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SPACE STATION FREEDOM ASSEMBLY AND OPERATIONS

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ABSTRACT

The United States and its international partners are well on the way to developing Space Station Freedom which will be a very large orbiting facility with many capabilities for conducting space operations. Adjustments in the program content and station design have been implemented as a result of the recent restructure activity. This paper addresses the assembly and operations aspects of SSF. Assembly is achieved by sequential shuttle launches which carry portions of the station building the capability through the Manned Tended Capability and then on to Permanent Manned Capability. The pre-integrated truss segment resulting from the program restructure activity is shown and assembly techniques using the orbiter described. Both payload and station operations are examined. The payload operations include the conduct of materials processing and life science missions. These rely heavily on the microgravity capability of the Space Station. Station operations examined include EVA for assembly and maintenance and reboost techniques.

INTRODUCTION

The concept of a space station has been a dream for over 100 years. Today the United States and its international partners are well on their way to achieving that dream. The Space Station Freedom (SSF) program is an international cooperative effort that includes the space agencies of the United States, Japan, Canada, and Europe. Its purpose is to establish, in space, a permanent, scientific and commercial research, development, and operations support facility. The Space Station Freedom will be the most complex structure ever assembled in space. Key features of the station are listed in Table 1. On-orbit construction is scheduled to commence in November 1995 as the First Element Launch (FEL) achieves low Earth orbit delivered by the Space Shuttle. Subsequent shuttle mission build flights are scheduled at 30- to 90-day increments thereafter to achieve Man Tended Capability (MTC) by December 1996, Permanent Manned Capability (PMC) in December/1999, and finally

Eight Man Crew Capability (EMCC) by 31 December 2000 as shown in Figure 1.

Recent design changes as part of the SSF program restructure activity have altered the Space Station configuration and design from that baselined at the Integrated

Table 1. Key Features of Space Station Freedom

Purpose
■ International scientific and commercial research and a staging post for future missions to the moon and Mars
Assembly Orbit
■ 407 km (220 nmi)
Orbital Altitude
■ 370 to 460 km (200 to 250 nmi), 28-deg inclination
Dimensions
■ 145 m (476 ft) long open truss structure with solar panels (33 x 10 m) extending to either side at both ends
Weight
■ Approximately 227 metric tons (500,000 lb)
Power
■ Eight solar arrays, 75 kW (photovoltaic)
Crew Size
■ Eight astronauts, each staying in orbit up to 6 months at a time

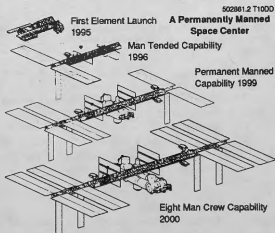


Figure 1. Space Station Freedom Assembly Sequence

System Preliminary Design Review (ISPDR). The pre-integrated truss design benefits the program by greatly reducing the EVA required for assembly and by preserving the integrity of a ground verified launch segment through launch and placement on orbit. The primary changes made by the restructuring in January 1991 that influence the assembly and operations of SSF are shown in Figure 2.

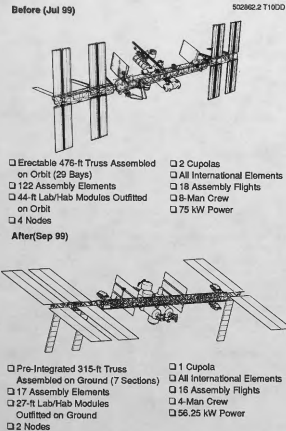


Figure 2. Restructured SSF Simplifies Assembly and Retains a Full Operations Capability

The truss concept was reduced in length, but more significantly, changed from a space-erectable truss to a ground-constructed and outfitted design. The truss is launched as pre-integrated segments in lengths of 25 to 45 ft compared to the prior approach of assembling 5-meter truss bays on orbit and installing subsystems on orbit. The number of assembly elements were greatly reduced along with the mounting of subsequent components in the truss itself.

ASSEMBLY SEQUENCE

Assembly sequence refers to the order, content, and schedule of the shuttle launches needed to implement SSF. Those launches that contain a particular portion of the station buildup are designated manned based (MB) flights. Those that provide a specific capability augmentation are

termed outfitting (OF) flights, those that provide resupply are designated logistics (L) flights, and those that deliver or service payloads are designated utilization flights (UF). The MB portion of the assembly sequence through the Permanent Manned Capability phase is shown in Table 2. The assembly sequence was derived through a series of iterative analyses that considered the desired SSF capabilities (size, power, number of modules, etc.) at each milestone such as PMC, the set of functions needed on orbit for orderly assembly, the configuration of the station itself, the capabilities of the shuttle, and the available budget.

Assembly analyses resulted in SSF being assembled from the starboard end of the transverse boom that is made up of seven segments of truss structure. The contents of MB-1 shown in Figure 3 include an 18.75-kW photovoltaic (PV) module provided by Work Package 4 (consisting of solar arrays, the integrated electronics assembly, the PV radiator, and the mounting structure), the Work Package 2 truss

Functions

- Provides Attachment Structure for PV Module and Radiator, SARJ, Propulsion Modules and Resistojets

Equipment Manifested

- Solar Alpha Rotary Joint (SARJ)
- Photovoltaic (PV) Starboard Inboard Panels - WP-4
- Four Deployable Propulsion Module Attach Structures
- Mobile Transporter
- Five Passive Dampers
- One Resistojet Attach Structure
- Utilities and Power Distribution

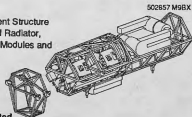


Figure 3. MB-1 Launch Configuration

structure which contains the appropriate utilities and the mounting location for two propulsion modules to be added on the MB-2 launch, five passive dampers for attitude stabilization, and an unpressurized berthing adapter (UBA) in addition to the solar alpha rotary joint (SARJ).

Figure 4 illustrates the MB-1 contents as they would be installed in the shuttle payload bay. The manifesting arrangement was analyzed to ensure that the shuttle capabilities and constraints were met. These include total

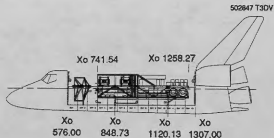


Figure 4. MB-1 Manifested

Table 2. Assembly Manifest

Date	Flight	Assembly elements
11/95	1	FEL MB-1 Truss section with starboard inboard PV system, alpha joint, propulsion module platforms, passive dampers, MT, unpressurized berthing mechanisms
12/95	2	MB-2 Truss section with CMGs, C&T (STS derived S-band), 2 propulsion modules (reduced capacity), temporary avionics
3/96	3	MB-3 Truss section with starboard TCS, UHF and Ku-band antennas, SSRMS
6/96	4	MB-4 Truss section with IUD, MTS, GCP, cryo berthing mechanisms (2), node umbilicals, CETA cart, MT batteries
9/96	5	MB-5 Aft port node, pressurized adapter (no docking slide), cupola
12/96	6	MTC MB-6 US lab module core-A, system racks, 4 user payload racks, MBS (ASRMs required)
3/97	7	MB-7 Airlock, pressurized docking adapter, SPDM, MMD
6/97	8	MB-8 Truss section with port TCS, C&T (UHF antenna)
9/97	9	MB-9 Truss section with dry cargo berthing mechanisms (3), 2 propulsion modules (reduced capacity)
12/97	10	MB-10 Truss section with port inboard PV system, alpha joint, propulsion module platforms
3/98	11	MB-11 Aft starboard node
6/98	12	MB-12 JEM module, ESA DDCUs and heat exchanger
9/98	13	MB-13 ESA module, ESA DDCUs and heat exchanger
12/98	14	MB-14 Truss section with starboard outboard PV module
3/99	15	MB-15 JEM exposed facility, JEM ELM PS, JEM ELM ES
6/99	16	MB-16 US hab module core-A, system racks
9/99	17	PMC MB-17 ACRV

weight, center-of-gravity location, 24-in. spacing between cargo elements to accommodate the shuttle remote manipulator system (RMS) runaway conditions, trunnion mounting locations, attach load limits, modal frequencies, and deflections. These analyses have been done for each MB flight to ensure shuttle compatibility. The shuttle would then launch the MB-1 payload into a 220-nmi circular orbit. After orbit achievement, the payload bay doors are opened and the shuttle RMS is used to remove the MB-1 as a unit from the cargo bay as shown in Figure 5. MB-1 is functionally passive and is then placed into orbit with its longitudinal axis oriented along the local vertical. After release, it is maintained in this orientation by the gravity-gradient torques with damping for stability supplied by the five passive dampers. MB-1 component temperatures are maintained at acceptable levels passively by equipment location, orientation, and thermal coatings.

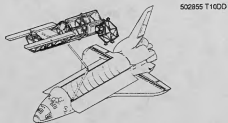


Figure 5. Pre-Integrated Truss MB-1

As shown in Figure 6, the MB-2 launch provides the second portion of pre-integrated truss structure and the two propulsion modules to be mounted on the MB-1 structure on orbit. The truss section contains the command, control, and communication avionics, the attitude reference assembly, and four control moment gyros (CMGs). Launch manifest

Functions

- Provides Avionics for Command Control, and Communications; Propulsion System Provides Initial AC

Equipment Manifested

- Power Distribution and Control GN&C (DDCUs, SPDAs)
- Data Management (SDPs, MSU, TGU, MDMs, Ring Concentrator, FDDI)
- C&T - S-Band Avionics, Antennas (2 Each)
- GN&C
- Attitude Reference (Star Trackers, Inertial Sensors)
- Attitude Control - CMGs (4)
- Utility Trays (2)
- Two Propulsion Modules (3000 lb of Propellant Each)

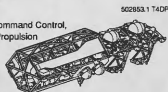


Figure 6. MB-2 Launch Configuration

analyses were accomplished, as on MB-1, to ensure compatibility with the shuttle.

After launch into orbit, the shuttle rendezvous with the orbiting MB-1 stage. Upon closure the shuttle RMS grapples the MB-1 stage and maneuvers it for attachment to the orbiter. The RMS places the MB-1 stage and berthing adapter into the forward payload bay location in the shuttle as shown in Figure 7. The RMS is then used to remove the MB-2 structure and to attach it to the end of the MB-1 structure. This is accomplished with a remote control attach system that engages the two. Full attachment and berthing connections from MB-1 to MB-2 are made using extravehicular activity (EVA). Figure 8 shows how the RMS is used to remove the propulsion modules from the shuttle bay and attach them to their mounting location on the MB-1 stage. At this point the MB-1/-2-orbiter combination is oriented with the longitudinal axis along the local vertical orientation as shown in Figure 9. The PV arrays and radiator are deployed. The WP-2 avionics are activated to provide

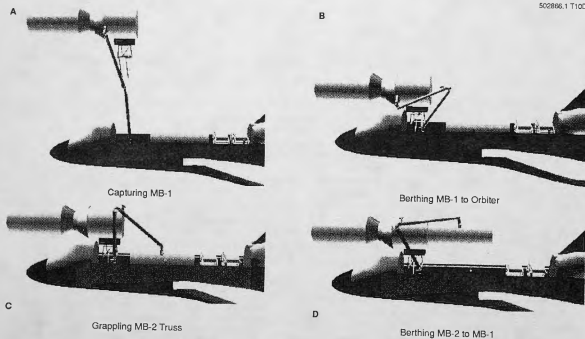


Figure 7. Mating MB-2 with MB-1 on Flight 2

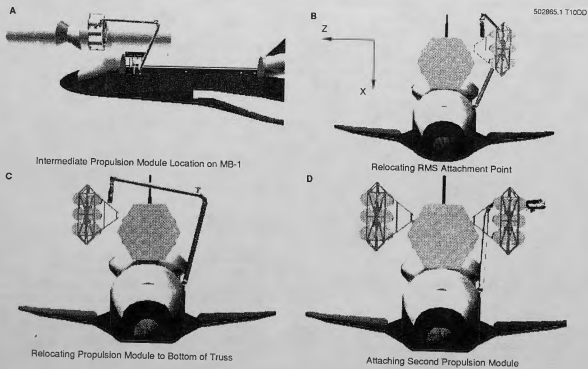


Figure 8. Propulsion Module Operations on Flight 2



Figure 9. Pre-Integrated Truss MB-1 and MB-2

command and control and avionics for the attitude control and propulsion systems. Thermal control is achieved by passive means as on MB-1. The MB-1/-2 stage is then released on orbit at which time the propulsion system is activated.

The MB-3 truss segment, shown in Figure 10, contains the active thermal control system. The radiator panels are stowed as shown. The MB-3 also includes the utilities and

Functions

- Utilities Distribution Enhanced
- Lights, MT Ports Reduced EVA Tasks
- Passive TC of ORUs

Equipment Manifested

- Starboard ATCS
- UHF and Ku-Band Antennas
- 2 External Video Camera Assemblies
- SSRMS

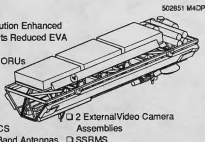


Figure 10. MB-3 Launch Configuration

avionics needed to operate the segment; the Canadian Space Station remote manipulator system (SSRMS) is also manifested. The MB-3 segment is manifested in the shuttle bay and launched to orbit to rendezvous with the MB-1/-2 stage. As on MB-2, the shuttle berths, then attaches the MB-3 segment to the prior orbiting stage as shown in Figure 11.

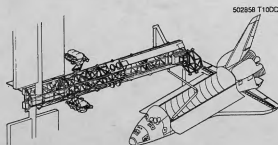


Figure 11. Pre-Integrated Truss MB-1 Through MB-3

The MB-4 truss segment is the center segment of the transverse boom. Its contents are shown in Figure 12 and include the electric power management system, the gas

Functions

- Gas Conditioning to Support EVAS
- Utility Distribution to Module Cluster
- CETA Rail to AL Route Support

Equipment Manifested

- CETA Cart and TESS
- Nodes 1 and 2 Umbilicals
- MT Batteries
- Cryo Berthing Mechanisms (2)
- Gas Conditioning System
- MTS, IUD, and IWGS
- Portable Work Platform



Figure 12. MB-4 Launch Configuration

conditioning equipment, provisions for later attaching logistics cargo elements, and the truss support for the later attachment of the resource nodes. This truss structure is designed to withstand the loads applied when the orbiter is berthed to the node on a later mission. As before, the MB-4 is put into place on orbit and attached to the prior orbiting stage using the RMS as shown in Figure 13.

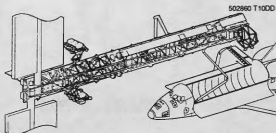


Figure 13. Pre-Integrated Truss MB-1 Through MB-4

At this point in the assembly sequence the starboard side of the transverse boom has been placed on orbit. The port side is nearly a mirror image of the MB-1/-2 and MB-3 segments as shown in Figure 14 and will be assembled in later flights (specifically MB-8, MB-9, and MB-10).

MB-5 will deliver the first pressurized module, resource node 2, to orbit. After the orbiter berths to the orbiting stage, node 2 is removed from the orbiter payload bay, manipulated into position, and attached to the MB-4 attach structure as shown in Figure 15. Note the handoff of the node from the SRMS to the SSRMS during this maneuver. Node 2 contains the avionics capability to fully activate all systems aboard the orbiting stage. This includes the CMGs and the active thermal control system.

After this launch, the pressurized module cluster is assembled around node 2 as illustrated in Figure 16. The US laboratory A follows the node 2 launch to achieve Man Tended Capability, then on MB-7 the airlock and pressurized berthing adapter (PDA). The PDA allows shirt-sleeve crew transfer from the orbiter cabin into the SSF pressurized

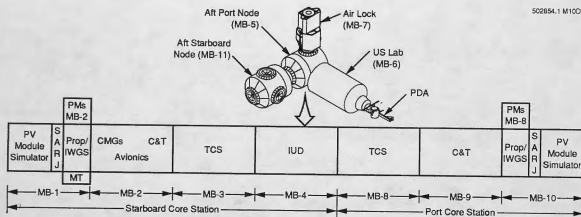
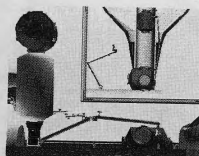
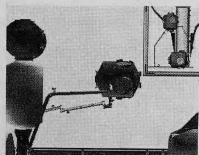


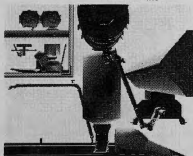
Figure 14. Assembly Sequence Pre-Integrated Structure



Node 1 Grappling with RMS



Handoff of Node to SSRMS



Berthing Node 1 to Node 2

Figure 15. Node 1 Assembly Operations—Flight 11

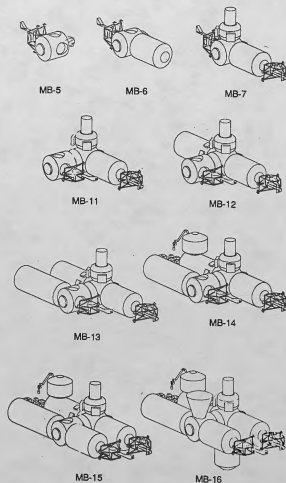


Figure 16. Pre-Integrated Truss Module Cluster Assembly Sequence

volume. The airlock will allow EVA excursions to assist assembly or provide exterior maintenance capability. On subsequent flights node 1 is added along with the Japanese module (JEM) and the ESA module. This is then followed by the habitation module A and assured crew return vehicle (ACRV) to achieve Permanent Manned Capability on flight MB-17.

The full orbital complements at the major milestones of FEL, MTC, and PMC are illustrated in Figure 17. SSF at each of these milestones represents a significant and useful measure of orbital capability. At FEL, the first launch and power generating base provides the sources for the buildup of the station. MTC provides 18.75-kW capability station that can be used to conduct laboratory operations with manned presence while attended by the orbiter. PMC provides a 56-kW station with four men in permanent residence. The station flies in a local vertical/local horizontal (LVLH) orientation to provide attitude control, microgravity, reboost potential, and a pointing base for communications antennas and sensors.

OPERATIONS

Space Station operations are categorized into two parts: payload operations and station operations. The payload operations for the initial station consist primarily of the life sciences and microgravity experiment operations. Additional small attached payloads will be operational on the station. The station operations include the day-to-day operation planning, resource control, and maintenance of the station.

A portion of available resources will be allocated to payload operations, and the core systems operations will become routine. Internal payloads are mounted in racks inside the modules and nodes, and external payloads are mounted to the Japanese exposed facility (JEM). The US

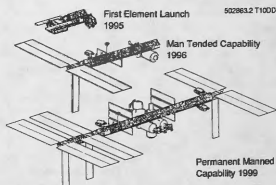
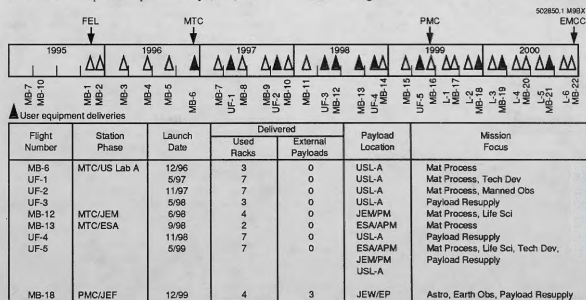


Figure 17. Space Station Freedom Assembly Sequence

payload complement emphasizes research on long-term effects of spaceflight on the crew and materials processing in the microgravity environment. The allocation of resources to payloads and the types of US payload equipment expected are as follows:

Payload Resources	Payload Types
67 racks in four labs and one node	Life sciences - Human
10 JEM exposed facility	Life sciences - Small animal
30-kW power	Life sciences - Plant
30-kW thermal cooling	Materials furnace facility
48-Mbps downlink (Ku band)	Crystal growers
72-kBps uplink (S band)	Combustion chambers
Six crewpersons	Fluid physics
Resupply missions	
Vacuum	
Microgravity	

The launch schedule for payload utilization flights is shown in Figure 18.



Notes: Pre-Integrated Truss Assembly Sequence Rev. C.

Payload equipment on MB-19, MB-21 and logistics flights TBD

Figure 18. Payload Utilization Flights Planned for Restructured Station

The modules are outfitted with laboratory support equipment for conducting onboard analyses in several research disciplines. Life sciences plans to conduct experiments with humans, animals, and plants to extend the knowledge of long-term exposure to microgravity and to readapt to various levels of gravity in space exploration. A large centrifuge is being developed that can provide various levels of gravity to support this area of research. Materials processing in microgravity has the potential to produce pure, high-quality crystals, new metal alloys, and advanced electronics that are not possible on earth.

Payload flight operations are controlled by the Payload Operations Control Center (POCC) at the Marshall Space Flight Center, and Space Station Freedom core systems operations are controlled by the Space Station Control Center (SSCC) at the Johnson Space Center. The POCC in consultation with the payload investigators plan the payload activity timeline in weekly increments (short-term plan) that is forwarded to the SSCC for incorporation into the overall flight plan. A team of POCC ground controllers and investigators, whose payloads are active, make modifications of the timeline to accommodate contingencies and add experiment activities dictated by natural phenomena or evolving research results.

Microgravity is a key SSF capability to be exploited. The microgravity environment in the laboratory modules is a function of the station configuration, altitude, and orientation. At the SSF altitude, the gravity-gradient influences around the center of mass are the dominant impact on the microgravity environment. (The aerodynamic drag is well below the $10^{-6}g$ level.) Figure 19 illustrates the gravity environment profiles around the center of mass of SSF in an LVLH orientation. The $10^{-6}g$ level is defined by an ellipse of +8 ft vertical dimension and +24 ft horizontal dimension, thus placing about half of the US lab within that level.

Overall Assessment

□ The Local Vertical Local Horizontal mode of flight will accommodate

- Half of the US lab at no greater than $5 \mu g$ of acceleration
- Half of the US lab at no greater than $6 \mu g$ of acceleration
- Based on a TEA of 11 degrees of yaw, with no pitch or roll



Figure 19. Microgravity in the LVLH Mode

Second only to the microgravity in priority for the station payload operation is the life sciences payloads. Figure 20 shows equipment for some of the planned life science payloads including the centrifuge to provide access to various levels of artificial gravity.

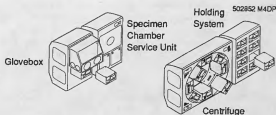


Figure 20. Centrifuge System

Typical Space Station operation activities are the EVA for assembly, maintenance, and reboost. These are briefly discussed. The time required by the orbiter astronauts to prepare and assemble the station for each of the mission build flights has been in excess of that available for the previous station design. With the introduction of the pre-integrated truss (PIT) design resulting from the program restructuring, the EVA assembly time has been considerably reduced as indicated in Figure 21. The reduction results from the elimination of the truss erection tasks, the time needed to assemble the construction aids, and the installation time for all the truss-mounted equipment. The goal is to reduce the assembly EVA time to one 6-hour two-man operation for each assembly flight.

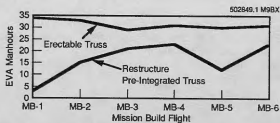


Figure 21. Assembly EVA Manhours

Central to the operations of the Space Station Freedom is the capacity to maintain its systems operational and in good working order. Maintenance of the station will consist of preventive and corrective maintenance. Preventive maintenance includes all scheduled maintenance actions performed to retain a system or end item in a specified condition. These actions include periodic inspection, condition monitoring, critical item replacements, and calibration. In addition, servicing requirements (i.e., lubrication and fueling) are considered a part of scheduled maintenance.

External equipment maintenance is accomplished by EVA or use of telerobotics. EVA maintenance time is a limited resource on the station because planned EVA is shuttle based and performed while the orbiter is present and only contingency maintenance is performed from the station between orbiter visits. Through restructuring, the EVA maintenance time demand has been significantly reduced as shown in Table 3.

Table 3. Restructured Space Station EVA Maintenance Improvement

Maintenance demand description	SSF configuration			
	Pre-PDR baseline (Fisher Price)	ISDR baseline (EMST)	Restructure* MTC + MB-7	Restructure** PMC
Number of ORUs	8158	4668	338	950
Avg maintenance actions/year	507	145	30	90
Avg EVA worksite man-hours/year	625	167	24	72
Avg total EVA man-hours/year	3276	461	42	126
EVA's/year	273	39	4	11

*Preliminary data limited model runs
 **Estimated

It is planned to perform reboost after the orbiter has departed from its periodic visits to the station. The station will orient itself in the proper attitude either in the "arrow" mode for early phase of the assembly sequence or to the LVLH attitude to reboost. The arrow mode is used when the reboost thrusters are only on the starboard side of the station during the early phases of station assembly sequence. When both port and starboard reboost thrusters are available, the station only needs to trim out the torque equilibrium attitude (TEA) to the LVLH orientation to align the reboost thrusters in the proper reboost direction. A typical reboost will require several hours of continuous thrusting. Station activities that cannot tolerate reboost accelerations and some attitude control thruster firings must be curtailed during this phase. Figure 22 shows a typical SSF altitude profile: orbited decay and reboost. In this particular case, the station orbit altitude is constrained to be maintained at 220 nmi so that orbiter always meets the station at an altitude slightly above 220 nmi when it arrives. The station and orbiter spend the next several days (7 days, typically) in assembly payload operations, logistics transfer, crew rotation, etc. such that when the orbiter leaves, the station is at or near 200 nmi. The variation in the reboost altitude in the figure results from

the variations in the orbiter revisit intervals and from the orbital atmospheric density variations over the time frame.

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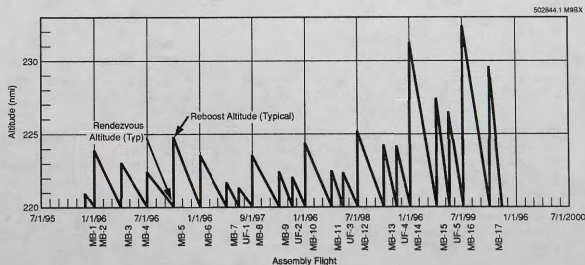


Figure 22. Constant Rendezvous Altitude Strategy