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Satellite Servicing in the Space Station Era

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SATELLITE SERVICING IN THE SPACE STATION ERA

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ABSTRACT

Repair and servicing of orbiting satellites in the Space Station era will realize significant enhancements to the capabilities available to date. The first on-orbit repair of an orbiting satellite was demonstrated in 1972 on the Skylab mission using makeshift tools, procedures, and Extravehicular Activity (EVA) techniques. Subsequently, in 1984, the repair and resultant extension of the Solar Maximum Mission (SMM) took full advantage of the spacecraft's having been designed at the outset to be repaired and modified on orbit. Although this mission, among others performed by the Space Transportation System (STS) (Westar 6, Palapa B-2, and Leasat F3), testified to the fact that much progress had been made in the on-orbit repair and servicing of satellites, it also served to highlight the areas in which considerable improvement and technology development were needed. The Space Station capabilities for on-orbit servicing will serve to provide these improvements and technology advances. By expanding on the servicing experience and capabilities provided directly by the STS, the Space Station will significantly enhance mission objectives of long-duration scientific missions, not only by repair and consumable replenishment, but also by the addition and replacement of scientfic instruments with upgraded versions. Major observatory missions such as the Hubble Space Telescope (HST), the Gamma Ray Observatory (GRO), and the Advanced X-ray Astronomical Facility (AXAF) will be among the beneficiaries of this new, enhanced capability. This paper will describe the satellite servicing capabilities planned for the Space Station.

INTRODUCTION

The Space Station will open up a new era in the repair and service of on-orbit space systems (Fig. 1). Much progress has been made since the first on-orbit repair, which was demonstrated in 1973 on the Skylab mission. With the advent of the Space Transportation System (STS), there was an evolution from the very limited contingency approach to the present capability for conducting well planned servicing missions. This new capability was demonstrated aptly during the retrieval, repair, and redeployment of the Solar Maximum Mission (SMM) in 1984. The Solar Maximum Repair Mission (SMRM), Fig. 2, had an added benefit: the satellite had been designed to be repaired and modified on orbit. Despite the success of recent on-orbit repair missions, there is considerable room for improvement.

This paper will discuss the lessons learned from these experiences, the requirements that apply to the various types of missions requiring servicing, and the present plans for establishing a system by which on-orbit servicing, assembly, and repair will become routine.

ON-ORBIT SERVICING - THE BACKGROUND

NASA's first experience with on-orbit servicing and repair was during the 1973 Skylab mission. The spacecraft had suffered a damaged meteoroid and thermal shield along with one Solar Array System (SAS) that had jammed in a partially deployed position while the other SAS had been lost during launch. During the 11 days between the Skylab launch and the subsequent manned launch, repair procedures and equipment to affect the repair of the SAS and the deployment of a backup thermal shield were designed, developed, and tested on the ground. Using a two-man Extravehicular Activity (EVA), both repairs were successfully completed, resulting in Skylab's remaining in orbit until 1979 when it reentered the Earth's atmosphere.

A significant advance in on-orbit servicing and repair capability was realized with the advent of the STS. With its ability to carry to orbit a substantial complement of servicing hardware and a seven-person crew, the STS brought to an end the era of the throwaway spacecraft. The spectacular retrieval, repair and redeployment of SMM, the retrieval to Earth of the Westar 6 and Palapa B-2, and the repair of the Leasat F3 serve as graphic examples of the advances in satellite servicing. Although these retrieval and repair missions were each laden with unique difficulties, they were all completed successfully and are the basis upon which our plans for the future are founded.

Some significant lessons were learned from having conducted the SMRM and the previously mentioned repair/retrieval missions on the Westar, Palapa, and Leasat satellites. These can be summarized as follows:

With consideration to design for serviceability being given in the early stages of a satellite program's development, along with the required servicing and repair operations, plans and procedures, and crew training, complex tasks can be accomplished in relatively short times. Indeed the actual replacement of the SMM's Attitude Control System module consumed slightly less than 1 hour of EVA time, which was considerably less than had been budgeted.

The value of accurate documentation describing the as-built hardware cannot be overemphasized. During the retrieval and capture phases of the Palapa and the SMM, the initial attempts were hampered by slight variances in the flight hardware as compared to the documentation to which the capture devices had been built.

The existence of real-time human involvement in the execution of these missions was key to their success. The human ability to respond to anomalous conditions with ingenuity to affect suitable work-arounds is paramount.

Environmental conditions during the servicing of a given satellite require special attention. Most satellites, due to the nature of each mission, are designed with a specific set of thermal conditions and orbital parameters in mind. As such, they are generally not able to survive large excursions from the boundary conditions to which they were designed. The SMM was no exception. Since SMM is a solar-viewing satellite, only one end of the spacecraft was intended to have solar exposure for extended periods. The other surfaces were used for thermal radiation to space and for mounting of sensors and solar array attachment hardware. It was known that the STS would not be able to provide for SMM the thermal and solar conditions for which it had been designed. Considerable analysis was therefore undertaken prior to the repair mission to guarantee that the spacecraft would not be damaged while being held in the STS Orbiter's payload bay. Of course, for satellites having different sensitivities than those of SMM (such as RFI, molecular and/or particulate contamination, etc.), the problems are different but are of equal or greater importance.

SERVICING MISSION REQUIREMENTS

Specific mission requirements for servicing can vary widely according to the satellite involved. Examples of some near-term science and applications missions and their projected servicing needs are as follows:

- Hubble Space Telescope (HST)
    - Axial and Radial Science Instrument (SI) replacement
    - Solar array replacement
    - Battery replacement
    - Support System Module Orbital Replacement Unit (ORU) replacement

- Solar Maximum Mission
    - Instrument module changeout
    - ORU replacement

- Gamma Ray Observatory (GRO)
  - Propulsion system refueling
  - Power and Data Management Module ORU replacement
- Spartan
  - Propulsion system refueling
  - SI replacement
- Space Infrared Telescope Facility (SIRTF)
  - Cryogen replenishment
  - Battery replacement
  - Electronics assembly replacement or repair
- Advanced X-ray Astrophysics Facility (AXAF)
  - SI replacement
  - Cryogen replenishment
  - Subsystem ORU replacement

Of these servicing missions, the HST is the major NASA on-orbit servicing activity between 1986 and the early Space Station era. This facility, planned to last for 2 decades or more, is designed with replaceable critical spacecraft subsystems and five on-orbit replaceable instruments for observatory upgrading over the life of the mission. HST's original plans were for on-orbit repair and upgrade at approximately 2-1/2 years into the mission, and for return to Earth after 5 years for major refurbishment. Present planning calls for repair and refurbishment at the Space Station. Any servicing required prior to Space Station activation will be conducted by the STS Orbiter.

An important design feature for the serviceability of any satellite or payload is the concept of modularity. As stated previously, the SMM spacecraft was designed with this approach (i.e., its power, attitude control, and command and data handling systems were designed as ORUs). This modular approach is evident in the more recent designs of the HST (Fig. 3), as well as the AXAF and SIRTF (Figs. 4 and 5).

SERVICING AT SPACE STATION - A NEW ERA

The Space Station will open up a new era in on-orbit servicing. It will provide the opportunity to use space in more rational, economical, and imaginative ways than has been possible previously. With the orbiting maintenance base called the core station (Fig. 6) and its associated Orbital Maneuvering Vehicle (OMV), it will be possible to reach, retrieve, and service the satellites, attached payloads, and platforms in an unprecedented manner. By performing periodic servicing, replenishing consumables, changing or enhancing instruments, and updating components and subsystems on orbit, the life and scientific and applications utility of the satellite missions will be lengthened from a few years to up to 20 years. Another important capability that will be made possible with the Space Station is the assembly of large structures in space. The ability to assemble an extremely large detector array in orbit, for example, could have a profound impact on the advancement in astrophysics investigations for generations to come.

Some of the significant attributes of the Space Station and its Servicing Facility that will make it particularly attractive as a servicing base are as follows:

- The Space Station will be a permanent facility, available at virtually all times, and subject only to restrictions in terms of traffic and other operational considerations such as crew time and customer spare parts and/or ORU availability. In contrast, the STS Orbiter is limited by its nominal 7-day on-orbit time.
- The Space Station Servicing Facility, due to its design as described, will be able to provide a controlled environment for the servicing of payloads in terms of thermal, contamination, solar impingement, and EMI/EMC. The STS Orbiter's capabilities in these areas are very limited.
- Because the Space Station is permanently manned, there is an inherent capability to respond to contingencies in near-real time whenever critical situations arise. This

capability may well prove to be the single most important attribute as the Space Station reaches full maturity.

Servicing of platforms and other free-flying satellites that are outside the reach of the Space Station and Space Station-based OMVs and Orbital Transfer Vehicles (OTVs), such as polar orbits or other orbits not coplanar with the Space Station, will require either the use of the STS Orbiter or servicing in situ. Although not directly involved with the Space Station Servicing Facility, the servicing techniques and hardware items used in the STS-based and in situ servicing will, in many instances, be identical to those used in Space Station-based missions with equipment commonality being an objective for cost effectiveness.

SERVICING FACILITY DESIGN

In order to allow the full realization of the Space Station's potential as a servicing base, NASA has undertaken the development of specific servicing capabilities to be incorporated into its design. The design of these capabilities is necessarily driven by two factors: First, the requirements of all foreseeable users must be accounted for, and second, the end product must have a cost-to-benefit ratio consistent with overall budgetary guidelines. To this end, the Goddard Space Flight Center has completed an extensive Phase B effort resulting in the definition and preliminary design of the Space Station servicing capability described in the following paragraphs.

The servicing capability consists of two elements: a multipurpose unpressurized Servicing Facility and a workbench, located in one of the Space Station's pressurized modules. These elements, when taken together and supported by a manipulation and transportation system (the Mobile Servicing System, (MSS)), the OMV, standard tools, EVA support equipment, and a telerobotic servicing system, make up a Space Station capability that can fully accomplish the goals ascribed to it. Figure 7 is a pictorial of some representative servicing missions that can be undertaken using these capabilities.

The Servicing Facility

The location of the unpressurized Servicing Facility on the Space Station structure is shown in Fig. 6. The Servicing Facility is approximately 10.6 meters square at the end and 27.3 meters in length. The volume thus enclosed allows for berthing a 4.5 meters diameter by 18 meters long satellite with sufficient clearance for movement of EVA crew and placement of workstations. The facility design incorporates a retractable cover to allow partial to full opening for access as required. Figure 8 shows the baseline Servicing Facility with the HST berthed within. The facility includes integral storage volumes for instruments, ORUs, and tools. The following paragraphs provide a summary description of the various elements that make up the facility (Fig. 9).

Power and Electrical Distribution. Power required to operate the facility is expected to be on the order of 3 to 4 kW with up to an additional 12 kW available for payload use during functional testing. The Power and Electrical Distribution System provides the power management and distribution of all electrical resources within the facility, including the interfaces for user systems, as well as the facility equipment itself.

Thermal Control. A thermal control system will be utilized to control the facility interior as well as the temperature of the satellite being serviced. This system will employ both passive and active means for the thermal control function. The active portion interfaces with the Space Station Active Thermal Control System.

Data Management. The data management system provides command and data collection and processing for items under service and for all facility subsystems. The system includes communications and data processing interfaces to the Space Station Information System (SSIS).

Contamination Control. The facility, when fully closed, will provide contamination protection for items under service, including monitoring and active collection capabilities for both particulate and molecular contamination.

Crew Accommodations. For support of servicing operations, the facility will contain the necessary lighting, EVA support equipment, closed circuit television system, and facility monitors such as contamination sensors and thermal sensors. EVA support equipment includes tools and restraint systems.

Manipulator System. A dedicated Servicing Facility Manipulator, integral to the facility, is an extremely important additional element that will be used to move payloads, ORUs, and other equipment within the facility. The manipulator will be used to position the EVA crew with or without a portable control station and will be able to support the Telerobotic Servicer in the performance of servicing tasks in a teleoperated mode with increasing levels of autonomy as the robotic capabilities mature.

Retention and Positioning System. The Servicing Facility will be outfitted with a retention and positioning system to hold satellites and other payloads in a fixed position for servicing. This system will have the capability for ±180-degree rotation and 90-degree tilt to facilitate access to all areas of the item under service. Also incorporated into the design of this system will be remotely actuated umbilicals for the transfer of power, data, and commands to and from the satellite.

Fluid Services Accomodations. An important service to be provided is the replenishment of consumables of various types. A survey of the early servicing missions indicates a need at the Initial Operating Configuration (IOC) to be able to refuel with monopropellant hydrazine only. The Servicing Facility will therefore provide accommodations for the use and temporary storage of a transportable refueling module such as the Orbital Spacecraft Consumables Replenishment System (OSCRS). This system will be ground-based and carried to the Space Station by the STS when required. The Servicing Facility will provide power, monitor, and control interfaces to accommodate the operation of such a system. In the Space Station's growth phase, the capability to replenish bipropellant fuels and cryogens will be added.

Communications and Tracking (C&T). The C&T system provides the interfaces between the Space Station C&T system and the Servicing Facility and user equipment. For instance, any RF communications required between a free-flyer berthed within the facility and the Space Station will be accommodated by this system. Additionally, this system will provide the audio and video services required to communicate with the EVA crew while in the facility and to provide visual monitoring of facility activity to the Intravehicular Activity (IVA) crew and the ground.

EVA Control Station. The EVA Control Station provides the flight crew with local (within the facility) monitoring and control for all facility equipment and for hardware being serviced. The control station consists of two elements: one is a fixed control station, and the other is a portable work station that can be employed at the end of the Servicing Facility Manipulator in a 'cherry-picker' mode.

Storage Accommodations. As previously mentioned, the instrument, ORU, and tool storage are integral to the facility allowing items to be retrieved from and placed into storage without opening and closing the facility enclosure. The storage locations are outfitted with the appropriate holding fixtures to accommodate instruments, ORUs, tools, and their carriers. Utility connections (power and data) will also be provided in these locations to operate survival heaters and monitoring equipment.

THE IVA WORK BENCH

The second major element of the Space Station's servicing capability is the IVA work bench located in one of the pressurized modules. Figure 10 is a conceptual representation of this shirt-sleeve servicing capability. This work bench will provide a clean (class 10,000) environment for servicing instruments, ORUs, and other customer hardware elements that are sufficiently small to be brought into the airlock hatch. The bench will be equipped with tools to support component replacement, printed circuit board changeout, wire soldering and crimping, etc. A limited amount of diagnostic capability will also be provided, such as voltmeter, ammeter, etc.

Telerobotic Servicing

Telerobotic servicing and, eventually, fully autonomous robotic servicing are essential ingredients to the full realization of on-orbit servicing as a routine endeavor. As previously mentioned, the Flight Telerobotic Servicer will be fully supportable by the Servicing Facility

Manipulator, which is being developed to relieve the flight crew from hazardous or routine tasks and is expected to enhance productivity significantly.

A representative sample of tasks for robotic servicing is as follows:

- Removing and installing payloads and modules
- Performing precision mechanical assembly as in the buildup of an instrument system
- Servicing of manufacturing facilities such as for materials processing systems
- Making electrical and fuel line connections using automatic or robot-compatible mechanisms

A TYPICAL SERVICING SCENARIO

Figure 11 depicts a typical servicing scenario for the HST. In step 1, the OMV is deployed from the Space Station and maneuvers a short distance away using its cold gas system. It then translates to the satellite location using its standard propulsion system. Reverting to its cold gas system (for fine control and to reduce contamination impact on the HST), the OMV docks with the powered-down spacecraft using a grapple fixture positioned to ensure that the OMV thrust vector is near the center of mass of the satellite (steps 2 and 3). After attaining the proper orientation, the OMV performs the appropriate maneuvers to place the OMV/HST combination to within 15 meters of the Space Station (step 4) at which time the Servicing Facility Manipulator grapples the OMV/satellite and places it on the Servicing Facility's Payload Retention and Positioning System (steps 5 and 6). The OMV is then removed and transferred to its storage location within the Servicing Facility. The HST is then repositioned on the retention and positioning system to allow access by the crew or the FTS for servicing operations. The Servicing Facility enclosure is then closed to provide the necessary environmental protection (step 7).

The satellite umbilical connector is automatically engaged and functional checkout performed from the satellite's ground control center via the transparent Space Station data system. The satellite is then powered down and is available for servicing, repair, or reconfiguration. A variety of tasks could be accomplished by either teleoperated manipulators, full robotics, or EVA. A mission could have its instrument exchanged or upgraded; a cryogenically cooled instrument, such as those on SIRTF or AXAF, could have its dewar refilled; a materials processing mission could have its end product removed and new raw materials installed; and any mission experiencing a failure could be repaired.

Upon completion of the required service and a successful functional test, the satellite is judged ready for deployment in which the predescribed sequence is reversed. Once the OMV/satellite combination is back into the satellite's mission orbit, an additional checkout is performed, the satellite's appendages are redeployed, and the OMV releases the satellite.

This scenario is a generalized description of a satellite servicing with the Space Station. During the upcoming development phase, the GSFC and its contractors will be concentrating on the development of more detailed servicing scenarios.

CONCLUSION

The experience gained thus far in on-orbit servicing and the design of the Space Station's servicing capabilities necessarily impose some requirements on users. Some of these requirements are as follows:

- Satellites must have a standard grapple for capture and a standard berthing interface, such as the STS Orbiter sill and keel trunnions, for attachment to the holding and positioning fixtures in the Servicing Facility.
- Standard electrical interfaces with remotely operable umbilical connectors will need to be implemented.
- Space Station safety requirements must be met to preclude damage to the Space Station or injury to the EVA crew.

- Sensitive instruments will need to implement remotely controlled protective devices, such as shutters and aperture covers, to prevent damage.

- Satellite thermal systems must be designed to maintain survival temperatures during transfer from orbit to the Space Station Servicing Facility.

- Large appendages, such as solar arrays, should be retractable to maximize efficiency in handling, translation, accommodation, and servicing.

The Space Station will offer a capability for on-orbit servicing that will significantly lengthen the life and the scientific and applications utility of satellite missions from a few years to an indefinite period of time. The Space Station Servicing Facility will be designed to provide for replacement of consumables, changing or enhancing of instruments, repair and replacement of systems, storage of replacement units and satellites, and on-orbit assembly. It will also provide the necessary support systems for retrieving and deploying satellites that need servicing. Incorporation of design features in user systems is key to the effective utilization of these capabilities.

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Logan, Francis J., "On-Orbit Platform Servicing in the 1990's," presented at the AAS/AIAA Astrodynamics Specialist Conference, Vail, Colorado, August 12-15, 1985.

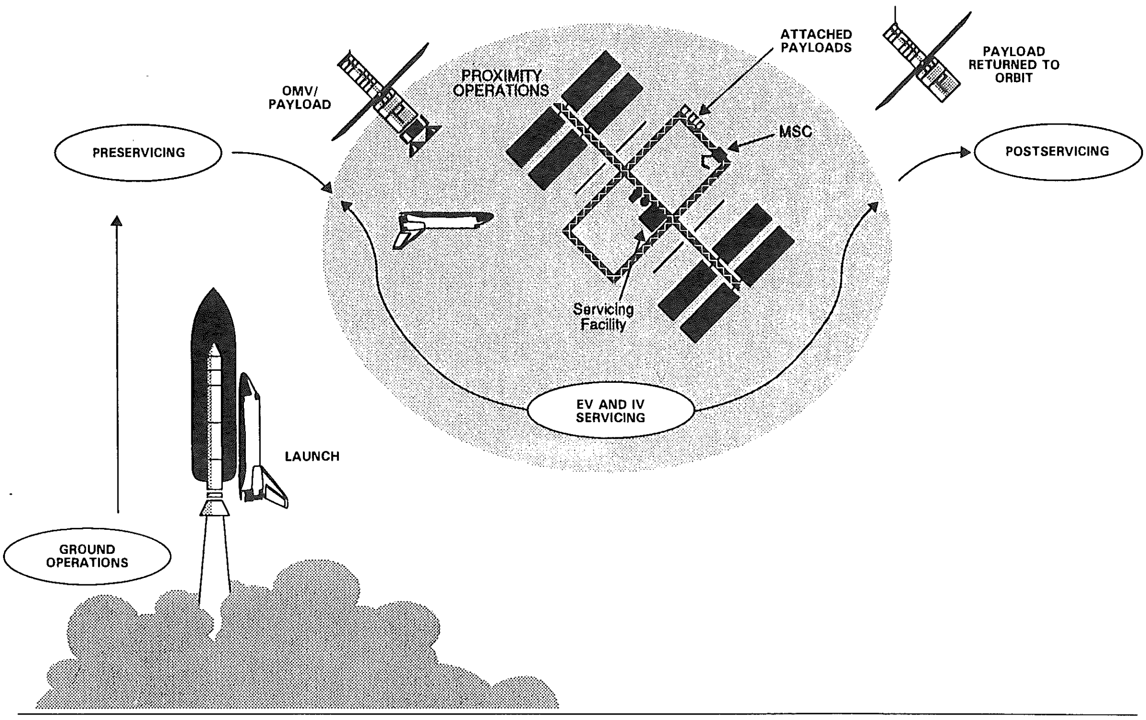

Figure 1. Space Station Servicing

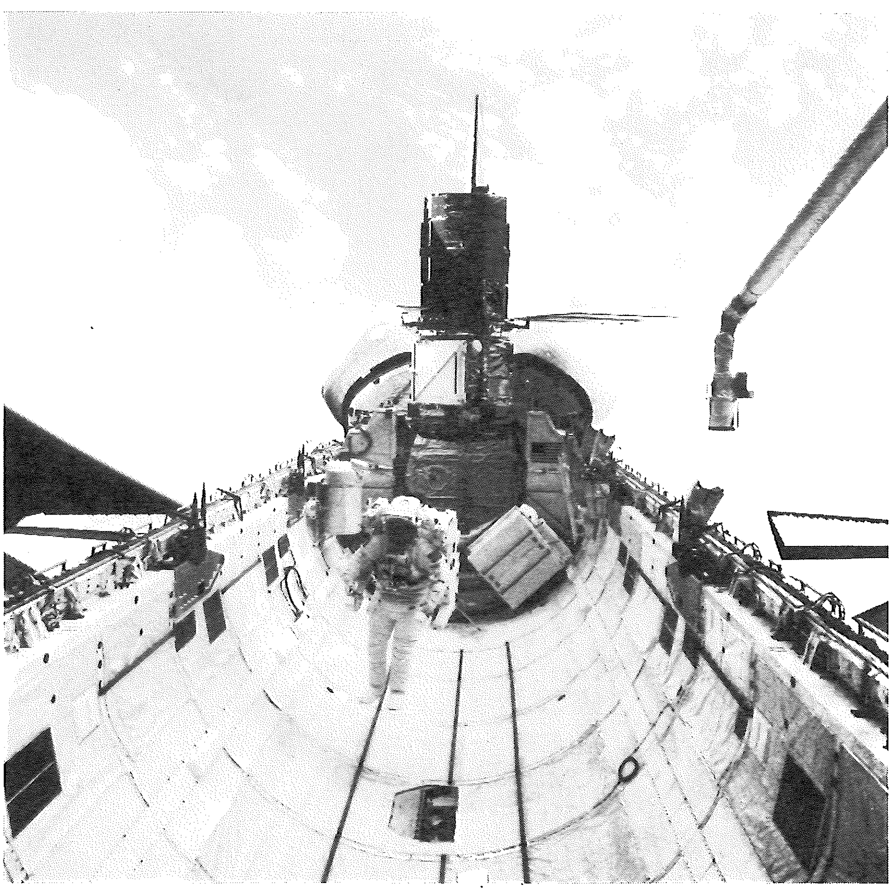

Figure 2. Solar Max Repair Mission

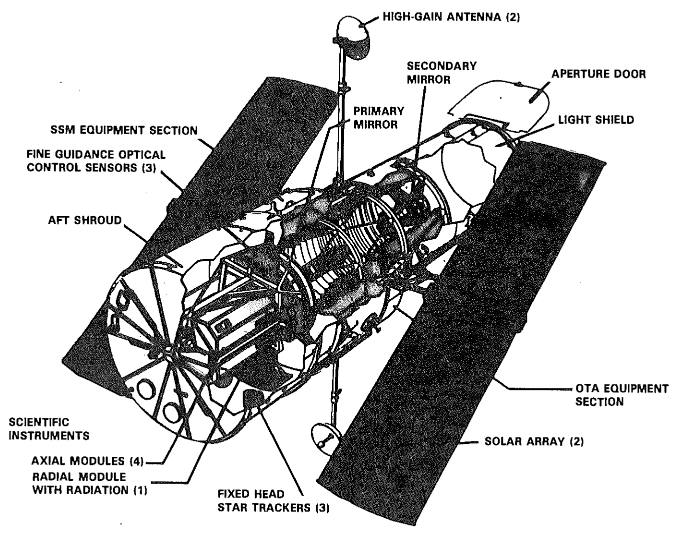

Figure 3. Hubble Space Station Telescope Configuration

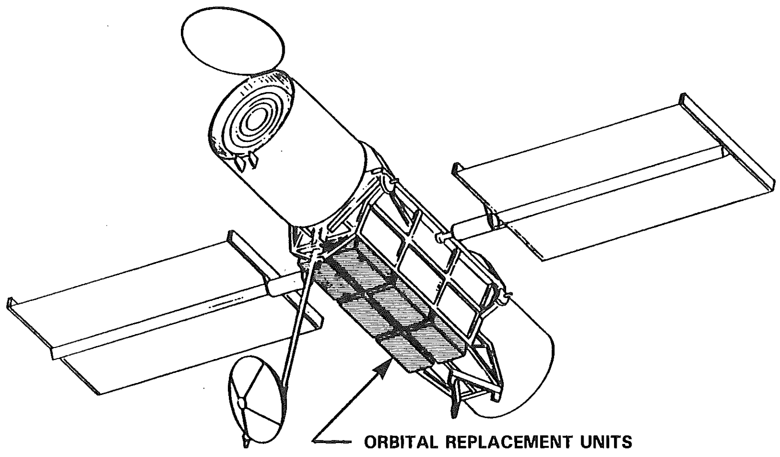

Figure 4. AXAF Configuration

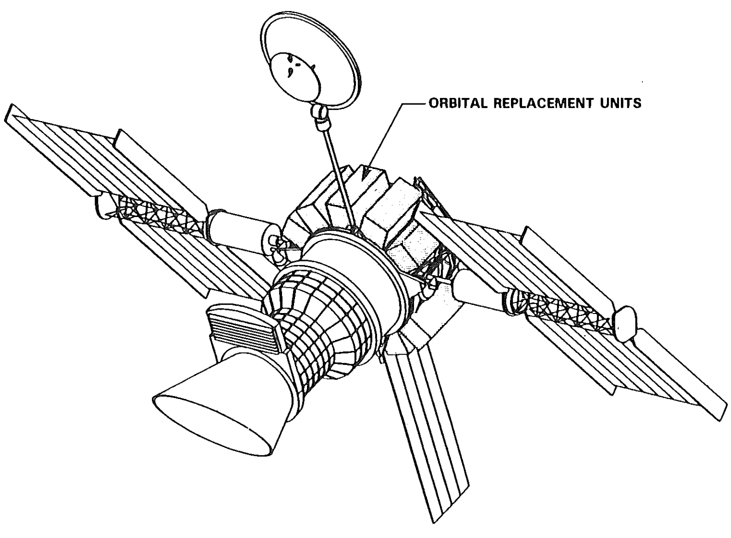

Figure 5. SIRTF Configuration

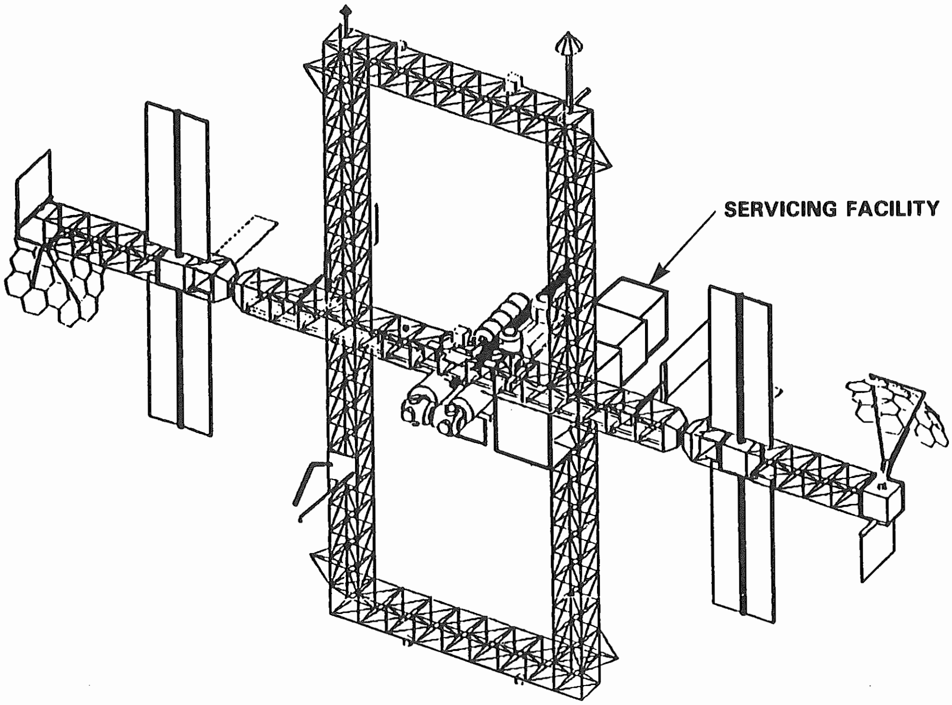

Figure 6. CORE Space Station

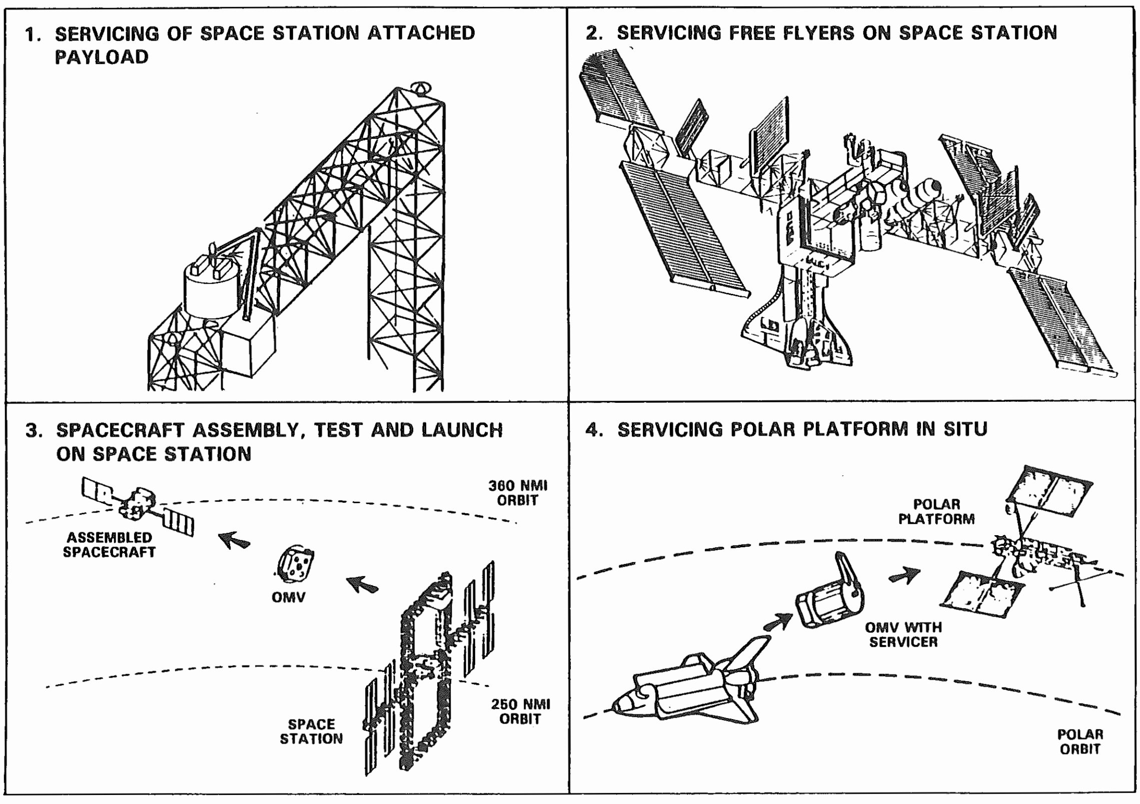

Figure 7. Representative Servicing Missions

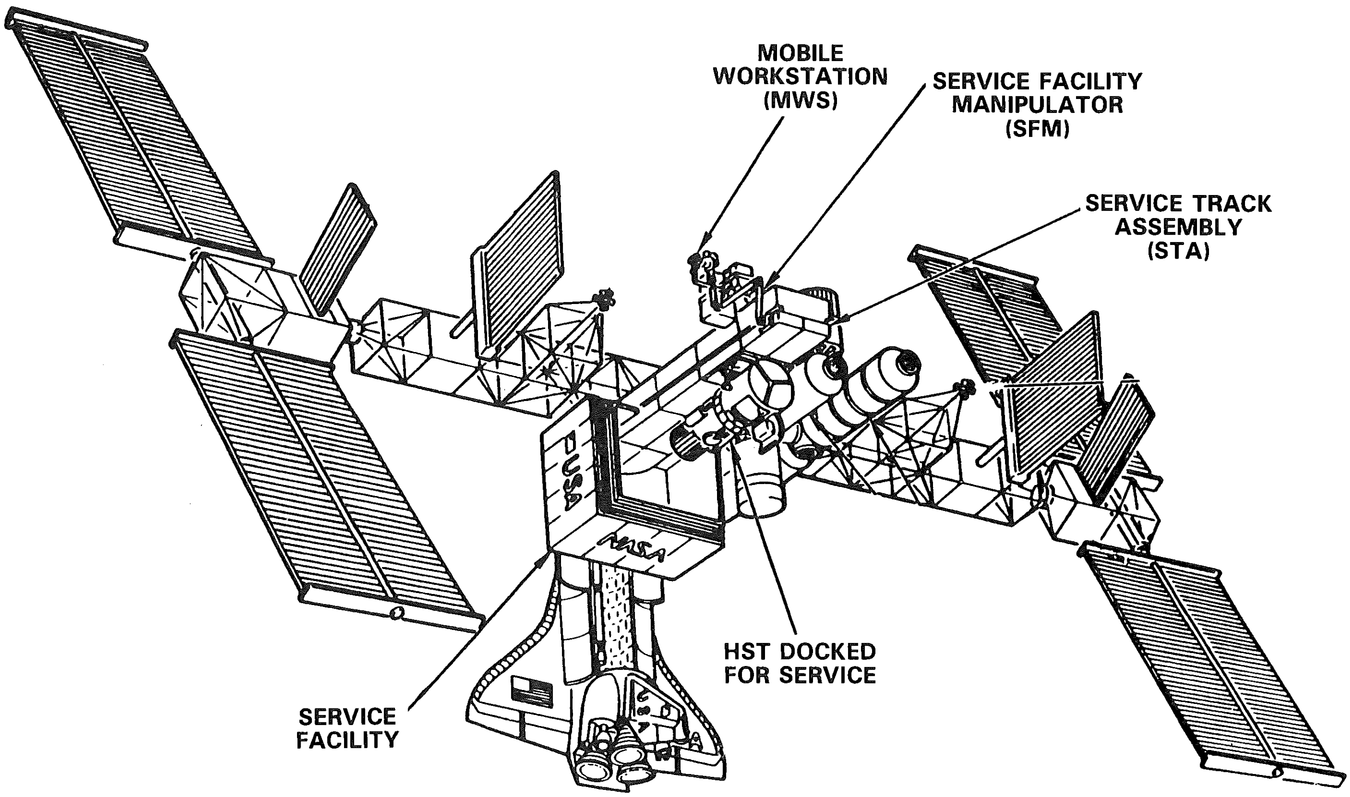

Figure 8. Space Station Servicing Facility Configuration

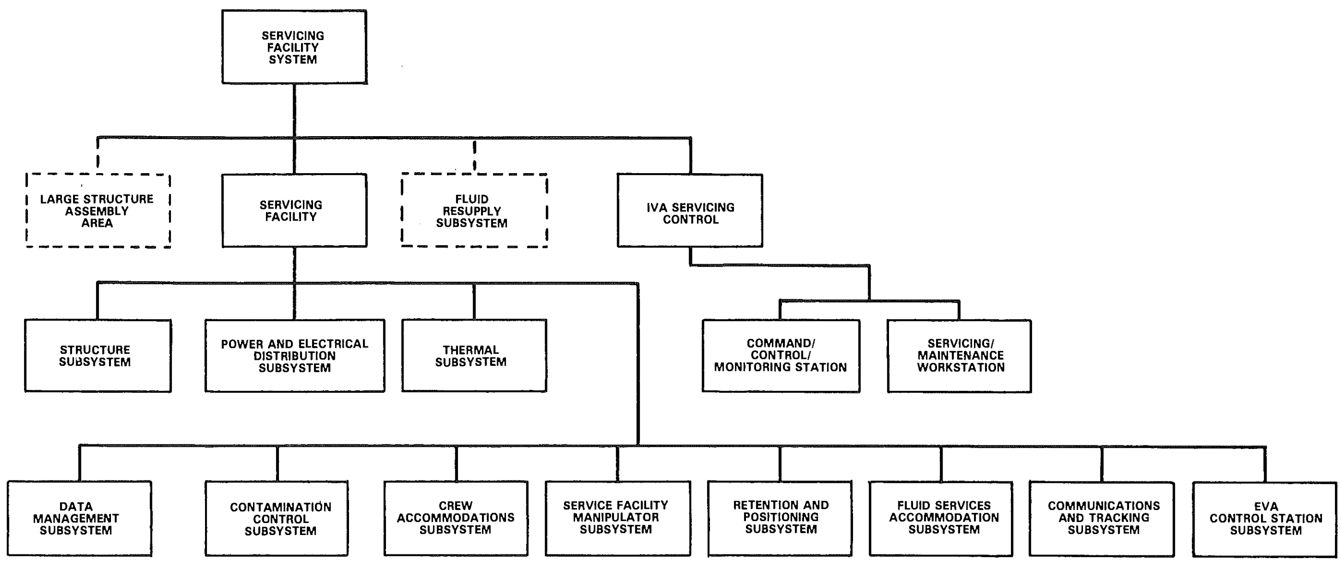

Figure 9. Servicing Facility Block Diagram

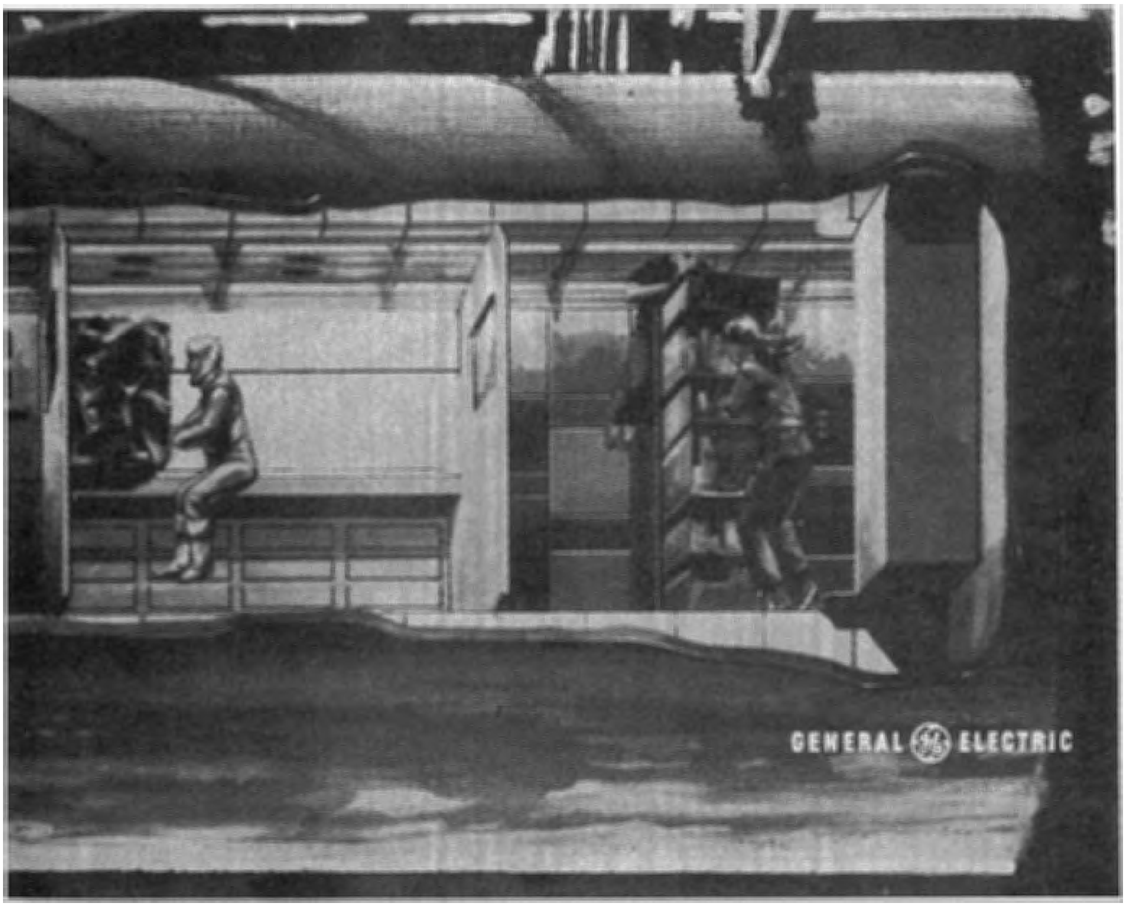

Figure 10. Intravehicular Activity Servicing Area

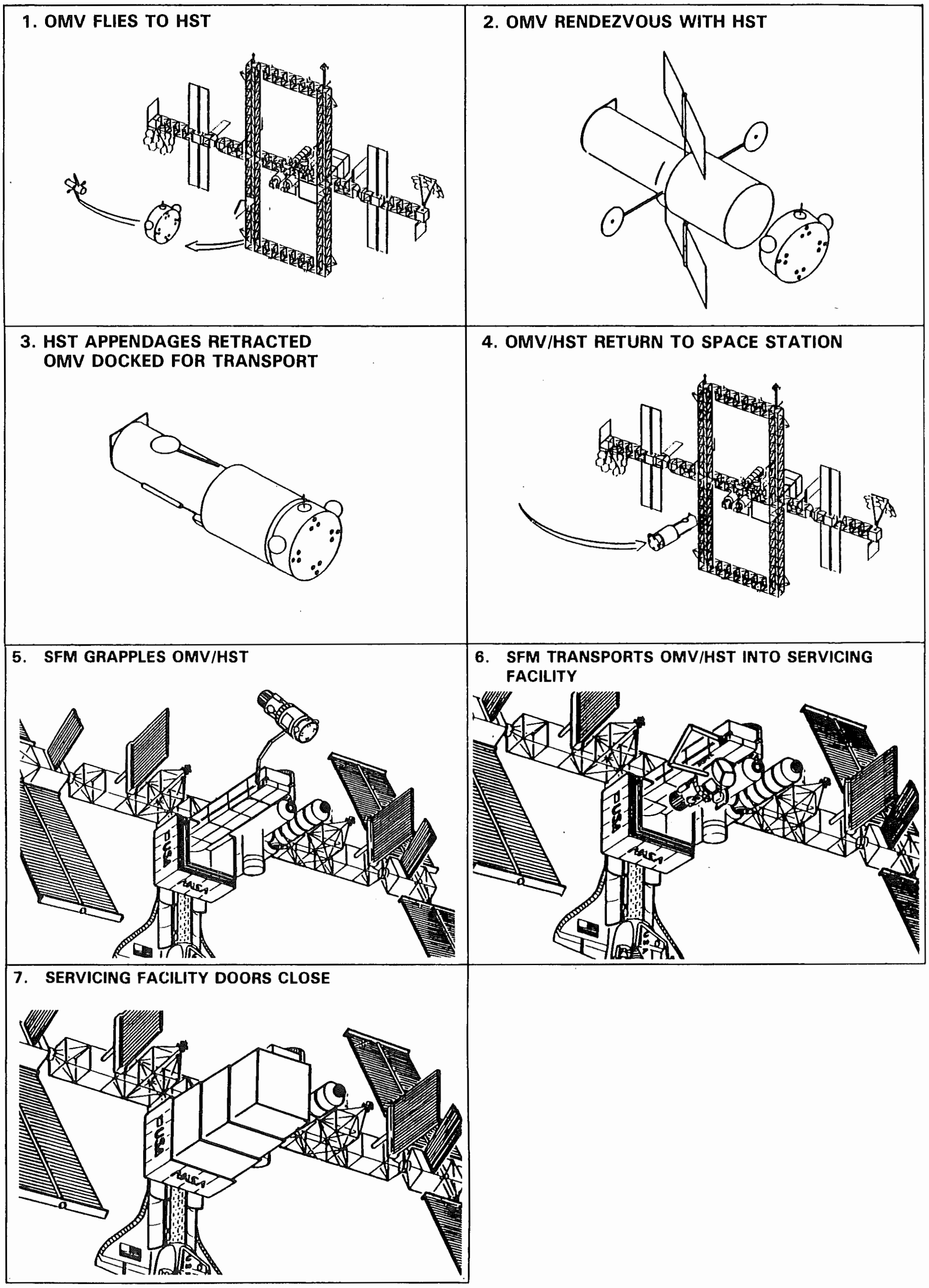

Figure 11. Typical HST Servicing Scenario