseline design calls for two completely redundant systems in each cylindrical module. Each of these systems (schematically shown in figure 9.3-3) utilizes a water loop to collect the waste heat from the crew quarters and deliver it via a common heat exchanger to a Freon-21 loop passing through the radiator system. This use of Freon-21, with its -211°F freezing point, coupled with the flow proportioning feature of the system, allows the flexibility to handle the wide heat load range that could result from quiescent to full up operation.

9.3.4 Service Module System

The external surface of the core of the service module is utilized for docking ports or external equipment stowage racks. Therefore, insufficient area is available for integral radiators. The surface of the solar array boom was considered as a location for the radiator system, but analysis indicated that insufficient area was available. Therefore, a radiator system deployed off of the boom on each side of the vehicle is baselined. This system consists of four 7.5' x 23.3' two-sided Orbiter technology radiators. Figure 9.3-2 illustrates the detailed construction of these panels. The design consists of two thin aluminum face sheets bonded to a lightweight aluminum honeycomb core. The design deviates from the Orbiter design in that the heat transport fluid tubes are protected within a rectangular cross-section aluminum extrusion bonded into the panels. This type of construction is required to provide stiffness for stowage and deployment.

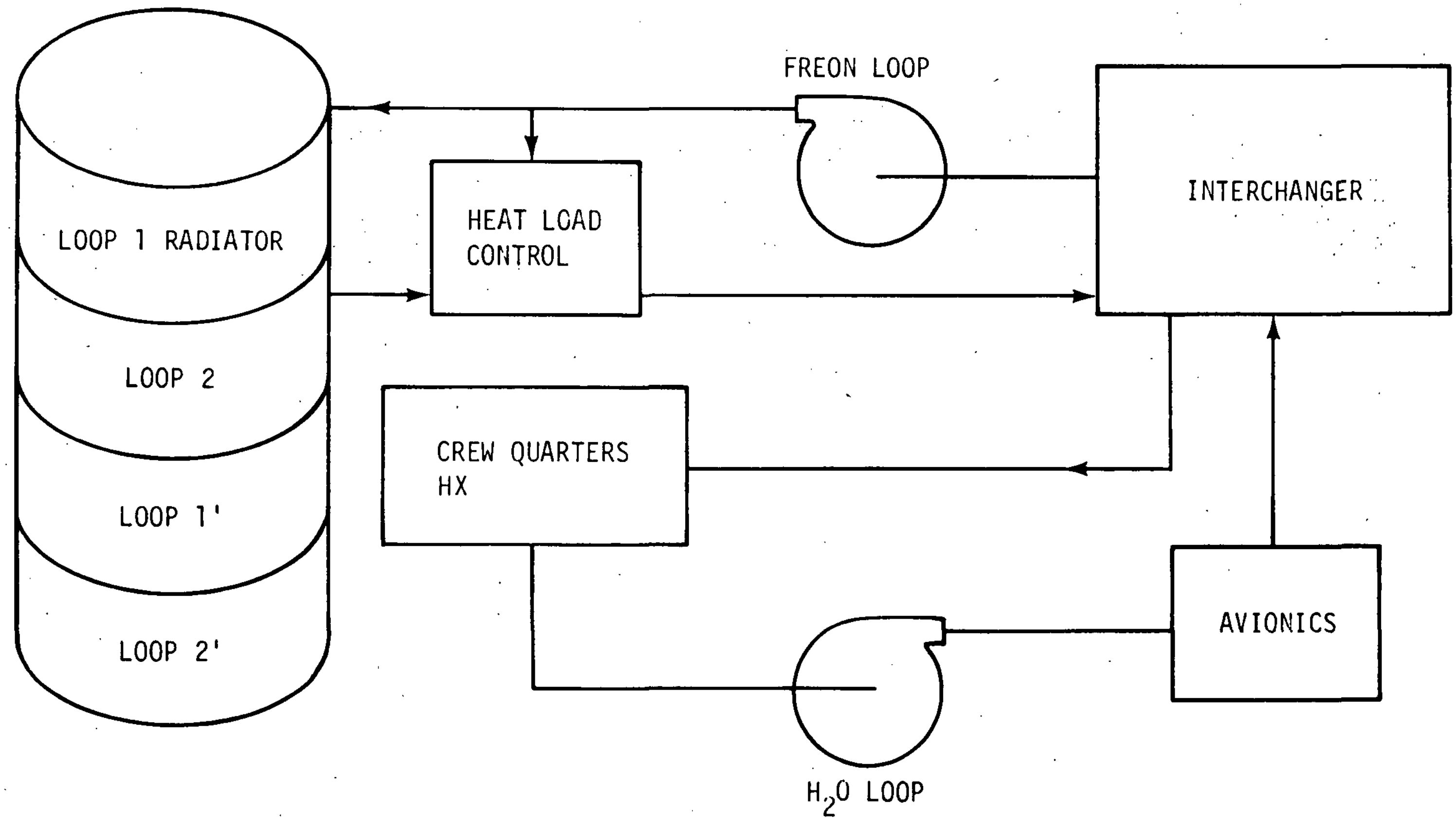


Figure 9.3-3. Coolant Loops

Each of the four panels has its own Freon-21 loop, so that loss of a panel due to meteoroid penetration or damage due to construction operations will cause only 25% reduction in system capability. The pressurized portion of the service module includes dual water loops for collection of the waste heat.

Although not baselined, either of two types of advanced radiator systems under development could potentially provide improved reliability and maintainability for the service module. These are illustrated in the bottom half of figure 9.3-2.

The long life flexible radiator is a nonmetallic fin radiator with flexible metal bellows manifolds and steel cross-flow tubes that can be rolled up and stored on a drum and then deployed. It can be plumbed directly into an existing system as a radiator only, or it can consist of a complete subsystem package, including pump, accumulator, valves, etc., which would interface with a vehicle fluid loop through a contact heat exchanger.

The constructable radiator module is a concept consisting of a large heat pipe with radiator fins attached. This portion, where the heat is removed, acts as the condensor section of the heat pipe. The evaporator section is embedded within a contact heat exchanger plate or plates in the vehicle heat collection loop. Pressure is applied to the two heat exchangers, the waste heat is exchanged through the contact conductance between the two surfaces, and the heat is rejected to the space environment from the radiator fins. This concept allows immediate replacement of damaged radiator area or addition of radiator area (assuming mating heat exchangers already exist on the collection side) without breaking into the vehicle's fluid loop.

9.3.5 Experiment Module System

Although the basic SOC design does not specifically define a module such as the experiment module, it has been speculated that modules other than the 40' long habitability module might be utilized on the SOC. It is possible that a small module could contain an experiment such as a space processing experiment that would require more heat rejection than could be provided by its own area. For such a case, the previously defined flexible radiator system is proposed. It could be deployed when heat rejection is required, and then retracted out of the way of other operations when not in use. It also can accommodate different heat load requirements by varying the amount of area actually deployed. As an alternate approach, with the proper interfaces included in the experiment module's design, the constructable radiator module could be utilized for this purpose.

9.3.6 Programmatic Considerations

- Development Status

  - The radiator systems baselined for the basic cylindrical modules and service module use existing technology.

  - The extended life flexible radiator prototype is currently being fabricated under a RTOP program for thermal vacuum testing at JSC this fall.

  - Proposals are currently being evaluated for a contract to develop the constructable radiator module concept.

- Previous Use of Hardware

  - Pumps, accumulators, heat exchangers, and control valves are used on Orbiter.

- Critical Efforts Required Before Phase C/D

  - The only critical effort anticipated is to evaluate an acceptable concept for stowage and deployment of the service module radiators.

- Key Major Systems Tests Prior to a Design Program

  - Systems tests are proposed for both the habitation module and the service module radiator systems.

- Estimated Cost ($M)

  - A rough estimate of the costs for the two basic types of modules is:

modules is:	DDT&E	PRODUCTION	TOTAL
Service Module	7	2	9
Cylindrical Module	6	3	9

9.4 ELECTRICAL POWER

9.4.1 Requirements

The stated power level is 35 kW net to the main buses. By conference with Center power distribution and conditioning personnel, it was concluded that a main bus voltage of 120 VDC was required, as in the case of the 35 kW free-flying Orbital Service Module derived by McDonnell Douglas Astronautics Company under contract NAS 9-15532. Provision for conditioning, conversion and inversion to AC and other DC voltages as necessary is described in Section 9.5.

Within the solar array and battery, internal redundancy is obtained by the multiplicity of parallel strings of cells required to provide 35 kW at the main bus. Modular design provides capability to experience small power depressions from failed units, followed by manual replacement with onboard spares. Thus system weight is minimized. The system weight breakdown is shown in Table 9.4-1.

Table 9.4-1 POWER SYSTEM WEIGHTS

Item	Wt.-lbs
Solar Array (blankets, wing box assys, cannister & masts assy)	2950
Gimballing	878
Regulators	1102
Battery System (batteries, chargers, cold plates, delta structure)	3425
	8355# (3798 kg)

9.4.2 Description

The array blanket is as described in the above MDAC report: 871 m^2 area, delivering gross power of 98.9 kW at beginning of life and 83 kW at end of life (10 years projected). Configuration of the booms, deployment means and gimballing are described elsewhere in this report.

The blankets will be stored for launch in, and extended from, wing boxes on-orbit as in the SEPS, PEP and OSM arrays.

Energy storage of 26 kWH/orbit is required for this 35 kW system. Lower load levels result in less energy storage per orbit. Nickel-hydrogen batteries operated at 50% depth of discharge have been baselined for this system. A nickel-cadmium battery of equal life, but operating at 25% depth of discharge and weighing approximately 2,280 kg more is carried as a backup option. Nickel-hydrogen is a relatively new battery system. Its technology status is described later in this section. A typical battery for this application would consist of 5 to 10 parallel strings of 100 cells in series, each string having a capacity of 50 to 100 amphere-hours, depending on the number of parallel strings finally selected.

A discrete charger design has not been selected at this time. A conventional system involving chargers and separate array power regulation may be used. On the other hand, the power processing device described in the MSFC 25 kW power module report of December 1978 appears interesting and may be necessary if nickel-cadmium batteries are finally used.

9.4.3 Development Status

The proposed solar array design has not flown but has been subjected to extensive analysis, substantial technology effort and much ground testing of partial and full-scale components and subassemblies. Effort on this design started at the time of the Phase B Space Station studies under the JSC Large Area Space Station Array Contract with LMSC. More work followed under MSFC contract, resulting in baselining this design for SEPS. All subsequent large arrays (e.g., PEP, OSM 25 kW Power Module) have been based on this design, due to the depth of technology and analysis to which it has been subjected, and to its eminent feasibility.

Specific effort at this time would be required to detail the blanket and extension mast design, the wing box beam, gimballing design, tracking systems and other assemblies which can only be finally detailed in context with a firm vehicle design. The cost of effort required can be minimized by utilization of the DDT&E work which will precede it on PEP.

The possibilities in the nickel-hydrogen battery system as a space battery were first recognized by ComSat in 1972. Since that time, both ComSat and Air Force have engaged in extensive technology and engineering effort on the system. There is strong evidence at this time that the system is electrically more rugged and longer-lived than equivalent nickel-cadmium batteries. The major data at this time are as follows:

Flight Experience

o Operating successfully for two years (currently) in a 12-hour orbit as prime power in the NTS-2 satellite. As a result, it is scheduled for use in NTS-3.

o Operated successfully for one year in an Air Force Agena experiment in LEO, yielding 1,700 cycles between 7 and 100% depth of discharge before the experiment was terminated without failure.

Ground Testing Experience (all tests continuing):

o Hughes - One year at 80% depth of discharge in LEO simulation, and two years at 80% depth of discharge in GEO simulation.

o Lockheed - Nine months at 50% depth of discharge in LEO simulation.

o AF, ComSat - various in-progress tests.

o AF bases nickel-hydrogen battery designs on life projections of two years at 80% depth of discharge and five years at 50% depth of discharge.

9.4.4 Critical Efforts and Tests Before Phase C/D

Follow PEP array effort closely and add such incremental design and test effort as required. Special effort on SOC will be required in the areas of deployment booms, gimballing devices and power transfer devices for example.

The individual nickel-hydrogen cells consist of about 50-60% void volume to contain the hydrogen used as the anode active material. Consequently, heat transfer from within the cell to the external cooling medium can be inefficient unless cold plates are carefully designed. A specific design and test effort is required for this factor.

It is necessary to obtain much additional test data on ground tests of LEO simulations, just to increase confidence by increasing the data base. Specifically, a thermal/electrical breadboard test is necessary.

A complete system breadboard of batteries (modules thereof), chargers, regulators, power transfer devices and solar array input simulator should be made and used to verify system circuit designs and operation.

9.5 AVIONICS

9.5.1 Introduction

The avionics system consists of several subsystems including guidance, navigation, flight control, data processing, operational instrumentation and electrical power distribution and control. This section provides a general description of each of these functional elements.

The basic design provides for dual redundancy which can be satisfied by either an active standby or inflight spares replacement technique. During the initial buildup phase and into early operation, the only time critical period identified was during Orbiter docking.

Local processors have been baselined for those subassemblies which can make significant use of processing capability. Specific units include the intertial measurement unit (IMU), control moment gyros (CMG), multifunction CRT display system (MCDS), mission events controller (MEC) and reaction jet drivers (RJD). These various processing elements are combined with a central computer and several nonprocessing units to form the guidance, navigation, and flight control system.

A data acquisition system similar to the one utilized on the Orbiter has been included for operational instrumentation. This data is gathered for use onboard by the data management systems and for downlinking to the ground upon request. Continuous downlink of onboard data was not considered a requirement but system design does not preclude this capability.

Electrical power distribution is also similar to the Orbiter system. The 120 Vdc power from the solar cells is brought into distribution assemblies in the service module, then regulated and conditioned for distribution throughout the SOC. Both dc and 400 Hz ac are distributed as necessary.

9.5.2 Requirements

The requirements which have been identified or assumed are listed in Table 9.5-1. There do not appear to be any specific problems in satisfying these requirements with existing or planned Orbiter equipment. The present OV 102 Orbiter does not have GPS (global positioning system) capability, but the necessary hardware and software have been baselined and will be added.

Control moment gyros are not part of the Orbiter system and will not be included in the program. However, they were used on Skylab and the basic techniques are developed. The only new technology implication in this area is in the application software programs and some hardware interface development.

The one area which may require new technology is in the attitude control of the SOC when multiple flexible appendages are added to the service module. Simulation programs do not exist for multiple flexible body configurations although JPL does have a study contract to work this area. The question is whether or not the programs developed will be universal enough to be used on the SOC. Under extreme conditions, a sophisticated adaptive control system may be required with sensors in each of the modules. Software programs of this type are well beyond anything attempted in space vehicles to date.

9.5.3 Configuration

The baseline avionics configuration is shown in figure 9.5-1. The systems management and payload processors are independent computer systems and are not part of the general avionics system. These will be included in a vehicle data or information management system. Also shown in figure 9.5-1 is the operational instrumentation subsystem which includes a data acquisition unit, recorders and signal conditioners. A very brief description of each of the functional units follows.

Table 9.5-1

AVIONICS REQUIREMENTS

- Autonomous GN&C system operation.
- Inertial position computation to within ±5 meters.
- Initial placement of vehicle axis to within ±1° of a specified orientation.
- Maintain attitude control to within ±5° of specified orientation.
- Provide attitude control of ±0.5° during Orbiter docking operations.
- Provide close-in rendezvous and tracking operation.
- Provide guidance commands during orbit maintenance thrusting.
- Provide computations and control for CMG desaturation.
- Provide battery charging capability.
- Power distribution to include both AC and DC power.
- Support data acquisition for determination of status of all avionics equipment.
- Avionics systems will be fail safe.
- Avionics assemblies will be replaceable in flight.

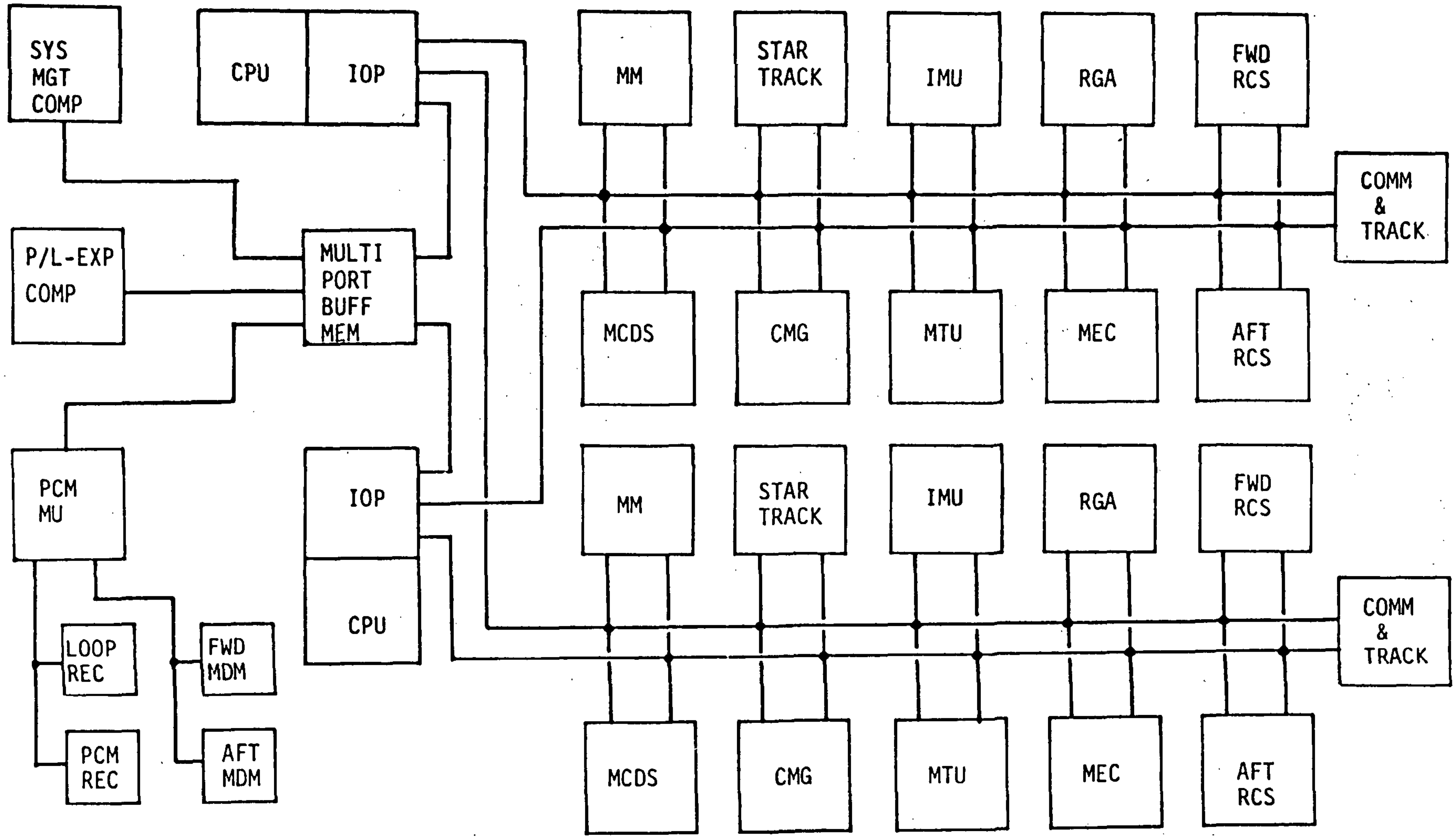


Figure 9.5-1. Avionics Block Diagram

9.5.3.1 CPU/IOP (Central Processing Unit and Input/Output Processor) - The CPU and IOP combination forms the general purpose computer (GPC). This may be one of the NASA "standard" computers being developed by GSFC and MSFC or a version of one of the advanced military fire control or avionics computers. Consideration would be given to use of the executive and basic operating system software which is developed with the hardware. The GPC will perform the guidance, navigation, and flight control computations similar to the functions on the Orbiter. However, the subsystem operating programs (SOPS), subsystem redundancy management (RM), jet select logic and a majority of the CRT display programs software can be eliminated from the GPC since these functions now reside in local processors.

It is also anticipated that the minor cycle requirements for the SOC will be less stringent than the Orbiter. All functions identified to date involve very low rates in a benign environment with a very sluggish vehicle. The big questionable area is the effect of multiple flexible bodies attached to a reasonably rigid core through relatively flexible couplings (airlocks). These problems may indicate a requirement for a high sampling rate or possibly sensors in each module. If these flight control requirements begin driving the GPC minor cycle back toward the Orbiter system then consideration will be given to implementing a special flight control processor which is independent of the guidance and navigation processor. In effect, the flight control system becomes another local processor dedicated to one specific function. One extreme of this concept would be to make the flight control computer a parallel processor which conceivably could achieve rates of 35 to 60 samples per second. An independent flight control computer would also permit development of sophisticated adaptive control techniques in phases as the SOC grows with minimal impact on the remainder of the avionics.

9.5.3.2 MCDS (Multifunction CRT Display System) - This is a CRT display system with keyboard display generator and local processor similar to the system used on the Orbiter. Capability would be increased to provide full graphics and color on the CRT and the internal memory increased so all display formats and programs can be resident in the MCDS instead of the GPC. Detailed diagnostics and self test programs would be contained in internal PROM's and called directly from the keyboard. The MCDS could also contain a mode of operation which would allow it to monitor and display data bus traffic. It could then be used as a system troubleshooting device during system integration and in times of onboard system failure.

9.5.3.3 MM (Mass Memory) - The MM contains the complete set of software required by the GPC's, MCDS, and all local processors. This function will be eventually included in the data management system, but is needed for the first flight so has been included in the avionics area. The unit can be a tape device as on the Orbiter or may include holographic or bubble memory technology. A full definition of the mass memory will require a definitive evaluation of total memory storage requirements.

9.5.3.4 IMU/Star Tracker - A triad of IMU's is mounted on a NAV Base with a star tracker which has automatic tracking and update capability. Local processor provides redundancy management, automatic updates and realignment with the star tracker, derived rate and whole angle outputs. Redundancy management includes mid-value selection or averaging and internal fault detection, isolation and annunciation for both single and dual failures.

9.5.3.5 CMG (Control Moment Gyros) - A triad of CMG's is mounted on a common platform or in a fixed relationship when attached to the external structural member of the service module. A local processor will provide redundancy management, desaturation torque control, initial and intermediate (as required) alignment torquing and internal fault detection, isolation and annunciation.

9.5.3.6 MEC (Mission Event Controller) - During orbit thrust maintenance and CMG desaturation, the reaction control system will be used. This requires operation of pressurization and isolation valves, closure of motor driven switches to apply power to the reaction jet drivers and verification of operational readiness of the combined systems.

The event controller will utilize a local processor with specific events contained in PROM's such that each operation is a defined sequence of logical steps. A request for a desired function would be issued to the event controller which would then control all necessary steps including workarounds for failures. When the function had been successfully completed or if a set of failures precludes completion, the central processor would be notified.

9.5.3.7 RJD (Reaction Jet Drivers) - The RJD contain a local processor which controls the jet logic, redundancy management, thrust management and failure annunciation for the reaction control system. The RJD will be used to control the thrusters for both orbit maintenance and CMG desaturation. There may also be special requirements placed on the reaction control system such as control of SOC impulses during Orbiter docking or emergency stabilization after a puncture in one of the main modules. Commands could be for a specific thrust level and time by axis or a command matrix which the local processor would interpret into the necessary reaction jet commands. The local processor would also fire specific jets to maintain a predetermined balance of fuel in the tanking system or to produce equivalent usage of redundant thrusters. Redundancy management would include all necessary fault monitoring and plumbing reconfiguration to insure maximum utilization of fuel and subsystem capability.

9.5.3.8 OI (Operational Instrumentation) - The OI subsystem is a relatively standard data acquisition system similar to the one on Orbiter. A pulse code modulation master unit (PCM/MU) containing preprogrammed fetch routines collects data from the various subsystems. The interface to the subsystems is provided by a special connector on the particular black box when built-in signal conditioning is included or through a multiplexer/demultiplexer (MDM) when built-in signal conditioning is not available. For some sensors, additional signal conditioning may be required. All of the equipment necessary is available from the Orbiter. In addition to the PCM/MU and MDM's, two data recorders have also been baselined. One contains a data for downlink and is a dump-on-command type assembly.

The other is a maintenance recorder and is used to record subsystem failures for later analysis and maintenance operations. Although Orbiter equipment has been baselined, it is expected that it will be replaced with improved hardware as the SOC data management system evolves. The PCM/MU would be upgraded to include a local processor and more memory so a large variety of fetch sequences can be provided. The PCM/MU could then also provide data tolerance and limit checks for the data management system. The other area which requires improvement or replacement is the recorders. They should be replaced with holographic or bubble memories as these technologies evolve. The final design for the operational instrumentation system will depend on the design and development of the data management system. A large onboard data management system would include an operational instrumentation system function whereas a smaller data management system would merely interface with an independent OI subsystem.

9.5.3.9 EPDC (Electrical Power Distribution and Control) - The EPDC subsystem is baselined with modified Orbiter hardware. The power from the solar arrays is brought into main distribution assemblies (MDA's) where it is dioded together to form a dual redundant 120 Vdc distribution bus. This power is then routed to local distribution assemblies (LDA's) in the service module, habitation modules and any other appendages which will require power. The power is then regulated and reduced to 28 Vdc or 400 Hz, 120 Vac as required by each module. Power between the LDA's and subsystems is controlled by remote power control assemblies (PCA's) which will be driven by switches or keyboard entry on the main display and control consoles of the habitability modules. In effect, the PCA's will be commanded by an EPDC data bus command system which can be directly under control of the data management system or indirectly via an EPDC local processor in each module.

There will also be battery chargers which can be driven from the raw solar array output or from the regulated 28 Vdc available from the LDA's in the service modules.

9.6 DPS SOFTWARE

9.6.1 Software Environment

SOC DPS software comprises a number of individual onboard (and ground) computer programs. Each program is designed to reside in one of several computer systems associated with the SOC. Each computer system (and its software) supports a set of logically grouped SOC support functions. Each computer system's software is designed to operate (for the most part) independently of other SOC software. Certain functions may require direct access to local mass storage to allow (or prolong) its independent operation. Each computer system may access a centralized large mass storage device to allow (or prolong) autonomous SOC operations.

9.6.2 Redundant Operations

SOC DPS software will not be required to run in a truly redundant fashion (with identical software in separate computer(s)). In certain vehicle maneuvering cases, an active standby computer may be required. In all other cases, computer hardware replacement and software restart is assumed to be sufficient redundancy.

9.6.3 Basic SOC Computer Systems

The basic SOC (core plus dual habitation modules) will require computer programs for each of the following systems:

- Guidance, Navigation and Control
- Vehicle Systems Management
- SOC Command and Control
- Information Processing and Data Base Management

9.6.3.1 Guidance, Navigation and Control (GN&C) - The GN&C system itself comprises a number of local processors (dedicated to individual sensor management and specialized computational tasks) tied to a central processor. The basic ongoing functions are for the attitude control and maneuvering for the SOC along with orbit maintenance, and provision of inertial position. Rendezvous targeting and proximity operations will be provided by this software for launch/retrieval of free-flying payloads.

9.6.3.2 Vehicle (SOC) Systems Management - Selected support subsystems internal to the SOC that require continuous monitoring (and management) are interfaced to this computer system. Vehicle systems management software is designed to acquire and apply standard processing against a very large number of parameters acquired from the SOC's electrical, environmental, and communications systems. Out-of-limits data will cause one of several levels of caution and warning annunciation where crew intervention is required. This software may also perform routine management functions (in lieu of crew action), closing the loop to control subsystems based upon acquired sensor data from those subsystems.

9.6.3.3 SOC Command and Control - Each habitation module is assumed to contain a standardized, multi-bay console containing reconfigurable (via software) crew interface devices. Each console would be interfaced to other computer systems (and be fed data) via a local, dedicated processor (and software). The console would have multiple CRT devices, dedicated function keys to assign external systems to console bay or display device, and reconfigurable (via command and control software) push-button indicators (and event lights). These consoles are the only crew interface to the basic SOC computer systems.

9.6.3.4 Information Processing and Data Base Management - A large mass storage device (and its controller) is interfaced to other SOC computer systems to serve as a data repository (archive). A separate computer system (and program(s)) in conjunction with the mass storage device provides the crew with a variety of operation and planning tools plus systems libraries, inventories and a means for scheduling/tracking SOC system maintenance. Significant parts of these functions may be off-loaded to equivalent ground systems assuming that SOC/ground communications are essentially continuous.

9.6.4 Additional SOC Computer Systems

Computer programs (and computer systems) will be required with each of the following additional SOC functions. The addition of each function brings its own self-contained hardware, software, and dedicated crew interface devices.

- Payload Handling
- Construction Management
- Biomedical
- Scientific

Payload Handling and Construction Management software should draw upon the Space Shuttle experience base with the Remote Manipulator System software.

9.7 PROPULSION

9.7.1 Requirements and Assumptions

The orbit maintenance propulsion requirements were determined for the full-up SOC configuration for a 265 N.M. orbital altitude. The requirement was determined to be approximately 2500 lb-sec per day at the specified orbital altitude. It has also been determined that the orbit maintenance propellant could be expended parallel to the orbital path, but with significant moment arms, such that large torques could be provided in the pitch and yaw axis. This technique would allow simultaneous orbit maintenance correction and CMG desaturation.

By design it is intended that the normal short-term attitude control requirements will be satisfied by CMG's (control moment gyros). The expendable mass propulsion system will be utilized only when the CMG system becomes saturated.

As explained in the previous paragraph, it is anticipated that most, if not all, CMG desaturation requirements in the pitch and yaw axis can be satisfied simultaneously with the orbit maintenance requirement without use of additional propulsion system propellant. If the orbit maintenance propellant is expended with a torque arm of 40 ft., a CMG desaturation capability of 100,000 ft-lb-sec per day will be available without expenditure of additional propellant. This would allow CMG desaturation of over 10 times per day in the pitch and yaw axis. Additional small amounts of propellant will have to be expended in order to desaturate CMG's in the roll axis.

Another requirement which has been identified for the attitude control propulsion system will be attitude control for disturbances, either planned or unplanned, which exceed the torque capabilities of the CMG's. These disturbances may arise from emergency cabin leakage and docking or construction disturbances. There is a potential for these disturbances to occur at any time, therefore continuous attitude control capability in three axis will be provided by the attitude control propulsion system.

The attitude control system thrust level has been sized by providing excess control authority in the event of a puncture of the cabin pressure vessel, equivalent to a one-inch diameter hole, occurring at the maximum distance possible from the center of gravity. The resulting thrust level has been selected as 20 lbs and is used in all three axes to avoid the necessity for more than one engine design.

9.7.2. <u>System Description</u>

The SOC Propulsion Systems thrusters are located on the solar array booms in order to maximize the moment arms. Stiffness problems of these booms may prevent the installation of thrusters on the booms as structural capabilities become better known. If another location is required, shorter, stiffer booms will be provided for the thrusters.

The SOC Propulsion System propellant will be stored internally within the service module. Thermally controlled propellant distribution lines will provide propellant to the externally mounted thrusters. Active thermal control may be required in order to prevent freezing of the propellant in the distribution system.

The SOC Propulsion System will utilize monopropellant hydrazine as the propellant. The engines will decompose the liquid hydrazine into a hot gas by use of a spontaneous decomposition catalyst. This type catalyst does not work on a thermal principle and will provide instant control capability without the requirement for a warm-up period.

It is anticipated that most of the SOC Propulsion System burns will be on the order of one minute or longer. This means that most propellant will be expended at near thermal equilibrium conditions and, therefore, at near theoretical specific impulse if significant catalyst degradation can be prevented. Specific impulse of 240 to 250 lb_f-sec/lb_m should be attainable.

At this time a requirement for coupled attitude control operation has not been identified for the SOC. With only the requirement for uncoupled operation, dual redundancy can be provided with only four thrusters per axis, or a total of 12 thrusters for three axis control.

All attitude control in the pitch and yaw axis will be achieved with AFT firing thrusters. This allows orbit maintenance and CMG desaturation to be achieved with the same propellant. It is anticipated that orbit maintenance propulsion requirements will always exceed CMG desaturation requirement. When CMG desaturation requirements have been satisfied, the remainder of the orbit maintenance requirements can be satisfied by firing more than one aft pointing engine. This will allow the propulsion system to produce delta-v without producing torque.

With anticipated total impulse requirement of approximately 2500 lb-sec/day, it is anticipated that 3600 lbs of hydrazine per year will be required and that approximately 900 lbs of hydrazine will have to be resupplied every three months.

In order to satisfy a six-month resupply interval, it is necessary to provide approximately 1800 lbs of hydrazine onboard storage capacity.

The hydrazine storage requirements can easily be satisfied by use of six or seven Space Shuttle APU tanks which provide pressurized storage for 300 lbs of hydrazine each. These tanks are available "off-the-shelf" and contain a positive expulsion diaphragm fabricated of AFE-332, a well-proven long-term hydrazine-compatible elastomer. The pressure vessel is a spherical shell 29 inches in diameter and fabricated from 6Al-4V Titanium, another proven material with long-term hydrazine compatibility. The approximate weight is 30 lbs per tank. Usable hydrazine is 300 lbs/tank.

A particular engine design has not been selected at this time; however, there are many existing hydrazine engines which would be capable of fulfilling SOS Propulsion System requirements. A number of configurations are available "off-the-shelf" from Commercial Communication Satellite Systems. It is expected that one of these engines with an extensive qualification program would satisfy SOC requirements.

9.7.3 Development Status

All components which are required for a SOC hydrazine system are considered to be state-of-the-art. Most components would be of proven design which have already been qualified and subjected to space flight.

Although the SOC Propulsion System components would be of proven designs, a fairly extensive qualification program would be necessary to demonstrate compliance with SOC requirements which may exceed their original design requirements. Examples of these requirements are long life and man rating.

9.8 COMMUNICATIONS AND TRACKING

9.8.1 System Requirements

The communications and tracking (C&T) system for the SOC provides RF communications links with all spacecraft operating with the SOC, as well as communications internal to the SOC. The capabilities for each RF link/internal function are shown in Table 9.8-1. Primary communication with earth is through the TDRSS. Coverage provided by the TDRSS will depend on scheduling availability and user charge considerations. The space-to-space links provide a tracking capability in addition to the normal voice, T/M, and command capabilities. Navigation data will be obtained by using the L-band global positioning system (GPS). Communications with up to four EVA's is provided using present Shuttle EVA communications systems. Proximity operations involving berthing, remote work stations, construction aids, etc., will require accurate range and range rate data, and will be provided by a TV/laser tracking system at strategic locations on the SOC. Internal switching and distribution is provided for most functions and an RF relay capability is provided for voice and television.

TABLE 9.8-1

COMMUNICATION AND TRACKING LINKS

Link \ Capability	Voice	TV	Commands	T/M	Text/ Graphics	Tracking	Prox. ops.
TDRSS °S-band °Ku-band	2 Channels	 Downlink	X	Lo-rate Hi-rate	X	X	
Free-Flyer	X	From F.F.	X	X		X	X
Shuttle OTV Planetary Probe	X		X	X		X	X
EVA	X			X			
GPS						X	
OPS Center °Distribution °Switching °Relay	 X X X	 X X X	 X X	 X X	 X X	X	 X X

A simplified block diagram of the SOC communications and tracking system is shown in figure 9.8-1. Major interfaces are shown along with equipment locations and physical characteristics. The 4.8m dish antennas, as well as the omniantennas, are located on the extreme ends of the solar array boom in an effort to minimize the antenna blockage problem. The SOC service module contains the necessary equipment for basic TDRSS communications, navigation and subsequent Orbiter dockings, as well as emergency communications control. Habitation #1 contains primary communications, tracking and control. The remaining SOC modules contain audio/video systems as required. Proximity operations capability is provided in the launch and recovery module and the docking port for the logistics module.

9.8.2 Programmatics

The majority of the C&T systems are derived from Shuttle Orbiter systems, with an estimated 25 percent requiring some design/development due to new interfaces. Of the total C&T flight set, approximately 25 percent will require new development. The major items are: (1) the data distribution/acquisition units, (2) TV/laser tracker, (3) space-to-space transceiver and processor, (4) the SOC antenna system, and (5) free-flyer transceiver and processor.

A major critical effort required before Phase C/D is a comprehensive study of operating frequencies and the associated trade-offs of interference, frequency allocations, and frequency management. Another concern is the amount of antenna blockage because of the complex and varying nature of the SOC configuration.

Key major systems tests include (1) the integration of the total onboard C&T system, (2) end-to-end performance verification/certification with outside RF elements, and (3) individual equipment qualification and acceptance tests.

9.9 CONFIGURATION DESIGN CONSIDERATIONS

The SOC configuration design was responsive to numerous considerations relative to its missions and system requirements. These considerations

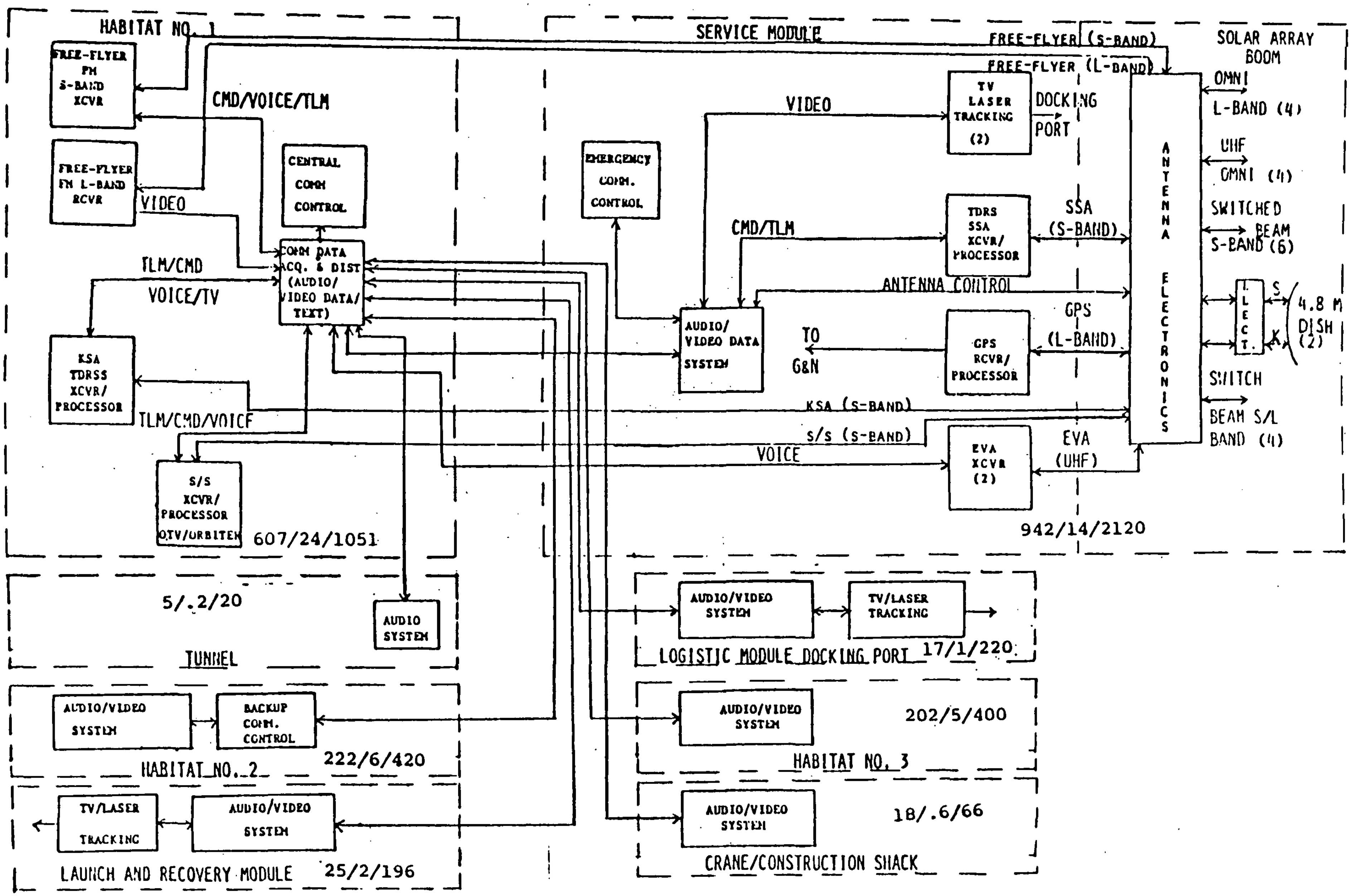


Figure 9.8-1. Communications, Tracking And Data Handling

are listed and discussed in the following paragraphs. It was evident that the configuration would be an assembly of multiple, shuttle-launched modules.

9.9.1 Basic Functional Requirements and Sizing

The construction facility and orbital launch vehicle stage assembly facilities are primary SOC configuration drivers, requiring appropriate locations, operating clearances, electrical power, crew size, logistics, etc., and have a dominant effect on the overall system mass properties, stabilization and control, and flight orientation. A crew of eight and an electrical power requirement of 35 kW was established as being appropriate. The first module launched must be self-supporting, requiring almost all basic subsystems; therefore, logic dictated that it be a "core" module, or Service Module -- to which the other modules are joined -- containing the solar array, stabilization and control, etc. Crew habitation, operations and safety require at least two modules of maximum possible size. Logistics and 90-day supply requirements dictate that a logistics module of moderate size is needed, which should remain attached to the Service Module. The Logistics Module would be replaced by a "full" Logistics Module, when empty, and returned to earth for later reuse. At least one operational airlock, plus backup airlock provisions, is required for the potentially extensive EVA required.

9.9.2 Orbiter Operations and Assembly of SOC

It was assumed that the Orbiter spacecraft at this time frame is thoroughly developed and improved and has enhanced performance, that the RMS meets or exceeds all performance expectations, and that the Orbiter has a docking module installation in the forward 7 feet of its payload bay, the docking interface being extendible to 15 inches above the upper mold line for docking.

For the SOC operational altitude of 265 nautical miles, the Orbiter will require additional OMS propellant for maximum payload weight capability. An OMS kit installation was assumed, which would occupy up to 10 feet of the aft portion of the payload bay. Clearance between the modules and the payload bay is necessary for safe removal and installation of the modules by the RMS, and 3 feet longitudinal and 1 foot lateral clearances were assumed. Therefore, the maximum module size would be 40 feet in length and 14 feet in diameter. However, some of the configuration drawings were based on assumption of only a 5 foot long OMS kit, and that the Service Module -- containing RCS, guidance and control, etc. -- could propel itself from a low initial orbit.

Assembly of the modules to the SOC is accomplished by docking the Orbiter to the Service Module and using its RMS to remove the module from the payload bay and "berth" it onto the Service Module berthing port. When the Orbiter is docked to the SOC, there must be clearance for payload removal from the Orbiter's payload bay (on the order of 25 feet of free space above the bay), and the RMS kinematics must be considered, relative to berthing the module to the SOC.

The operations of "berthing" and "docking" are in substantial usage, and require definition as follows:

Berthing is joining a module to the SOC using a manipulator to move and control the module. The berthing port and associated berthing system provides pressure seals, structural latches, umbilical interconnections, alignment guides, automatic capture latches and impact attenuation. The configuration of each port may be identical (androgynous), except that the umbilical interconnections may be tailored to requirements of the module.

Docking is joining the Orbiter (or other spacecraft) to the SOC, either by free-flying the Orbiter to join its docking module to the docking port on the SOC, or utilizing the Orbiter's RMS to perform, or aid in, performing the final maneuver. The docking port is identical to the berthing port in basic structure, the pressure seals and the structural latches. It would differ in alignment and impact attenuation provisions, because of the Orbiter's greater size and mass, and would have different requirements relative to umbilicals. The docking port and system for a manned OTV might be basically identical to that for the Orbiter, because the OTV should probably be capable of abort back to the SOC shortly after launch with both stages joined and full of propellants. The docking system should also be androgynous, but some docking ports may be totally or partially passive (i.e., no latch actuation, impact attenuation, etc.). It may be desirable to build the berthing ports so that an "active" docking system could dock to it. This capability would appear to be a design driver on only the alignment provisions. It should be noted that the structural design of the berthing and docking ports will be determined, primarily, by the internal pressure and/or stiffness requirements after docking or berthing. The configuration of the SOC berthing and docking ports was selected as being 60-inch diameter cylinders, 15 inches long, having 40-inch diameter clear passageways, and having all mechanisms within the pressurized 60-inch diameter volume (approximately a 10-inch annulus around the passageway).

9.9.3 Stabilization and Control, Solar Array Installation, and Flight Orientation

The SOC missions do not impose special instrument pointing requirements. However, the large solar array should be pointed toward the sun within the order of 5°-10° accuracy at low solar beta angles. Reaction control thrusters are necessary to prevent orbital decay, and for desaturation of the CMG's; they have a preferred firing direction, including the necessity to minimize exhaust impingement on the SOC modules and solar array blankets. Communications antennas need a preferred location with respect to whom they communicate with. It is preferrable to have micro-rendezvous by the Orbiter and the OTV occur within the orbit plane and, generally, parallel to the orbital velocity vector. When constructing a long, massive space system, the aerodynamic and gravity gradient forces and torques that may result from the system under construction must be considered. Therefore, the SOC will have a preferred flight orientation (it may have two possible flight orientations, depending on mission-imposed configuration changes during its lifetime). At its preferred flight orientation, bias (cumulative) aerodynamic and gravity gradient torques must be minimized or RCS propellant consumption for CMG desaturation will be substantial. In principle, this can be accomplished by designing the configuration to be symmetrical about the orbit plane and be arranged and oriented such that the axis about which the moment of inertia is a maximum is perpendicular to the orbit plane. Furthermore, if the mass distribution is such that the magnitude of the moments of inertia about the principal axes in the orbit plane is large (such as during construction of a communications platform), then the SOC should be earth-oriented, with the minimum inertia axis maintained along the local vertical to earth.

The large area solar arrays are, basically, six Orbiter Power Extension Package (PEP) solar array "wings." The structural natural frequency of the solar array will be low (order of .02 Hz). It is to be expected that the space systems to be constructed on the SOC will have similarly low, and variable, structural natural frequencies, requiring that the attitude control system be "adaptive." Therefore, it is not contemplated that the basic SOC configuration and other attached facilities need to have very high natural frequencies. This minimizes structural stiffness requirements.

Further discussion of many of these design considerations, as applied to the SOC configuration, is included in Section 5.3, Configuration Description.

10.0 SPACE OPERATIONS FACILITIES DESCRIPTIONS

This section discusses in general terms the operational facilities to be attached to the SOC.

In most cases, the definition of these facilities has not been carried to the subsystem level, but only to a depth sufficient to identify the broad configurational requirements to be met by the SOC.

10.1 HEALTH MAINTENANCE FACILITY

The health maintenance facility has the primary objective of providing the materials, equipment and services to assure continuing good health and productivity of the crew and, secondarily, to provide physiological and psychological data relative to man's working and living in space, and the value of the habitat of the SOC within which he lives. The facility contains all necessary equipment and medicines for physical conditioning, health monitoring, and diagnosis and treatment of all ailments that might reasonably be expected to occur, including cure of most ailments, and treatment of life-threatening ailments until emergency evacuation can be achieved with the Shuttle. The medical equipment is located within a laboratory space in Habitation Module No. 1, occupying over half of one deck (reference figure 5.3-5). In addition, exercise equipment is located in the wardroom area of each Habitation Module. Emergency medical supplies are stowed in Habitation Module No. 2, in the event that Hab Module No. 1 is uninhabitable, because of accident or malfunction. The lab has direct interface with the SOC computer system for date stowage, retrieval and analysis. Equipment located in the lab includes a treatment "table," X-ray, general surgical tools and equipment, diagnostic and general medical examination and testing equipment, pharmaceuticals, and refrigerated storage. The design, installation, and arrangement concept for the equipment and facility is described in Section 5.3.

10.2 SPACE CONSTRUCTION TECHNOLOGY

The development of the general technology of space construction is a primary, initial mission of the SOC. To accomplish this objective, construction projects will be undertaken whereby construction equipment is emplaced on the SOC and used to construct large structures and install useful mission equipment on the structures. Figure 10.2-1 illustrates the construction equipment installed on the SOC, and figure 10.2-2 indicates the structure under construction. The equipment and structural configuration shown is from the space construction automated fabrication experiment definition study (SCAFEDS) being conducted by General Dynamics-Convair for JSC. This initial construction facility concept consists of an Orbiter RMS and operator's "cab" berthed to the SOC side port, and the construction fixture (jig) berthed to the end port. A beam builder is attached to the jig, and is positionably by a mechanism on the jig to fabricate the structural members "in-situ." The RMS positions modules of mission equipment and subsystems onto the constructed structural frame. The structural configuration is a "ladder," about 200m long and 10m wide. The results would include operational test/verification of all the construction equipment and operations (impossible to totally accomplish on earth), and creation of a useful system in orbit.

The basic construction principles on which this concept is based are as follows:

1. Fabricate a truss-type structural member from coiled strip material, etc., with a totally automated beam builder.

2. The beam builder fabricates the beams in a direction and position such that the completed structural element is in its final position relative to the other structural elements.

3. Hold the structural elements in their proper position with a specially designed jig -- which only encompasses the structure's width and height -- and join them with automated mechanisms integral with the jig.

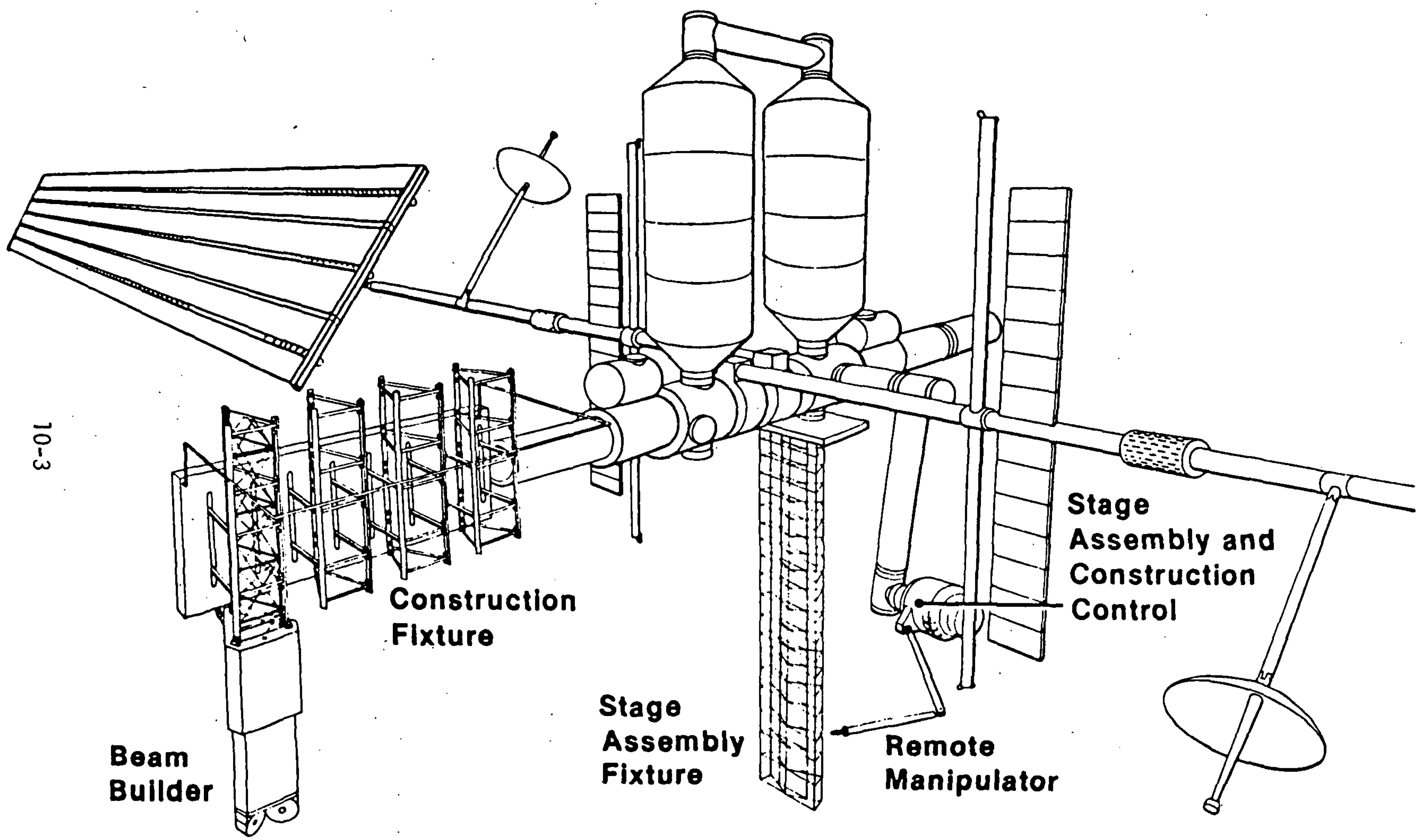


Figure 10.2-1. Space Operations Center

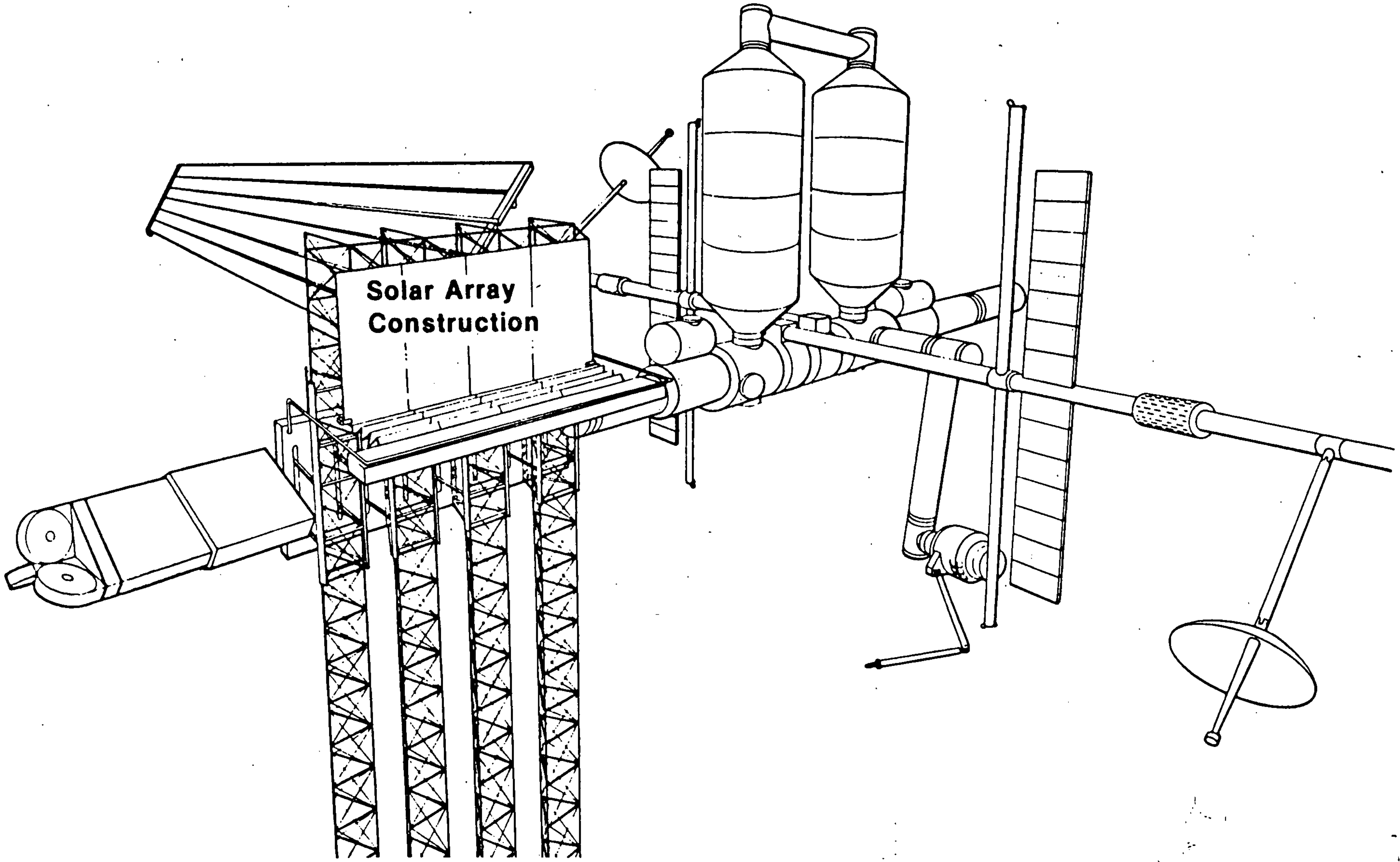


Figure 10.2-2. Platform Construction

4. Move the structure through the jig, along its length, to complete the structural assembly by adding structural elements in the lateral direction.

5. Move the completed structure back through the jig to add subsystems, making attachments to the structure at, or in the vicinity of the jig.

6. Utilize manipulators for transport and positioning of subsystems and modules onto the structure, where their installation is completed by automated or manually operated mechanisms on the jig or on a manipulator.

7. Manned remote work stations (MRWS) on the end of manipulators may be used to transport and position men at the work sites and to perform manual assembly operations; the MRWS may contain special tools and/or manipulators to aid in or perform assembly operations.

10.3 OPERATIONAL CONSTRUCTION

Figures 10.3-1, -2, and -3 illustrate the equipment for construction of a large communications platform that will be propelled to a position in geosynchronous orbit. The platform size is about 250m long and 20m wide, and supports a number of large antennas and associated subsystems. The construction facility includes a construction module, jig, beam builder, and dual cranes and MRWS. The construction module contains the avionics necessary to manage and control the construction processes and checkout the finished product.

All construction equipment and operations for this construction project are similar, in principle, to that of the initial space construction technology development project described in Section 10.2. The beam builder might be identical, except that during the time interval between these activities considerable improvements in beam builder technology and structural materials could have occurred.

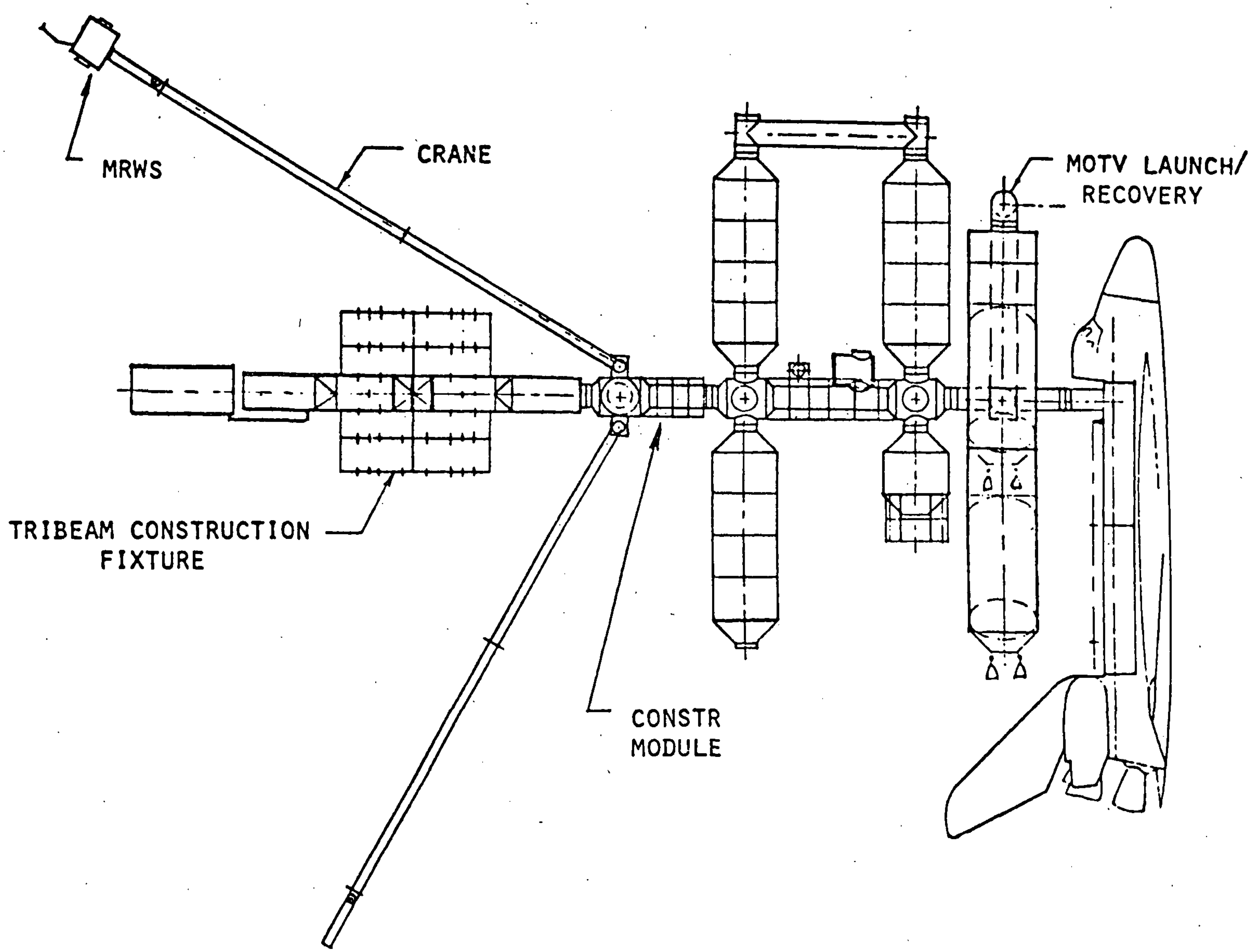


Figure 10.3-1 SOC WITH CONSTRUCTION FACILITY FOR COMMUNICATIONS PLATFORM (SIDE VIEW)

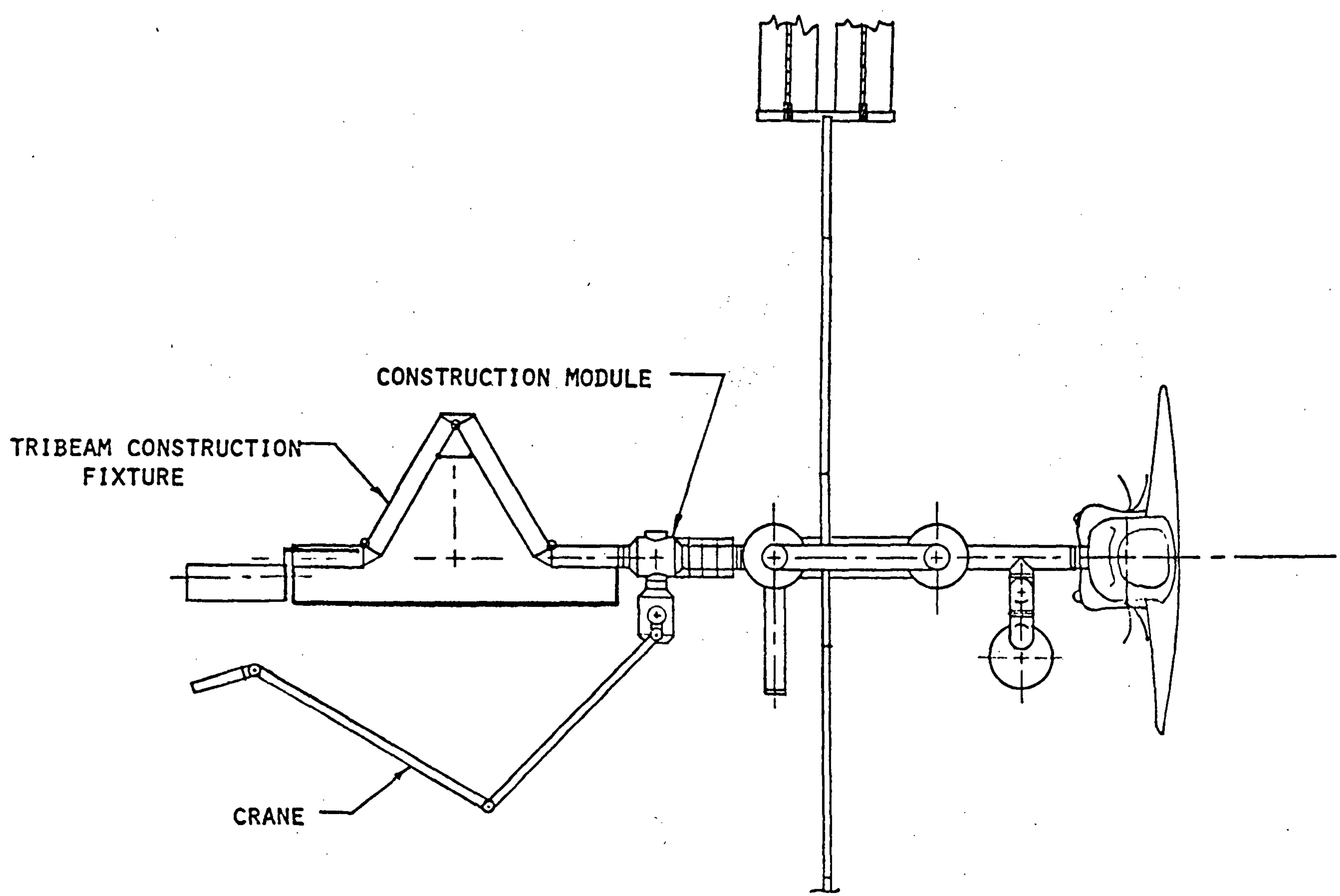


Figure 10.3-2 SOC WITH CONSTRUCTION FACILITY FOR COMMUNICATIONS PLATFORM (PLAN VIEW)

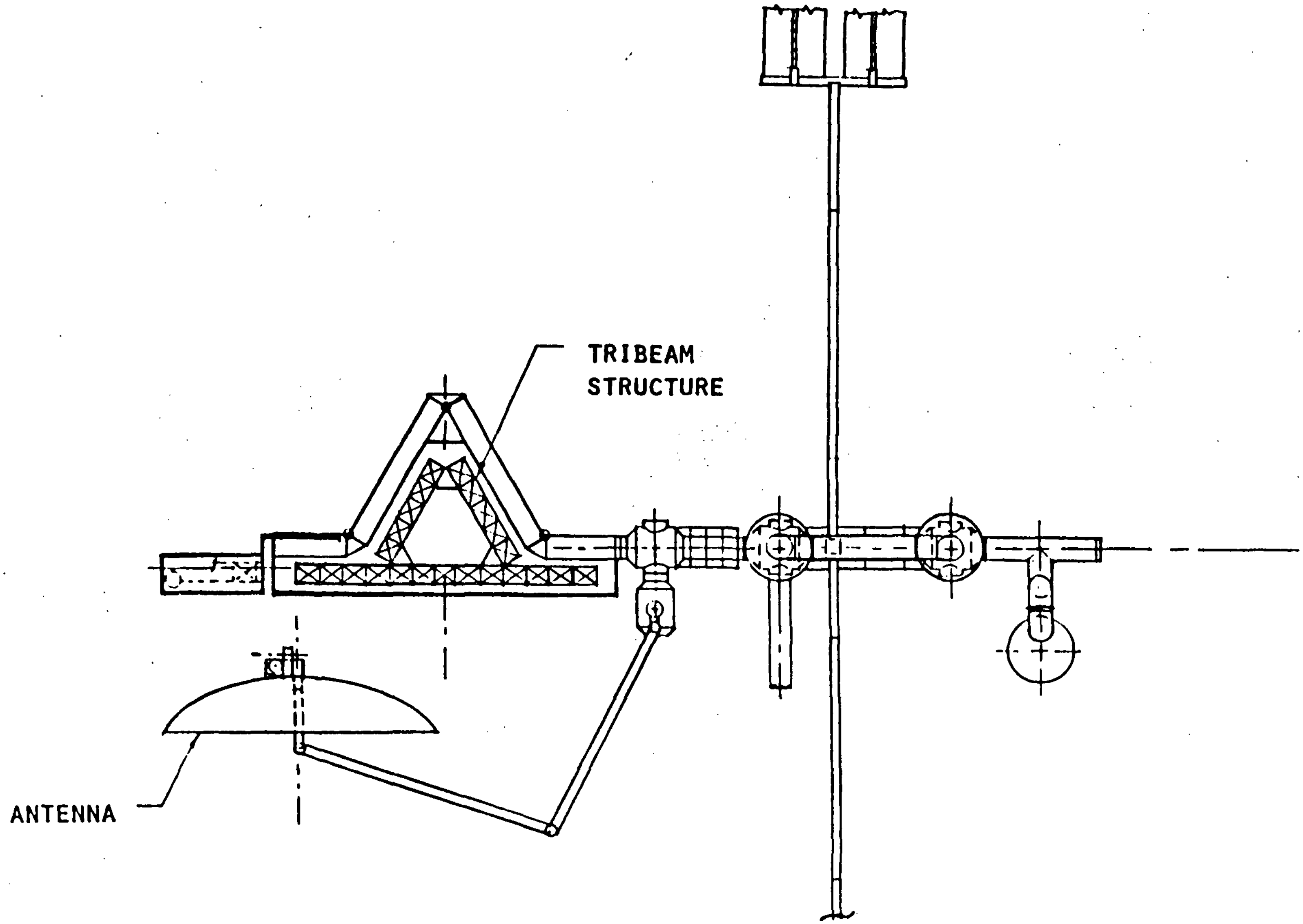


Figure 10.3-3. Construction Of Communications Platform

10.4 ASSEMBLY AND LAUNCH SUPPORT

Two classes of orbital launch vehicles are supported by SOC facilities: unmanned solid-propellant spacecraft, primarily for planetary missions, and manned orbital transfer vehicles (MOTV) for geosynchronous sortie missions. The structural/mechanical systems for assembling and launching these vehicles are described in this section.

10.4.1 Planetary Vehicle Stage Assembly

The planetary vehicle assembly facility consists of a strongback berthed to one of the service module lower berthing ports (figure 10.4-1) and associated mechanical systems. As stages and payloads are delivered by the Orbiter, they are placed in appropriate locations on the strongback by the SOC manipulator. When all stages have been delivered, mechanisms on the strongback mate the stages and payload to complete assembly of the vehicle.

After assembly, the completed vehicle is checked using automatic checkout equipment, and discrepancies within the capability of the SOC are corrected. For launch, the vehicle is rotated away from the strongback by a tilt table at the "bottom" of the strongback and separated. The vehicle then moves to a safe distance from the SOC prior to orientation and motor ignition.

10.4.2 Manned Orbital Transfer Vehicle

The MOTV consists of two identical LO_2/LH_2 propulsion stages and crew and service modules attached to the second stage. See Section 10.6 for details of the MOTV configuration and operational timeline. The SOC is involved in the following events in the MOTV mission: first stage retrieval, second stage retrieval, stage mating, checkout, refueling, separation, and launch.

The first stage returns to the SOC before the second stage and consequently must be stored temporarily. It is retrieved by the manipulator and placed in the stage assembly strongback. On return from synchronous orbit, the crew module with the second stage either docks or is berthed

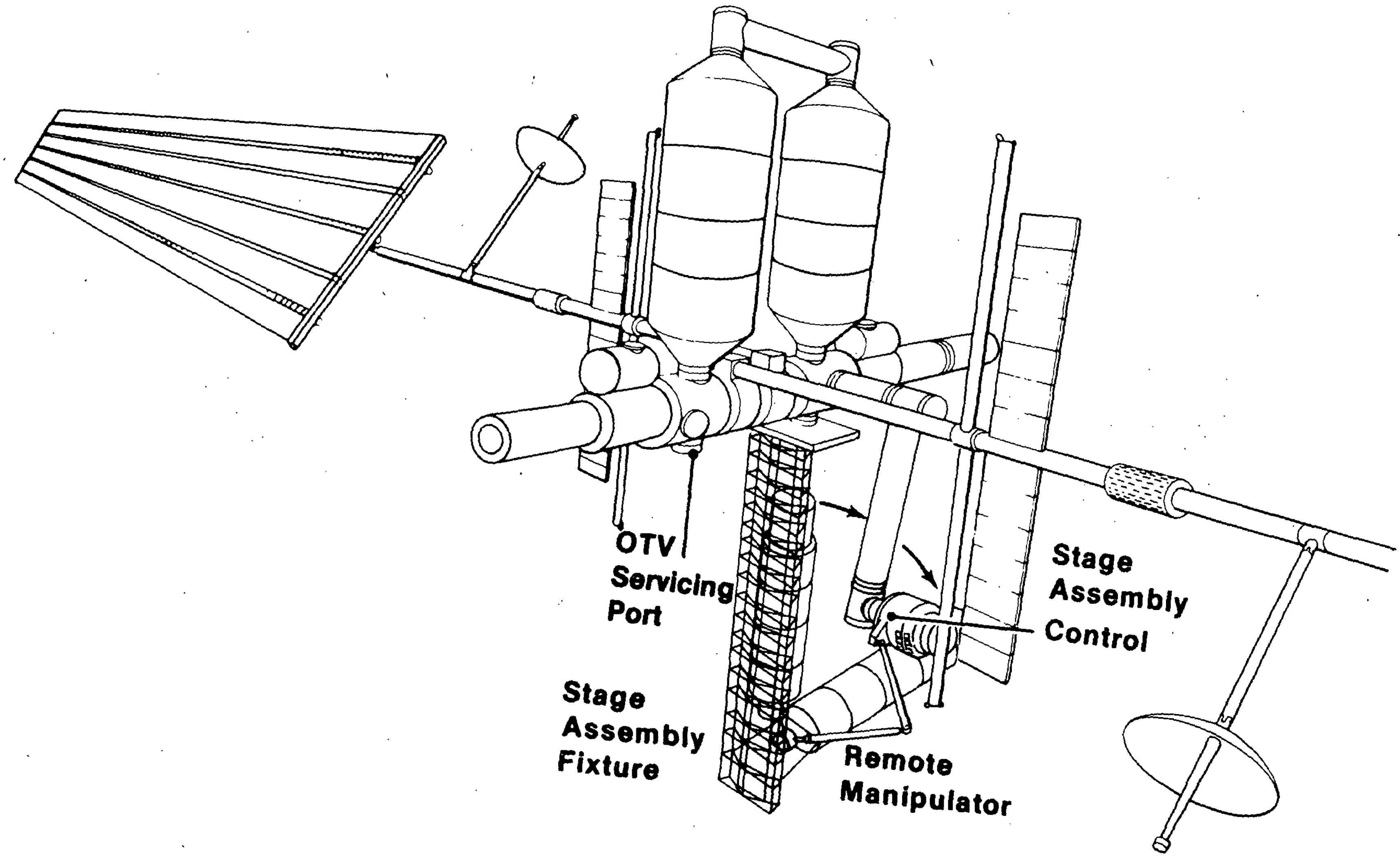


Figure 10.4-1. Planetary Vehicle Assembly Fixture

by the manipulator to a port on the service module (figure 10.4-2). This permits shirtsleeve transfer from the MOTV to the SOC.

Using the manipulator, the first stage is mated to the second stage. The entire vehicle is checked out and any necessary repairs are made. The manipulator and MRWS provide access to the exterior of the MOTV. An indexing docking port may be required for access to all points on the MOTV exterior.

Refueling is accomplished by transfer from tanks in the Orbiter Payload bay. Hoses, pumps, metering equipment, etc., are mounted on the SOC as a permanent part of the MOTV facility.

For launch, the MOTV undocks and backs away from the SOC until a safe distance for main engine ignition is achieved.

10.5 PROPELLANT TRANSFER TECHNOLOGY

Cryogenic orbital transfer vehicles in the future are expected to require on-orbit fueling since the individual stages loaded will exceed the earth launch capability of planned vehicles. The alternate possibility, loaded propellant tanks launched for orbital assembly to a core vehicle, suffers degraded performance and reliability due to heavier structure associated with multiple tanks and the associated structural and propellant line interconnects. Previous studies have conceptually examined this technology on a scale up through quantities of propellants necessary to support SPS scenarios. The conclusions of these efforts indicate that Shuttle Orbiter tankers are effective for all but the most ambitious flight scenarios.

The technology for achieving operational cryogenic propellant transfer capability will be developed in a multi-phase program: component and subsystem development on Shuttle and Spacelab flights, a prototype total system early in the SOC program, and growth of this system to MOTV sized operational capability in the late 1980's.

The precursor flights on Shuttle involve the demonstration, in a LeRC experiment, of LH_2 transfer between two dewars, with quantities in the 100 lb range. Several other key developments need to be pursued in these precursor

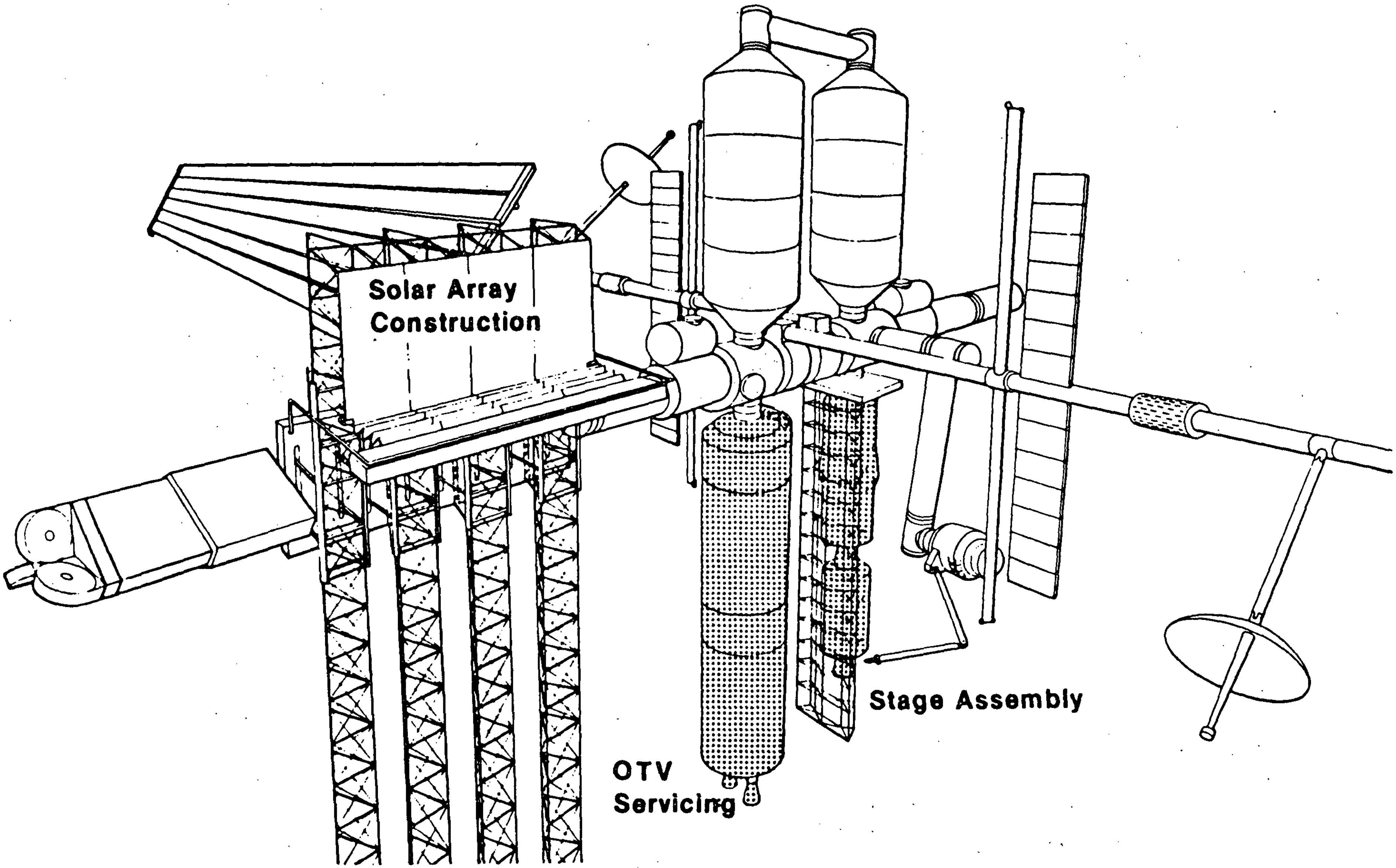


Figure 10.4-2. MOTV Servicing

missions. One major trade involves propellant acquisition by settling vs. use of capillary devices. Settling cryogenic propellants has been proven on the Centaur program. Thrusters would be fired to settle propellants, and then propellant transfer will be conducted in a low-g environment. The only development is for thrusters that are smaller than those currently on the Orbiter. Flight operations could be compromised due to the need for settling. System performance will compare favorably to that of screen acquisition systems, unless the low settling thrust level cannot maintain the propellants over the tank outlet during transfer.

A partial screen concept uses a capillary device located over the tank outlet to communicate with liquid in that vicinity. A 1-lb settling thrust level is required to contain propellants over the tank outlets. The advantage of this concept over the settling concept is that variations in propellant orientation (such as sloshing) can occur without suffering a break in continuous liquid transfer. Concept performance is probably better than for the settling concept because fewer propellant residuals are likely to result.

A third approach uses a full screen channel system which is the most costly and complicated of the acquisition concepts because it will maintain communication with propellants located anywhere in the tank. Consequently, the screen device must encompass a substantial portion of the tank surface area. Ground operations will be more complex because of the need to perform tests that will verify the integrity of the system between flights. Further, system weight could be greater than for the other concepts. This concept may be preferable because it imposes no restraints upon Orbiter operations since propellant transfer can be successfully performed for any Orbiter orientation, even during maneuvers.

Another area of investigation is the choice to be made between use of vacuum jacketed dewars vs. use of purged multi-layer insulation (MLI). The weight and cost of large dewars argues strongly in favor of the MLI approach while operational interface complexity and safety may favor the dewar approach. Other developments necessary include development of accurate zero g propellant gaging sensors, and liquid free, no-thrust vent devices. Basic experiments must be developed to investigate the entire phenomenon of zero g flow.

The prototype system, to be implemented early in the SOC operational phase, would combine all of the results of the precursor missions into a total propellant transfer system. A concept of the development facility, based on the outfitting of a basic logistics module structure, is shown in figure 10.5-1. To avoid Orbiter tanker scar weight, the entire pumping system and transfer lines are SOC mounted. Quick disconnect lines are then plugged in the tanker and receiver vehicles for transfer. In the development facility, it is proposed that the receiver vehicle be a Centaur stage. This approach will allow the confirmation of mass and volume scaling predictions and allow investigation and demonstration of complete systems operation and interaction and provide an operational demonstration wherein the Centaur receiver could then fly an unmanned OTV mission.

The fully operational, MOTV-sized system would then be implemented. This system may be no more than a modification and upgrading of the development system should the initial design prove to be adequate for the job.

10.6 MANNED ORBITAL TRANSFER VEHICLE (MOTV) SUPPORT

Support by the SOC of an operational MOTV is to some extent MOTV configuration dependent. A potential MOTV concept, described in table 10.6-1 and shown in figure 10.6-1, was chosen to illustrate the required support functions.

Table 10.6-2 lists the operations sequence envisioned for the Nth mission. (All hardware elements are assumed to have been placed at the SOC previously.)

An analysis was performed to determine the timeline for a typical Orbiter tanker propellant transfer operation. Shown in table 10.6-3, the results of this analysis indicate that the actual propellant transfer operation is insignificant in terms of the time required for overall MOTV support.

A very preliminary analysis of the personnel and man-hour requirements for checkout and maintenance of the vehicle was performed in

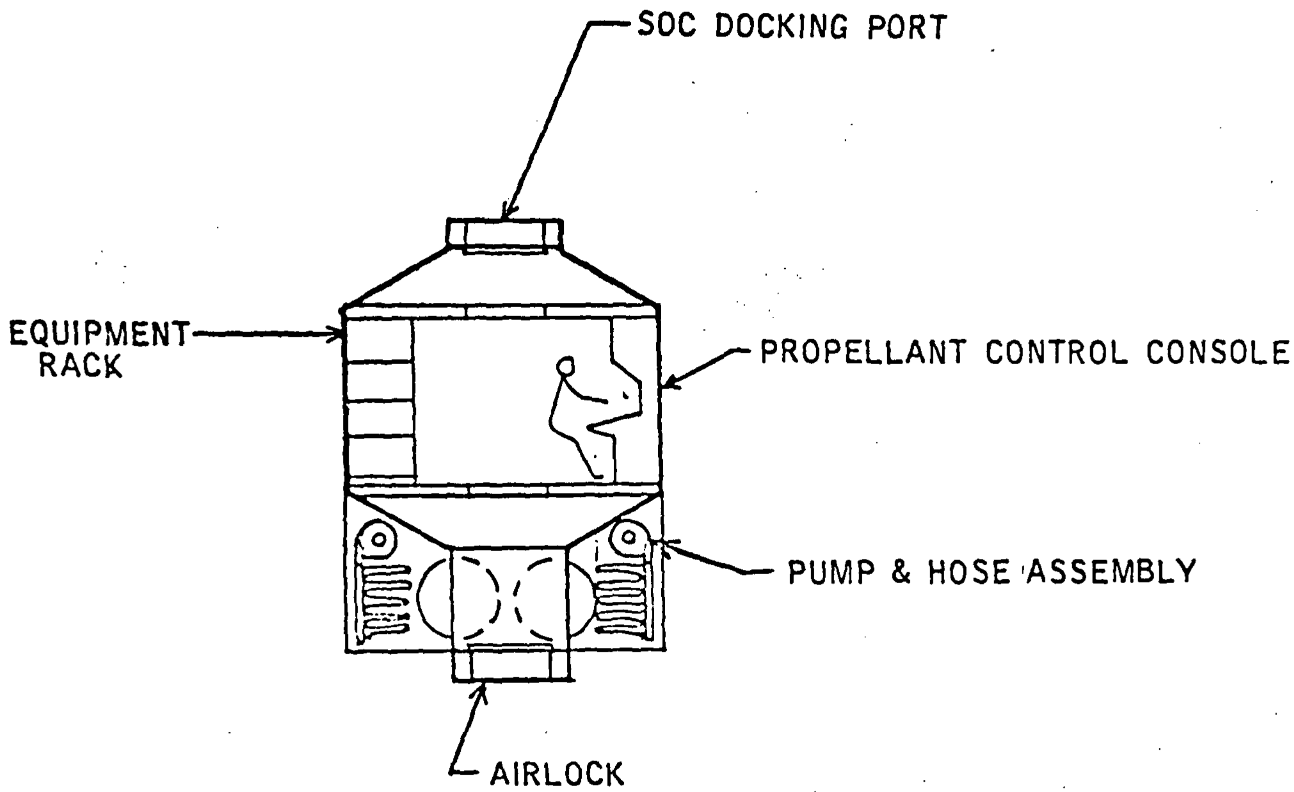


Figure 10.5-1. Propellant Handling Facility

Table 10.6-1

MOTV VEHICLE DESCRIPTION

Two Common Stage All-Propulsion Space Based OTV

MISSION CAPABILITY	
Duration:	7-14 days
Operations:	45° Traverse to visit 4 satellites
CREW MODULE	
Ignition Weight:	11000 lb
Payload	2000 lb
Dimensions	15'D x 15'L
Crew Size:	4
STAGE 1	
Dry Weight	4759 lbs
Prop. Wt. (LO_2/LH_2)	54733 lbs
Prop. System	RL-10 Cat 2B (2) @ 459 Isp
Dimensions	15'D x 33'L
STAGE 2	
Same as Stage 1	

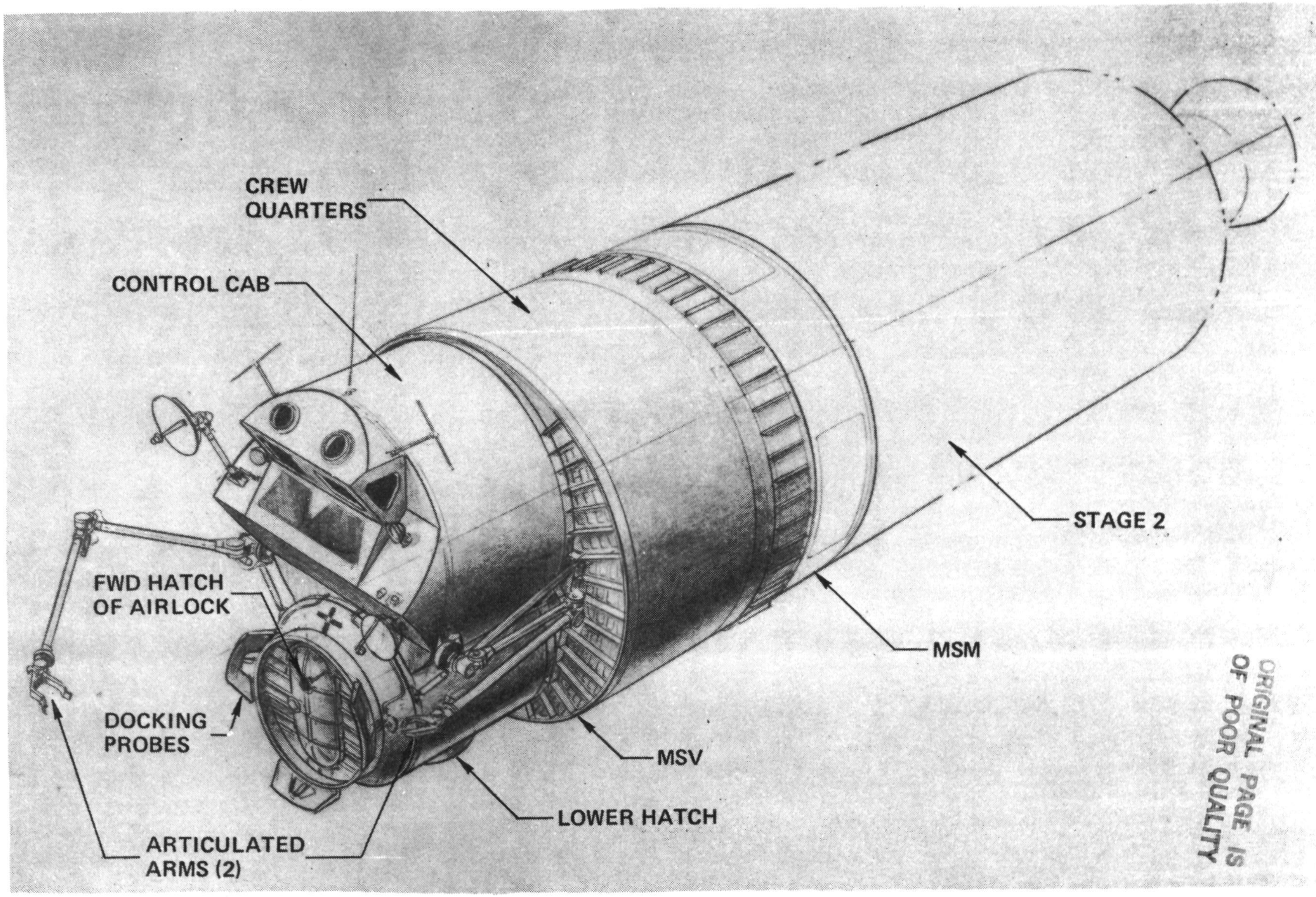


Figure 10.6-1. Manned Geosynchronous Mission

Table 10.6-2

SOC/MOTV OPERATIONS SEQUENCE
(Nth MISSION)

Dock and Position Stage 1

Stage 1 C/O and Maintenance

Dock CM and Stage 2

Transfer Crew and Payload to SOC

Position CM and Stage 2 for C/O and Maintenance

CM and Stage 2 C/O and Maintenance

Mate Stage 1 and 2

Dock Tanker 1 and Load Stage 1 Propellants

Tanker 1 departs

Dock Tanker 2 and Load Stage 2 Propellants

Tanker 2 Departs

Dock Tanker 3, Top off Stage 1 and 2 Prop.*

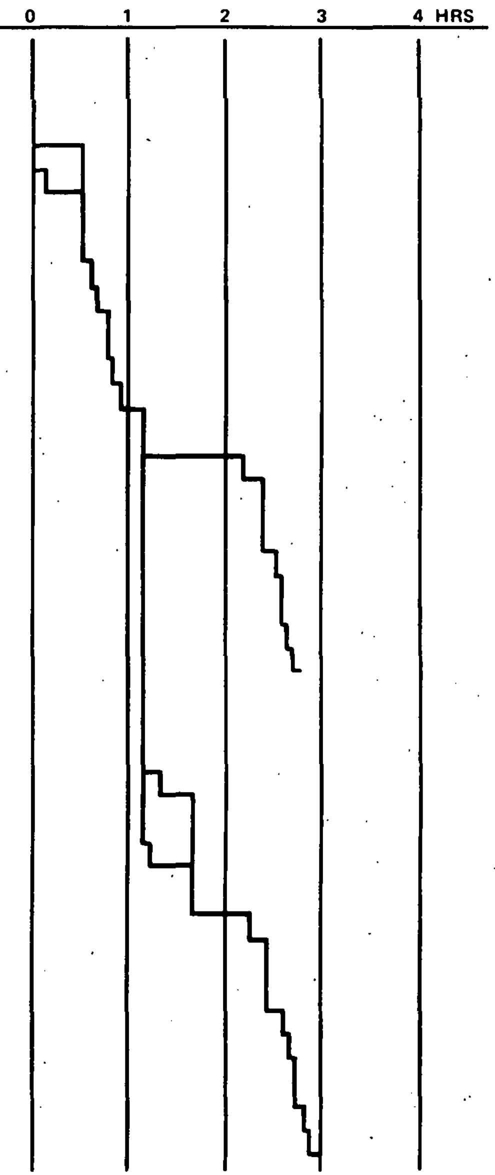
Load CM Expendables, Crew and Payload

Preflight and Launch

*Requirement for 3rd Orbiter dependent on Orbiter payload capability to SOC orbit in 1990 timeframe.

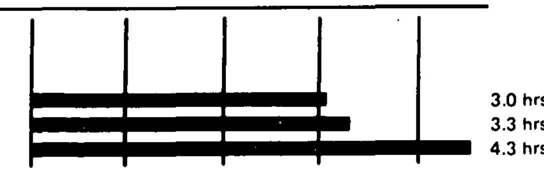
TABLE 10.6-3
PROPELLANT TRANSFER OPERATIONS TIMELINE

EVENT	ELAPSED TIME (MIN)	CUMULATIVE TIME (MIN)
4.3.2 TRANSFER LH_2		0
Vent OTV LH_2 tank	30	30
Attach LH_2 transfer line	8	8
Vent LH_2 transfer line	1	30
Close LH_2 transfer line	–	30
Close LH_2 tank	–	30
Transfer LH_2 chilldown	1	31
Thermal hold	5	36
Vent LH_2 tank	15	51
Close tank	–	51
Transfer LH_2 chilldown	1	52
Thermal hold	5	57
Vent LH_2 tank	15	72
Close vent	–	72
Transfer LH_2	60	132
Switch to topping rate	10	142
Sense vapor flow	–	142
Close valves	–	142
Vent LH_2 transfer line	5	147
Purge LH_2 transfer line with He	5	152
Close LH_2 transfer line vent	–	152
Disconnect LH_2 transfer line	1	153
Purge LH_2 transfer line with He	2	155
Return LH_2 transfer line to Orbiter	8	163
4.3.3 TRANSFER LO_2	–	72
Attach LO_2 transfer line	7	79
Vent LO_2 transfer line	1	104
Close LO_2 transfer line vent	–	104
Hold	2	74
Vent OTV LO_2 tank	30	104
Close LO_2 tank	–	104
Transfer LO_2	35	139
Switch to topping rate	10	149
Sense vapor flow	–	149
Close valves	–	149
Hold	8	157
Vent LO_2 transfer line	5	162
Purge LO_2 transfer line with He	5	167
Close LO_2 transfer line vent	–	167
Disconnect LO_2 transfer line	1	168
Purge LO_2 transfer line with He	2	170
Return LO_2 transfer line to Orbiter	8	178



Alternative Propellant Transfer Sequence

Overlapping transfer – LH_2 first
Overlapping transfer – LO_2 first
Separate transfer



Contract NAS9-15779, "Manned Geosynchronous Mission Requirements and Systems Analysis Study," currently underway with Grumman Aerospace Corporation. The approach used was to select from a ground based checkout scenario those elements applicable to space basing and apply a factor to those ground hours to account for the added difficulty of space operations. The results of this procedure are high and misleading. A subsequent analysis of space based checkout and maintenance is required which is based on an aircraft operations approach and an MOTV designed for space maintenance. The data on projected personnel and man-hours are presented in tables 10.6-4 and 10.6-5, respectively, only as a point of departure since no other data are yet available. One potential reduction possibility is the ground basing of the test engineers shown in table 10.6-4, thus reducing the personnel complement from 10 to 6. With judicious use of maintenance monitoring equipment onboard the MOTV and the selection of ease of maintenance as a prime design consideration, the final manpower requirements are expected to fall well within the support capability of the SOC.

The physical handling and stage assembly devices are discussed in section 10.4.

Table 10.6-4 Summary Manpower Estimates

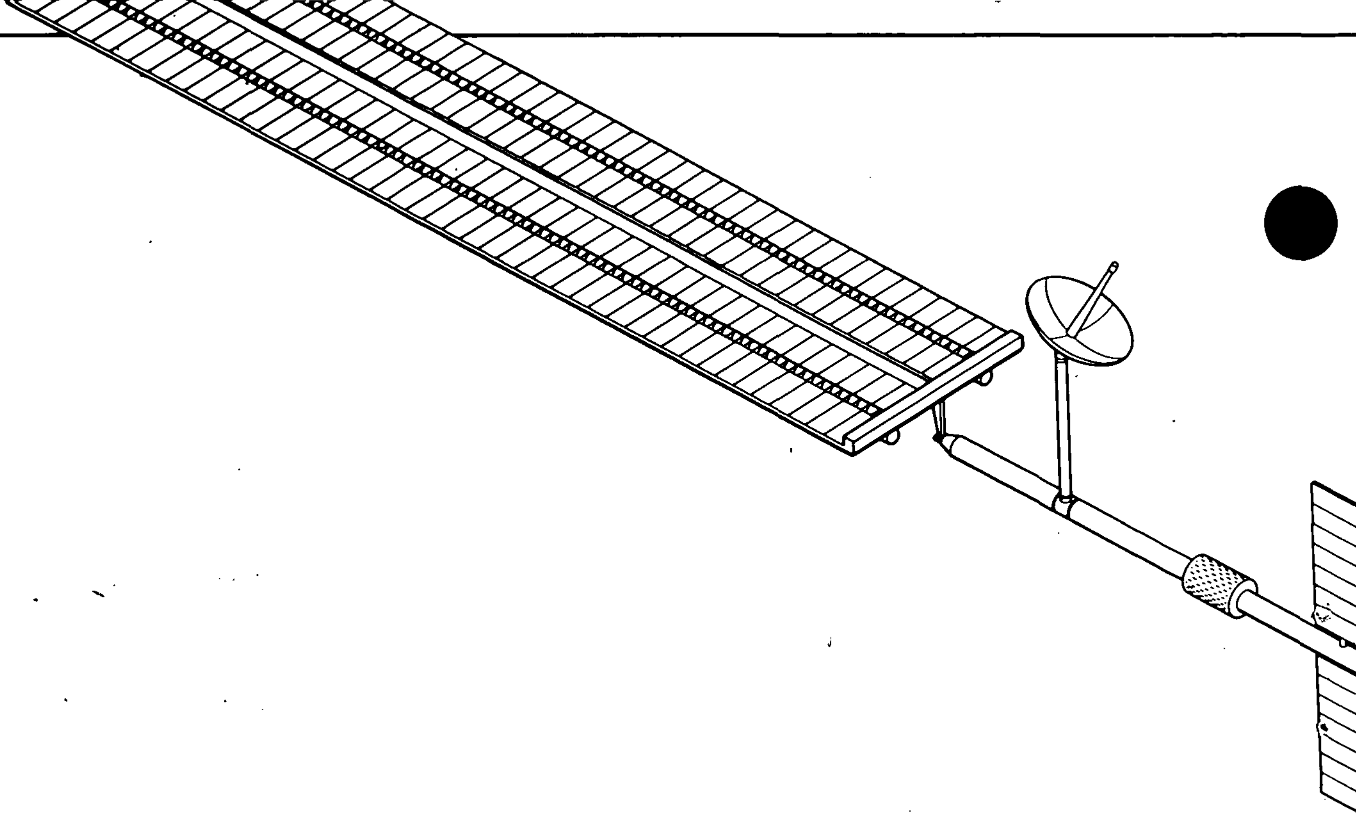
ACTIVITY	GROUND PERSONNEL REQUIREMENTS: # OF PEOPLE		SKILL MIX					LEO DEPOT PERSONNEL REQUIREMENTS
	TWO SHIFTS	PRIME SHIFT	ENG.	TECH.	QC	TEST DIRECT	OTHER*	
PREP	5	5		3	1		1	ENGINEERS 1 PROP. SPECIALIST 1 ECLSS SPECIALIST 1 AVIONICS SPECIALIST 1 ELECTRICAL SPECIALIST TECHS 1 SUPPORT EQUIPMENT 1 MECH 1 FLUID 1 AVIONICS 1 ELECTRICAL 1 QC/SAFETY 10 TOTAL
SCHEDULED MAINTENANCE	12	8	1	1	1	1	1	
UNSCHEDULED MAINTENANCE	15	9	2	4	1	1	1	
MOTV INTEGRATION	20	10	4	3	1	1	1	

*GROUND; LEVEL OF EFFORT FOR PHOTOGRAPHER, FACILITY EQUIPMENT OPERATOR AND SAFETY SPECIALISTS USED ON "ON CALL" BASIS THROUGHOUT ACTIVITY

TABLE 10.6-5

MOTV MAN-HOUR ESTIMATES

MAINTENANCE ACTIVITY	GROUND MAN-HOURS			SOC MAN-HOURS	
	CM	PM	TOTAL	1:1.3	1:1.5
PREP	59	79	138	180	207
Scheduled	770	280	1050	1365	1575
Unscheduled	2152	520	2642	3435	3963
Integration	278		278	361	417
Total			4108	5341	6162



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