Apr 1st, 8:00 AM

Phased Approach to the Space Operations Center

Allen J. Louviere
Assistant Director for Research and Development, Engineering and Development, Lyndon B. Johnson Space Center, NASA

SPACE MANUFACTURING SYSTEMS
AND
THE SPACE OPERATIONS CENTER

Allen J. Louviere
Assistant Director for Research and Development
Engineering and Development
Lyndon B. Johnson Space Center, NASA

ABSTRACT

The Space Operations Center and the Space Manufacturing and Processes Systems have major characteristics of compatibility and can be mutually influential in formulating the next major space initiative. The Phase Program Plan of the SOC provides for increasing capabilities and can be integrated with a Space Manufacturing System's concept in which both the development and operational phases can be implemented. The requirements for the Space Manufacturing System appear to be suitable for SOC on-board development and then operationally as a tender of a free-flying satellite in a station-keeping orbit. The free-flying satellite can be placed in an orbit which hovers about the SOC and never exceeds line of sight communications limits. The services and reboost requirements can likewise be accommodated.

The concepts of phased programs, development and operations, station-keeping orbit envelopes, propulsive Harbor Tugs and aspects of servicing will be an issue and presented.

INTRODUCTION

The utilization concepts for Low Earth Orbit Manned Space Stations have varied significantly in the past two decades. Science and applications were the early emphasis; gradually the station was conceived as a staging and operations center of a space transportation system with capabilities to access higher energy earth and trans-earth orbits; more recently, the business community has initiated studies which may lead to profitable commercial ventures. These concepts for utilization appear to have extremes in compatibilities, but analysis indicate many areas can be suitably integrated while some fewer cannot be resolved as convincingly. The Manned Space Station is the next logical and most promising candidate for a new Space Program Initiative.

In formulating the program, the issue of utilization emphasis will be very important and will significantly effect the structure of the program, the prospective users and the physical configuration of the Manned Space Station. The decisions for determining the utilization objective will also be ultimately influenced by the cost incurred, utilization cost benefits and program budgetary requirements.

The Space Operations Center (SOC) is presently envisioned as an accumulation of support capabilities which are incrementally increased. This concept is compatible with many of the prospective users and can readily support the Space Manufacturing System. The inherent ease of accommodation by SOC and the potential cost benefit qualifies the Space Manufacturing System as a ranking candidate for early implementation. The Space Manufacturing System is somewhat unique in its implementation since significant science is applied; orbital operational support services are a necessity; and, there is an excellent opportunity for profit in the commercial endeavors. Furthermore, the SOC Phased Program Approach is applicable to a phased development of the products of the Space Manufacturing System.

The SOC Phased Program Concept

The Space Operations Center is nominally conceived to be assembled in three phases, each of which provides increasing capabilities. Added capabilities may include pressurized volumes, more system redundancy, added crewmen and operational support equipment. The SOC design concept includes the technical and programmatic requirements for the entire three phase program. Inclusion of the total program requirements will avoid cost increases by initially planning for the incurrence of new requirements. The phased program has another feature which includes a segmented module shown in Figure 1. The segmented module provides the capability for modularization at the fabrication level and the capability to configure modules of various sizes. The conceptual orbital configurations for the Phased Program are shown in Figures 2, 3, and 4.

The SOC is a multi-purpose facility with core systems which provide utilities and services for several utilization concepts. The SOC is conceived to accommodate the servicing of satellites in compatible orbits, the servicing and final checkout of satellites in transit to high energy orbits, the assembly of propulsion stages and the accommodation of various types of on-board facilities and laboratories for research and development. The on-board research and development facilities and the Satellite Services capabilities can readily support the Space Manufacturing Systems requirements. The SOC provisions can also support both the development and operations phases, and the Space Manufacturing System can also be integrated with the SOC's Phased Program Approach. Pilot development equipment for Space Manufacturing products is now scheduled to be flown on several Shuttle Orbiter flights and should provide the initial design data for a larger facility with attendant larger quantities of products.

Space Manufacturing Systems Support

Initial large scale developments may dictate that the Space Manufacturing System be integrated with a continuously manned facility such as the SOC. The SOC can provide integral on-board volume or a structural interface for an attached module. The only constraint may be the quality of the zero-gravity environment which may degrade the quality of products. The advantages of the on-board/attached facility is the ability to provide continuous crew attendance and intervention which will reduce the automation requirements and the associated cost.

The on-board development phase would also have access to the routine Shuttle resupply flights and thus facilitate modifications and re-configurations of the Space Manufacturing equipment and systems. Once a processing technique is developed, the operational phase will be initiated and the Space Manufacturing System can be integrated with a free-flyer satellite. The SOC can also serve as a satellite tender which services the Space Manufacturing Satellites and harvests its products at routine intervals.

The accommodations required by a Space Manufacturing Satellite begins with the orbital location of the SOC. The Space Manufacturing Satellite requires no specific inclination, so a low orbital inclination SOC can serve as an adequate tender. Similarly, a low orbit inclination SOC will provide a most economical Shuttle delivery cost since the low inclinations provide maximum earth to orbit payloads, thereby minimizing cost/pound to orbit.

SOC and the Free-Flyer

Delivery of the Space Manufacturing Satellite to the SOC will begin a close association which is initiated by a checkout of systems and a verification of the products of the manufacturing process. Once the Satellite is berthed to SOC, the satellite and manufacturing systems will be operated for a sufficient period of time to deter the "infant mortality" occurrence which historically has accounted for a large percentage of failures. Compatibility verification between the SOC and Satellite Systems can also be determined during the process of checkout.

Two concepts for a free-flyer satellite are shown in Figure 5. It should be noted these conceptual features include requirements necessary for compatibility with SOC; most notable are the requirements of berthing and docking. Other requirements are not solely required by SOC for compatibility but are also required to sustain the free-flyer. The two concepts vary most dramatically in the electrical power source. The fuel cell and solar array powered electrical systems are sized to approximately 5kW average output and are conceived to be serviced by the SOC.

The fuel cell LOX and LH_2 systems are designed to sustain nominal operations for up to six months at which time replenishment of the cryo system, batteries, attitude control propellant and other general services will be performed. The retrieval of the Space Manufacturing System products will be also scheduled at these servicing intervals but may require more frequent intervals. The fuel cell systems operational advantages include no required pointing orientation, minimum projected frontal area, less aerodynamic drag with the combined effects providing for minimum altitude degradation. A comparison of the fuel cell and solar array drag characteristics is shown in Figure 6.

The 5kW solar array powered electrical system is similarly compatible with the SOC, but may not necessitate cryogenic replenishment but may require other services. In both cases, periodic checkouts and system statusing will be performed.

The free-flying satellite can be given a final check before being transported to its operational orbit. In a near proximity, stationkeeping position the satellite systems can be verified in their free-flying operational mode. Likewise, the Space Manufacturing System performance can be assessed.

The transport of the free-flying satellite to its orbital location to begin its operational life can be accomplished by several methods. The free-flyer could incorporate its own propulsion system and in conjunction with its other on-board systems capabilities, translate to the desired orbital location. This option burdens the free-flyer with additional requirements which will increase the free-flyer cost and operational maintenance. An alternative concept would be a small propulsive spacecraft which performs the function of a "Harbor Tug" and is an integral part of the SOC operational support systems. In this case, the Harbor Tug spacecraft will relieve the Space Manufacturing free-flying satellite of proximity operations, transport and reboost propulsive requirements.

The Compatible Orbit

Placement of the free-flying satellite can be accomplished by any of several propulsive spacecraft which are in various stages of design and development. Figure 7 illustrates their concepts and general characteristics. Each has appealing features and each varies in capabilities of propulsive authority and range. All are compatible with the SOC and final selection will depend on compatibility with the orbit keeping envelope characteristics. Figure 8 illustrates a concept for placement of a free-flying satellite in an orbit keeping envelope which maintains line of sight communications depicted in Figure 9 and minimizes the propulsive requirements of the propulsive spacecraft/Harbor Tug.

As indicated, the Harbor Tug places the free-flying satellite along the SOC orbital flight path forward of and at a slightly higher altitude. The illustration denotes the relative flight path of the free-flying satellite with respect to the SOC. The SOC itself is revolving around the earth, and the relative free-flyer flight path trace occurs over numerous revolutions and days.

As the relative rate of orbital altitude decay begins to separate the SOC and free-flyer, the separation distance never exceeds the line of sight communication envelope. The flight path relative to the SOC will appear to pass above and fall behind the path of the SOC. The velocity of the free-flyer will match the SOC as it is co-orbital. As the altitude decay continues, the relative velocity of the free-flyer increases and passes below the SOC and moves forward to the communication limit. At this point, the Harbor Tug would be dispatched and rendezvous, dock and reboost the free-flyer satellite to its initial orbit keeping position. During this operation, the Space Manufacturing Systems products would be acquired. The Harbor Tug would then return with its cargo to the SOC, and the free-flyer would begin its orbit keeping cycle again.

There are other options for station-keeping orbits but most exceed the line of sight communications envelope. There are some satellites whose requirements do not include line of sight communications, and therefore, can be placed in orbits which bring the free-flyer into serviceable range at much less frequent intervals. These orbits may also have characteristics which cause them to remain at the same inclination but may rotate out of plane/phase due to the differential regression of the orbits. Other factors which will require careful attention to obtain desired orbital characteristics are the atmospheric density and the free-flying satellite ballistic coefficients. The nominal orbit keeping envelope assumes a set of nominal conditions specified on the illustrations.

A more frugal propulsive energy concept may be to service and reboost the free-flyer when it is in radial alignment with the SOC. Essentially, this is equivalent to being above and below the SOC with respect to the earth's centroid. This reduced transit distance of the free-flyer will be more effective if the Space Manufacturing System can be serviced and its products acquired at the same interval. The station-keeping envelope can be adjusted within limits but is considered to represent a reasonable concept for maximum SOC and free-flyer compatibility.

SOC Services

There is a significant similarity in many of the services offered by the SOC. Most obvious is the generic provisions in attending to propulsive upper stages and Satellite Services. Figure 10 summarizes these commonalities. The recognition of these factors in the formulative phases is most important and will allow cost effective development of support equipment.

Servicing can be conceived and is now postulated to be an extension of Orbiter capabilities. Most Orbiter servicing equipment will be directly applicable to SOC and some are illustrated in Figure 11. The addition of the servicing fixture which is geometrically similar to the Orbiter Payload Bay will facilitate using existing equipment for payload securing and handling. The Orbiter retention system, including the trunnions and keel fittings, will require minimum modifications for use on the SOC servicing fixture. Similarly, the manipulator (payload handling system) can be similar to that of Orbiter. The use of a servicing fixture which is a surrogate Orbiter payload bay will similarly facilitate all orbital operations by exploiting the techniques developed on Orbiter. The concept includes Extra Vehicular Activity with a suited crewman.

Using the concept, the equipment utilized to transport, secure and handle the free-flyer in the Orbiter will be used in the service fixture. When a free-flyer is returned to the SOC, the servicing will be similar to Orbiter techniques. Some new techniques may be required for SOC proximity operations. As previously discussed, a Harbor Tug may be required to most effectively provide the proximity operations capabilities.

Concluding Comments

The Space Manufacturing Systems and the SOC appear to be compatible from technical and programmatic considerations. The development and operational phases of the Space Manufacturing System could be integrated with the SOC Phased Program Approach and the Segmented Module Concept. Furthermore, an early determination of a combined program could be most effective and could expedite the operational phase of Space Manufacturing Systems.

The multi-purpose capabilities of the SOC will support other utilization concepts in a similarly facile manner. However, it is not intended to implement all the utilization concepts simultaneously; but rather, selected concepts with common requirements will be phased to most efficiently increase the SOC services and capabilities. This phasing will most certainly be constrained by the budgetary fluctuations and allocations.

In summary the Space Operations Center will provide a cost effective means of implementing the Space Manufacturing Systems in addition to other utilization concepts. Its major advantage will be its performance as an extension of the Shuttle Transportation System and the provisions for orbital services. The continuous presence of man in space will be the most valuable asset of the SOC Program and will provide flexible capabilities for development and operations.

Segmented Module Concept

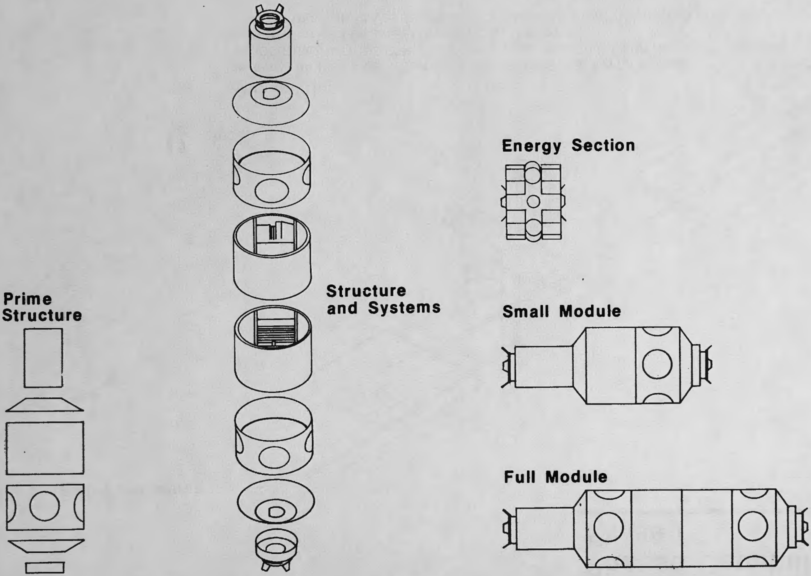
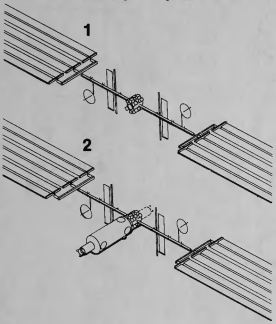
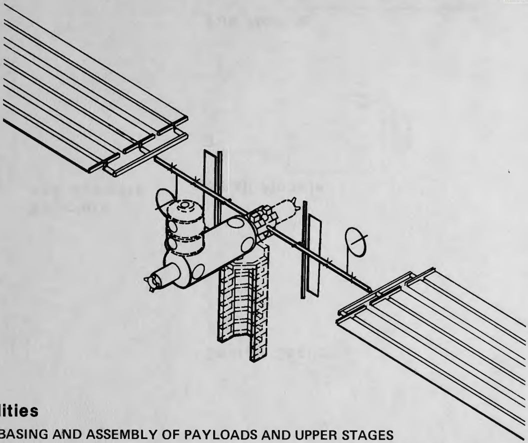


FIGURE 1

Phased Capability
Phase I

Core assembly sequence





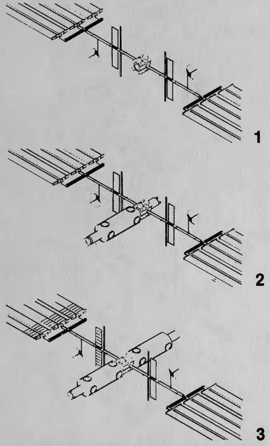
Capabilities

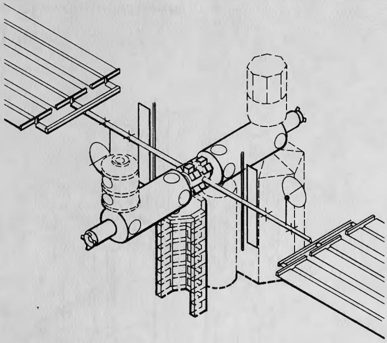
- SPACE BASING AND ASSEMBLY OF PAYLOADS AND UPPER STAGES
- ACCOMMODATIONS FOR SPACE MANUFACTURING/LIFE SCIENCE DEVELOPMENT
- PERIODIC OR LONG TERM MANNED ATTENDANCE
- PROVIDES FOR DEVELOPMENT OF OPERATIONS TECHNIQUES AND EQUIPMENT

FIGURE 2

Phased Capability
Phase II

Core Assembly Sequence





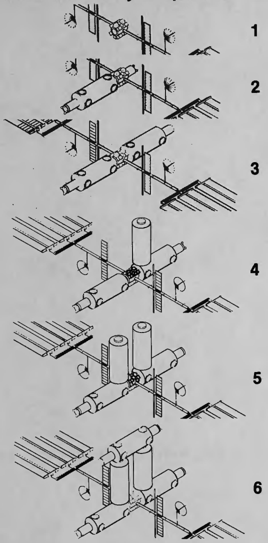
Capabilities

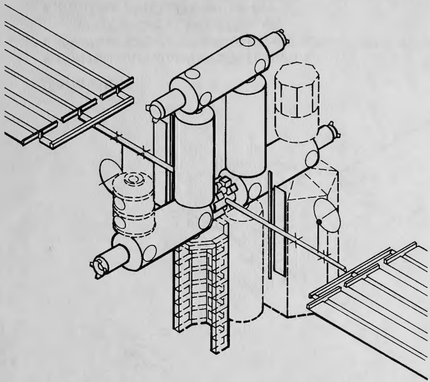
- CONTINUOUS MANNED ATTENDANCE
- ROUTINE ACCESS TO GEOSYNCHRONOUS ORBIT WITH SPACE BASED PROPELLANT STORAGE
- ROUTINE SATELLITE SERVICING
- INITIAL COMMERCIAL SPACE/LIFE SCIENCE PRODUCTS IN LARGE QUANTITY

FIGURE 3

Phased Capability
Phase III

Core assembly sequence



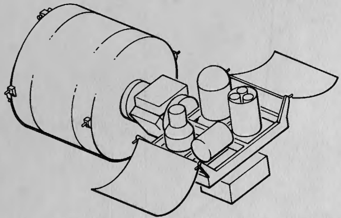


Capabilities

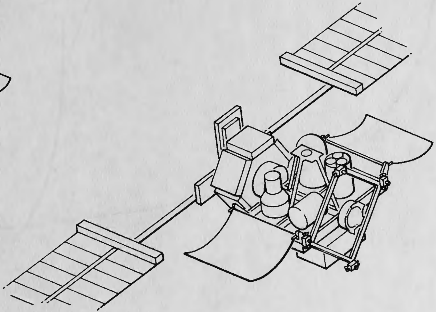
- LARGE CREW-CONTINOUS MANNING
- ROUTINE ACCESS TO GEO AND OTHER STRATEGIC/COMMERCIAL ORBITS
- ACCOMMODATES DOD REQUIREMENTS
- ACCOMMODATES LARGER COMMERCIAL/INDUSTRIAL FACILITIES

FIGURE 4

Free-Flying Satellite Concepts



Fuel Cell
Free Flyer



Space Cell
Free Flyer

FIGURE 5.

Satellite Orbital Life Comparison

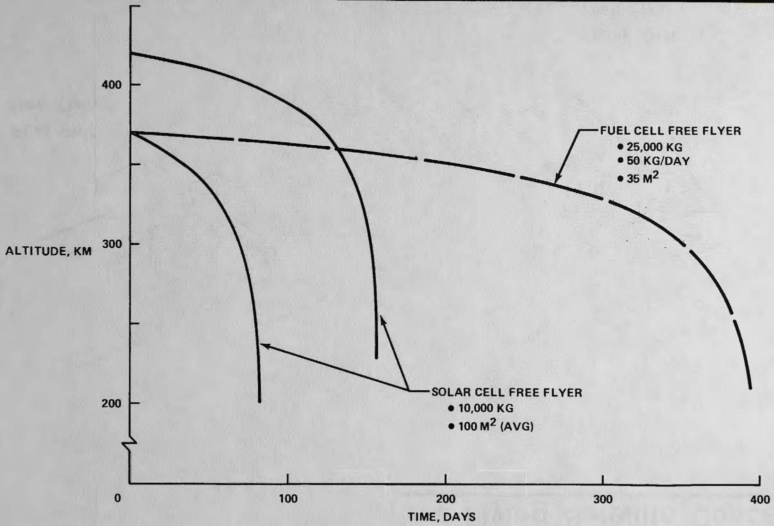
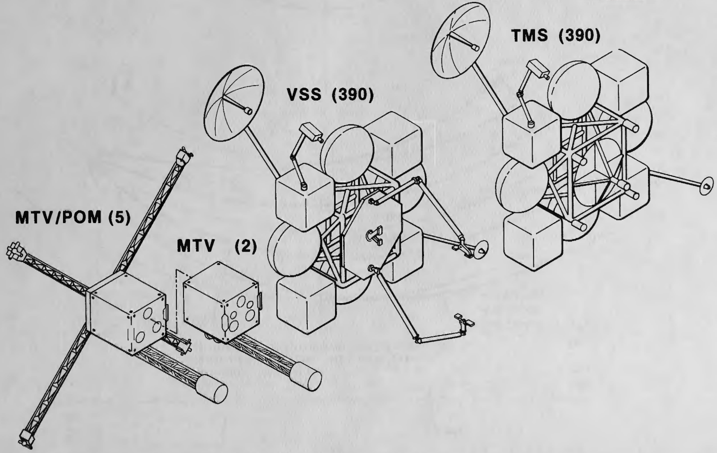


FIGURE 6

Propulsive Spacecraft Harbor Tug Concepts



( ) = One - way ΔV (M/sec) for 10,000 KG Payload Delivery and Return

FIGURE 7.

Orbit-Keeping Envelope

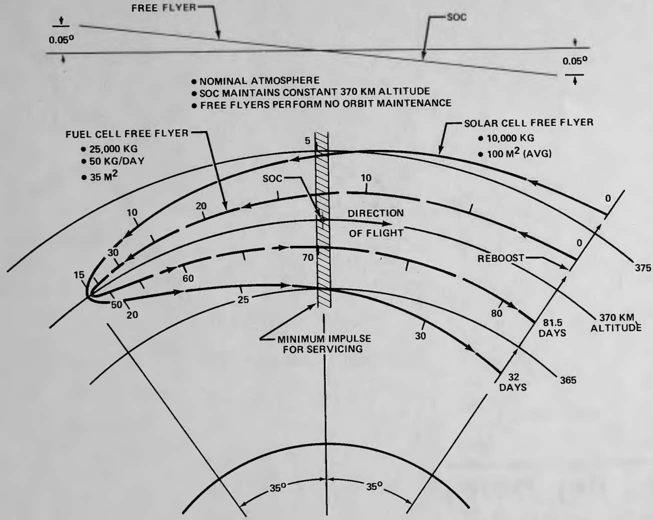


FIGURE 8

Line-of-Sight Communications Geometry

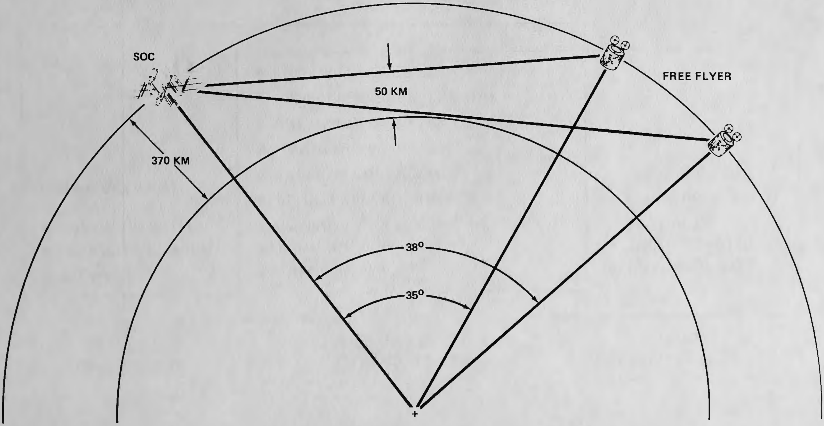


FIGURE 9

Soc Services
Upper Stages and Satellites

UPPER STAGE UNIQUE

- STORAGE
- LAUNCH/RECOVERY
- LARGE QUANTITY PROPELLANT REPLACEMENT

GENERIC TO UPPER STAGES AND SATELLITES

- CHECKOUT
- VERIFICATION
- COMPONENT REPAIR/REPLACEMENT
- FLUIDS REPLENISHMENT
- SYSTEMS CALIBRATION
- HANDLING EQUIPMENT
- CREW ACCESSIBILITY
- PROPELLANT REPLENISHMENT
- PROXIMITY OPERATIONS

SATELLITE SERVICES UNIQUE

- INITIAL BOOST
- ACQUISITION OF PRODUCTS
- PERIODIC REBOOST

FIGURE 10

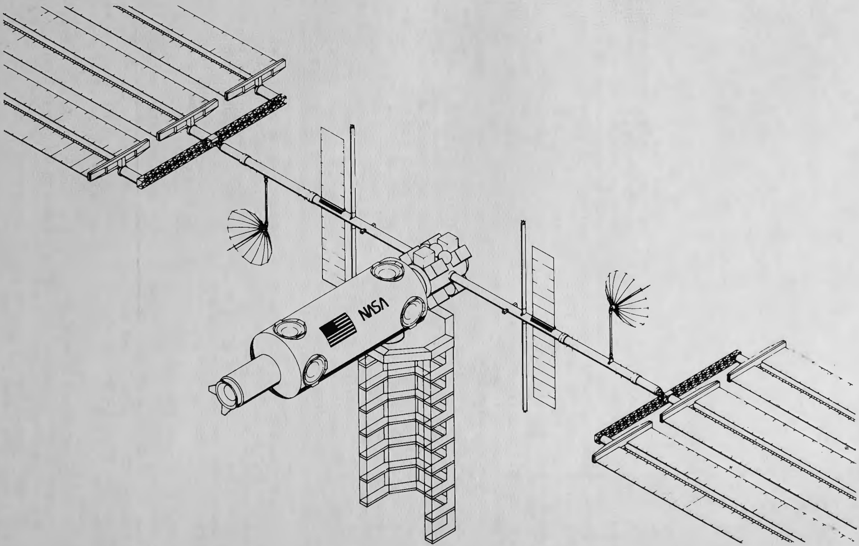


FIGURE 11