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DRL NO: MSC T-575, LINE ITEM 71

SD 71-221

MODULAR space station PHASE B EXTENSION

SHUTTLE INTERFACE REQUIREMENTS

PREPARED BY PROGRAM ENGINEERING
7 DECEMBER 1971

Space Division
North American Rockwell

12214 Lakewood Boulevard, Downey, California 90241

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APPROVED BY

Earl G. Cole

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FOREWORD

This document is one of a series required by Contract NAS9-9953, Exhibit C, Statement of Work for Phase B Extension-Modular Space Station Program Definition. It has been prepared by the Space Division, North American Rockwell Corporation, and is submitted to the National Aeronautics and Space Administration's Manned Spacecraft Center, Houston, Texas, in accordance with the requirements of Data Requirements List (DRL) MSC-T-575, Line Item 71.

Total documentation products of the extension period are listed in the following chart in categories that indicate their purpose and relationship to the program.

ADMINISTRATIVE REPORTS	TECHNICAL REPORTS		STUDY PROGRAMMATIC REPORTS	DOCUMENTATION FOR PHASES C AND D	
				SPECIFICATIONS	PLANNING DATA
EXTENSION PERIOD STUDY PLAN DRL-62 DRD MA-207T SD 71-201	MSS PRELIMINARY SYSTEM DESIGN DRL-68 DRD SE-371T SD 71-217	MSS DRAWINGS DRL-67 DRD SE-370T SD 71-216	EXTENSION PERIOD EXECUTIVE SUMMARY DRL-65 DRD MA-012 SD 71-214	MSS PRELIMINARY PERFORMANCE SPECIFICATIONS DRL-66 DRD SE-369T SD 71-215	MSS PROGRAM MASTER PLAN DRL-76 DRD MA-209T SD 71-225
QUARTERLY PROGRESS REPORTS DRL-64 DRD MA-208T SD 71-213, -235, -576	MSS MASS PROPERTIES DRL-69 DRD SE-372T SD 71-218, -219	MSS MOCKUP REVIEW AND EVALUATION DRL-70 DRD SE-373T SD 71-220			MSS PROGRAM COST AND SCHEDULE ESTIMATES DRL-77 DRD MA-013(REV. A) SD 71-226
FINANCIAL MANAGEMENT REPORTS DRL-63 DRD MF-004	MSS INTEGRATED GROUND OPERATIONS DRL-73 DRD SE-376T SD 71-222	MSS KSC LAUNCH SITE SUPPORT DEFINITION DRL-61 DRD AL-005T SD 71-211			MSS PROGRAM OPERATIONS PLAN DRL-74 DRD SE-377T SD 71-223
	MSS SHUTTLE INTERFACE REQUIREMENTS DRL-71 DRD SE-374T SD 71-221	INFORMATION MANAGEMENT ADVANCED DEVELOPMENT DRL-72 DRD SE-375T SD 72-11			
	MSS SAFETY ANALYSIS DRL-75 DRD SA-032T SD 71-224				

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CONTENTS

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ILLUSTRATIONS

TABLES

1. INTRODUCTION

The interface requirements between the modular space station (MSS) and the space shuttle described in this report cover both the ground and orbital phases of operation from the launch of the first MSS module until the initial modular station has been manned and in routine operation.

As a point of reference, the NR two-stage, fully reusable space shuttle, whose definition has been obtained from the space shuttle Phase B definition studies, has been selected around which the interface requirements have been described. Figure 1-1 depicts the space shuttle orbiter and the modular space station configurations.

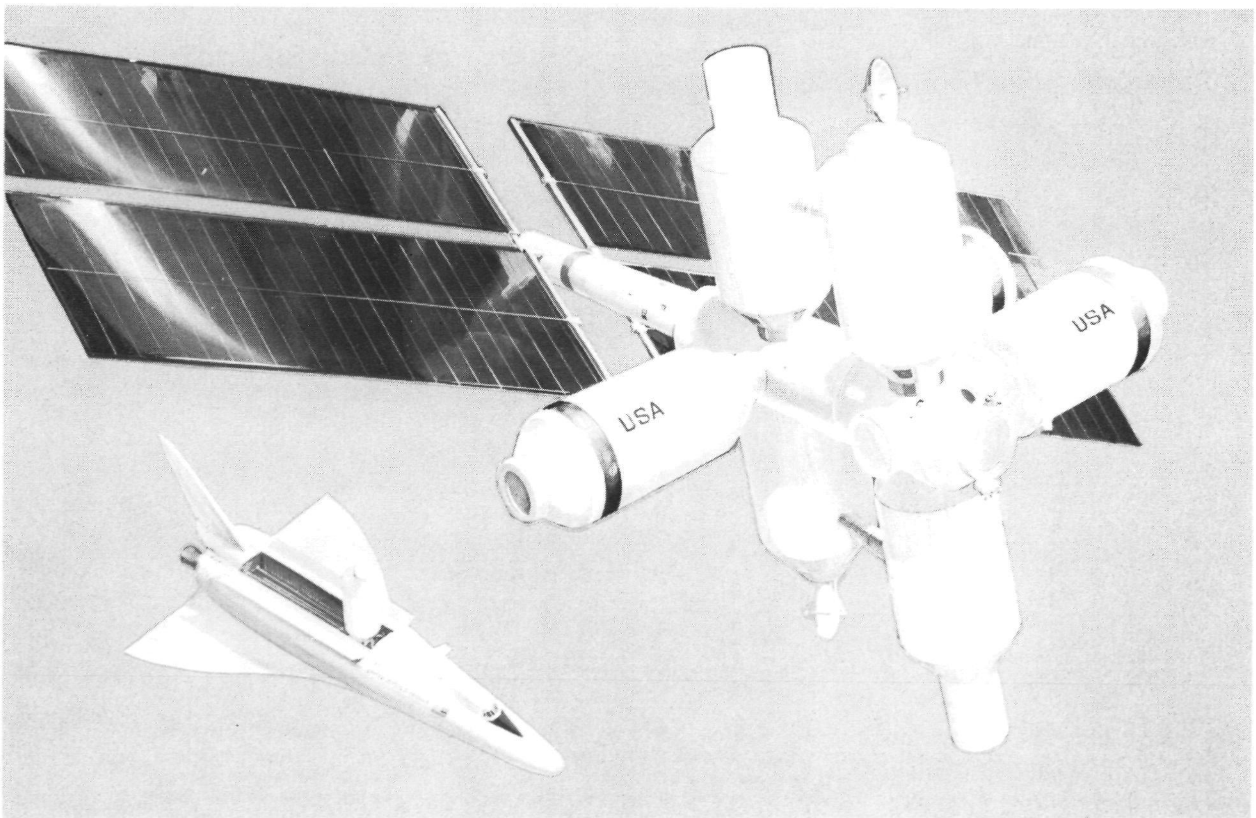

Figure 1-1. Space Shuttle Orbiter - Modular Space Station Configurations

The following sections of this report briefly describe the space shuttle from the standpoint of its features most important to the interface requirements with the MSS. The environment induced upon the MSS elements when transported to and from orbit by the shuttle orbiter also is included.

The mission operation section describes the space shuttle launch facilities, the ground flow of the MSS modules, and the orbital operations of rendezvous, MSS buildup, resupply of the manned station, and orbiter descent and landing. The shuttle's once-around abort case is described as it affects the MSS interface requirements.

The interface requirements section describes the interfaces between the orbiter and the MSS resulting from the ground and orbital operations.

It is recognized that major changes have been made in the space shuttle programs since the completion of its Phase B studies and as this program progresses, further changes may be anticipated. No attempt has been made at this time to incorporate any of the known changes in the shuttle program into the interface requirements with the MSS described. It is acknowledged that these major changes in the space shuttle program will have a pronounced effect on its interfaces with the MSS; consequently, the interfaces must be re-examined at the proper time.

2. SPACE SHUTTLE DEFINITION

The description of the space shuttle used in defining the interface requirements with the modular space station has been obtained from NR's Phase B space shuttle definition study completed in June 1971.

The major element in the space shuttle program which is important to the definition of the interface requirement with the MSS is the shuttle orbiter. However, only those features of the orbiter which are important from the interface standpoint are described.

The following portions of this section briefly summarize the Phase B space shuttle program, the operation concept, a description of the shuttle orbiter, and the environment induced on the MSS elements while being transported to and from orbit in the payload bay.

SPACE SHUTTLE PROGRAM

The space shuttle program consists of the following major articles:

1. Five orbiter and four booster flight vehicles
2. An orbiter and booster structural test article
3. An orbiter and booster main propulsion cluster development test article

Completion of prelaunch operations for all of the vehicles is as follows:

June 1976 (first horizontal flight)
April 1978 (first manned orbital flight)
Mid-1979 (shuttle will be operational)

To support the manned orbital flight date, the major milestones in the program are as follows:

1. Start Phase C/D on 1 March 1972
2. Complete PDR in May 1973
3. Complete CDR and 95 percent engineering release 1 May 1975

OPERATIONAL CONCEPT

Preparations for space shuttle launch normally require approximately four days. The launch sequence begins with independent premate checkout of the separated booster and orbiter vehicles in the assembly building. Payloads, which themselves may consist of complex systems requiring fueling and monitoring, are installed in the orbiter cargo bay. The two vehicles are then erected to the vertical position, the booster is mounted on the launch umbilical tower, the orbiter is attached to the booster, and the mated vehicles are transported from the assembly building to the launch pad.

Following arrival at the pad, launch-readiness checkout is performed, and a five-hour launch countdown is commenced with loading of propellants. When loading is completed, the crews (and passengers) board the vehicles for terminal countdown and launch.

The booster's 12 main engines are fired, and within three minutes after liftoff the combined vehicles achieve a comparatively level course at an altitude of 200,000 feet. In rapid succession, the orbiter's two rocket engines are ignited, the booster engines are shut down, and the two vehicles separate. As the orbiter accelerates toward orbit, the booster returns to the launch site.

The orbiter continues to accelerate until an elliptical insertion orbit of 50 by 100 nautical miles is achieved. The two main engines are then shut down and the three smaller orbit maneuvering engines are ignited to place the vehicle in the desired circular orbit.

Final critical adjustment of the orbiter into its correct orbital position is accomplished with the attitude control propulsion system consisting of 29 smaller thrusters located at various points on the vehicle. Once the vehicle is stabilized, the cargo bay doors are opened and payload modules are readied for deployment.

Payload module handling is accomplished by a pair of articulate manipulator arms described later. Movement and positioning are precisely controlled by cargo specialists located in the cargo-handling station aboard the orbiter. Television monitors and floodlights strategically mounted on the arms assure visibility during these operations.

On completion of the orbital operations, the orbiter is maneuvered to a 100-nautical mile oribt and rotated to a deorbit attitude. The orbit maneuvering engines are then fired to decelerate the vehicle and initiate descent. During enetry, the vehicle attitude is controlled to achieve any lateral cross-ranging required to assure the closest glide approach to the landing site. At 35,000 feet, four air-breathing turbofan engines are deployed and started to provide maneuvering capability to the launch site. Landing is made with typical aircraft-type landing gear and a drag chute.

Both the orbiter and booster are capable of horizontal takeoff and flight, powered by their air-breathing engine systems only. This capability enables the vehicles to return to the launch site following landings at alternative sites if required.

Ground turnaround procedures are essentially the same for booster and orbiter. Under normal conditions, the elapsed time between landing and launch-readiness is 14 calendar days. After landing, the vehicle is immediatedly taxied or towed to a safing area, where the crew (and passengers) deplane, mission flight data are removed, fluids and gas residuals are drained or vented, and the propellant tanks are purged with nitrogen. The safed vehicle is then towed into a maintenance hangar, service stands are installed, and the payload module is removed from the orbiter.

The entire operational sequence is illustrated in Figure 2-1.

Ground Operations

The launch pads, launch rates, yearly traffic, and prelaunch operations for the space shuttle orbiter are described in the subsection. It is planned that Pads 39 B and C at KSC will be modified for shuttle use. These pads will then be designated as Shuttle Pads A and B. The average launch rates for Pads A and B, to satisfy the traffic model, are shown in Figure 2-2. The shuttle traffic model is shown in Figure 2-3. The number in the circle represents the accumulated flights at that time. From early 1980 to program conclusion the prelaunch operations are as shown in the timeline in Figure 2-4.

The program is based upon two pads and two launch umbilical towers (LUT's). LUT refurbish time is four to five days. The maximum launch rate per pad is approximately eight to nine days. Figure 2-5 illustrates shuttle-LUT prelaunch configuration.

Orbital Operations

The shuttle's reference mission is logistics resupply of the modular space station. The insertion orbit is 50 by 100 nautical miles and the reference orbit is 270 nautical miles circular with a 55-degree inclination. For this condition, the payload capability is 25,000 pounds.

The orbiter has sufficient propellant to provide 1500 fps on-orbit ΔV capability in excess of amount required to attain the reference mission insertion orbit. The tanks are sized to provide 2000 fps ΔV capability.

The mission profile for resupply of the space station is presented in Figure 2-6. Total mission time is seven days, with five days allocated to on-orbit operations. During this period, the orbiter performs a powered-down stationkeeping maneuver.

On-Orbit Guidance, Navigation and Control

The one-sigma uncertainity in orbiter vehicle position and velocity at the time of a state vector update is presented in Table 2-1. The one-sigma uncertainty in orbiter vehicle attitude at the time of a stellar update is $\pm$ 0.1 degree about each axis (pitch, roll, and yaw). The one-sigma uncertainty in orbiter vehicle attitude rate is $\pm$ 0.01 degree per second about each axis (pitch, roll, and yaw). The one-sigma tracking uncertainties when the orbiter is tracking a cooperative target are presented in Table 2-2.

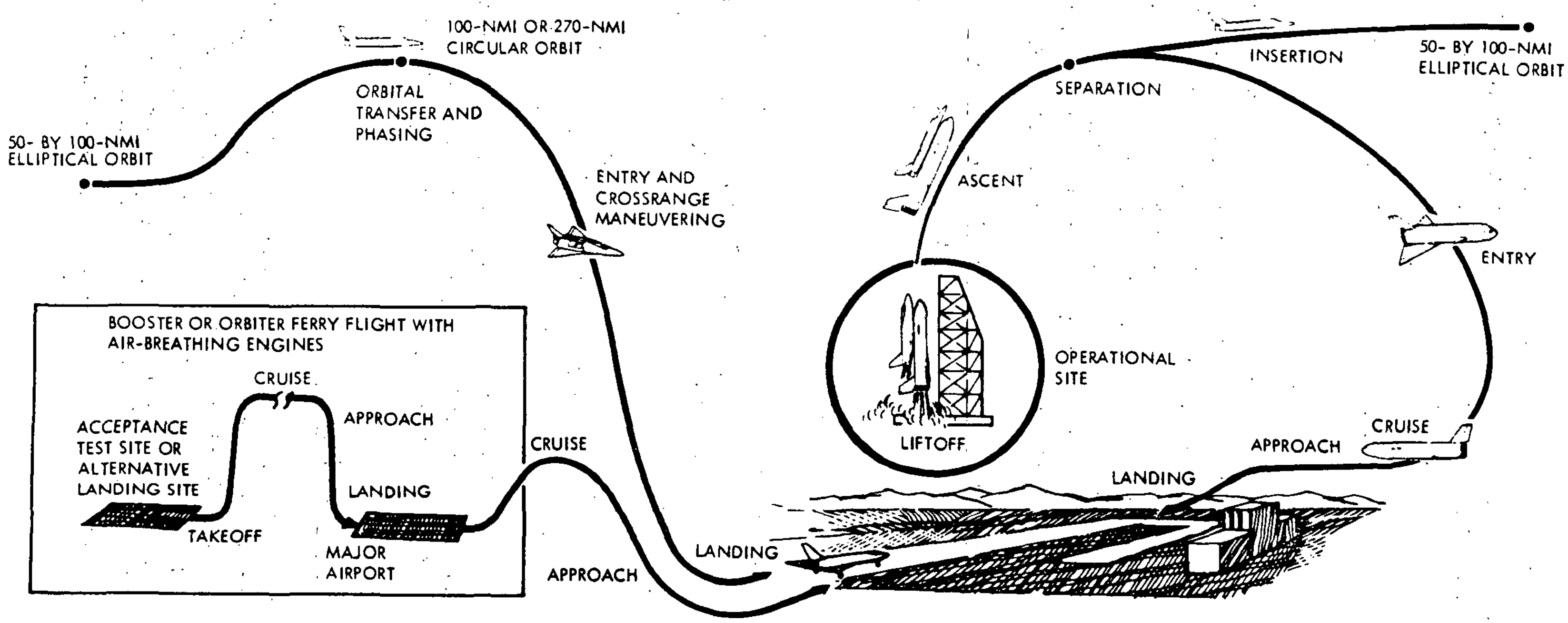

Figure 2-1. Shuttle Operational Sequence

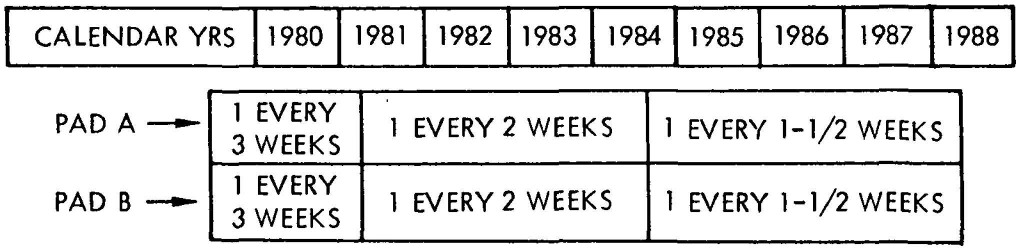

Figure 2-2. Average Pad Launch Rates

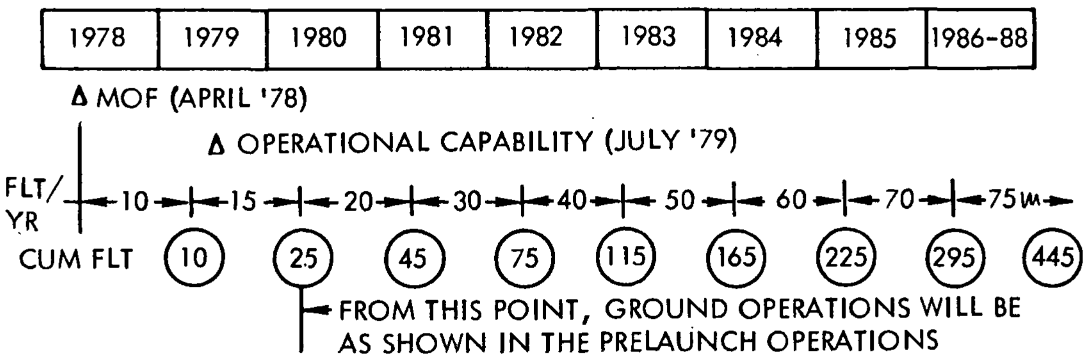

Figure 2-3. Shuttle Traffic Model

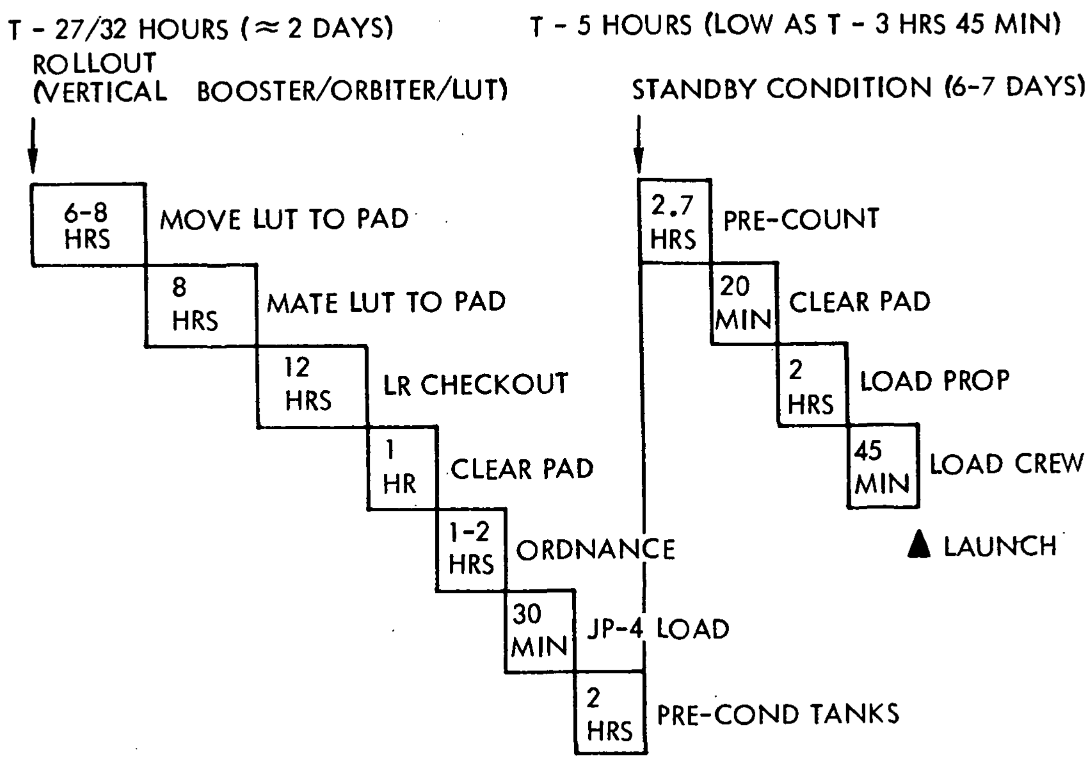

Figure 2-4. Prelaunch Operations Timeline

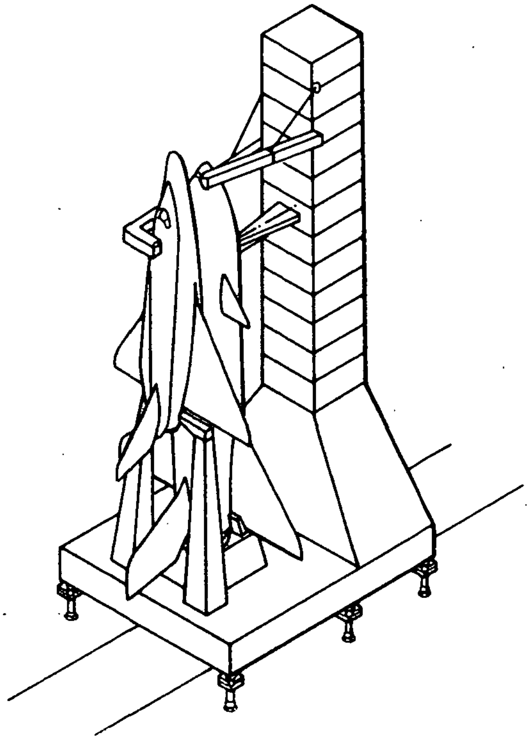

Figure 2-5. Shuttle and LUT at Launch Pad

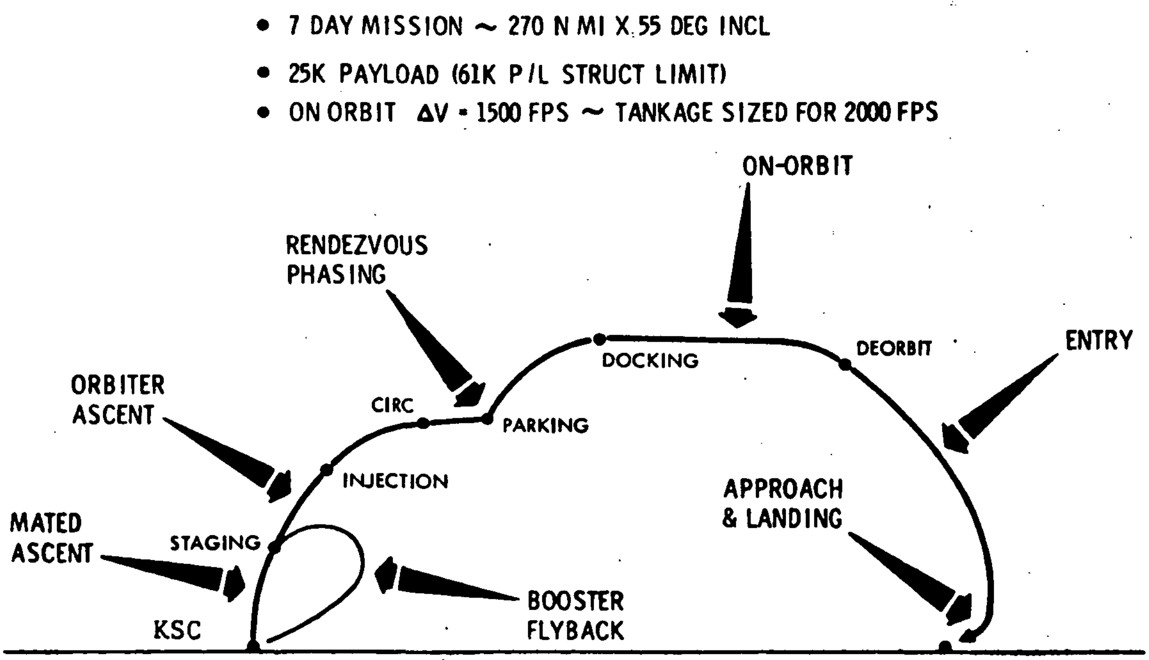

Figure 2-6. Mission Profile

Table 2-1. Position and Velocity Uncertainty

Component	Position (n. mi.)	Velocity (fps)
Altitude	± 0.25	± 1.5
In-track	± 0.5	± 0.6
Cross-track	± 0.5	± 3.0

Table 2-2. Tracking Uncertainty

Parameter	Uncertainty	
	At 30 n. mi.	At 500 feet
Range	± 0.1 n. mi.	± 5.0 ft
Range rate	± 10 fps	± 0.1 fps

In addition to range and range rate information, the orbiter is capable of optically determining the bearing angle to the target. The one-sigma bearing angle uncertainty is ± 0.02 degree. Orbiter vehicle translation control rates are defined in Table 2-3.

Table 2-3. Translation Control Rates
(Attitude Control Propulsion Systems Thrusters)

Orbiter Axis	Minimum Acceleration (fps^2)	Maximum Acceleration (fps^2)	Minimum Velocity Increment (fps)
X (roll)	0.26	0.78	0.026
Y (pitch)	0.51	1.56	0.052
Z (yaw)	0.26	0.78	0.026

The orbiter has selectable attitude deadbands of ± 0.5 degree, ± 10 degrees, and ± 45 degrees. Attitude control rates are defined in Table 2-4.

Table 2-4. Attitude Control Rates

Orbiter Axis	Minimum Angular Acceleration (deg/sec^2)	Maximum Angular Acceleration (deg/sec^2)	Minimum Angular Velocity Increment (deg/sec)	Minimum Angular Velocity (deg/sec)
X (roll)	0.5	1.0	0.05	0.025
Y (pitch)	0.5	1.0	0.05	0.025
Z (yaw)	0.6	1.8	0.06	0.03

CONFIGURATION DESCRIPTION

Mated Vehicles

In the mated configuration, the vehicles form a vertical stack 290 feet tall--approximately 75 feet shorter than the Apollo-Saturn vehicle. The orbiter, which is attached at three points to the flat dorsal surface of the booster, extends about 20 feet forward of the booster nose (Figure 2-7).

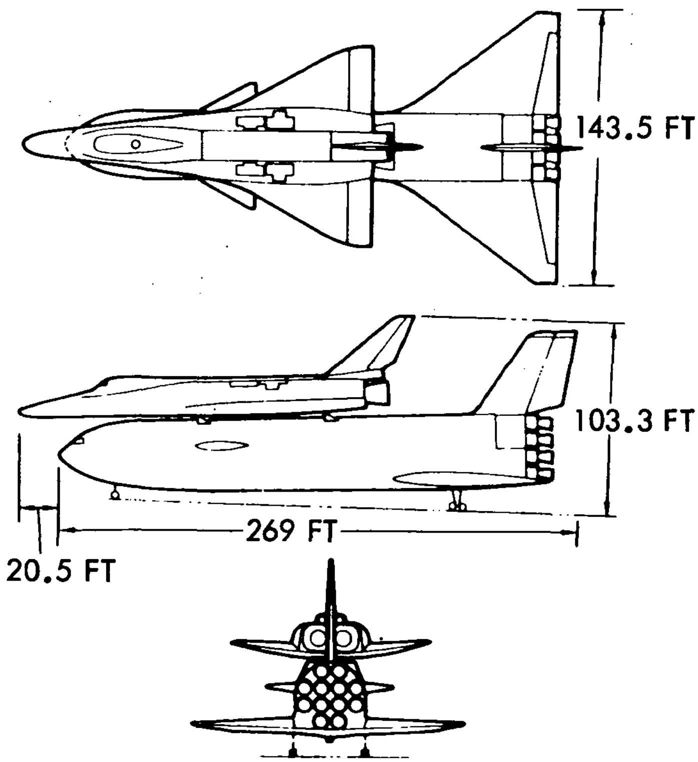

Figure 2-7. Mated Vehicle Configuration

Acting as a single vehicle throughout the ascent phase, the mated orbiter and booster are propelled by the booster's main engines to a separation altitude of approximately 40 miles and a velocity of about 6500 miles per hour.

Orbiter Vehicle

The orbiter configuration defined by the Phase B study is a delta-wing vehicle with an overall length of 206 feet and a wingspan of 107 feet (Figure 2-8). The profile of the orbiter incorporates a wide center fuselage (46.5 feet) which houses the two main liquid oxygen tanks and a cargo bay 15 feet wide and 60 feet long. Forward volume of the fuselage is occupied by the main liquid hydrogen tank and the crew compartment. Protection of internal structures is achieved with reusable heat shielding over all external surfaces subjected to the high heat load of boost and reentry.

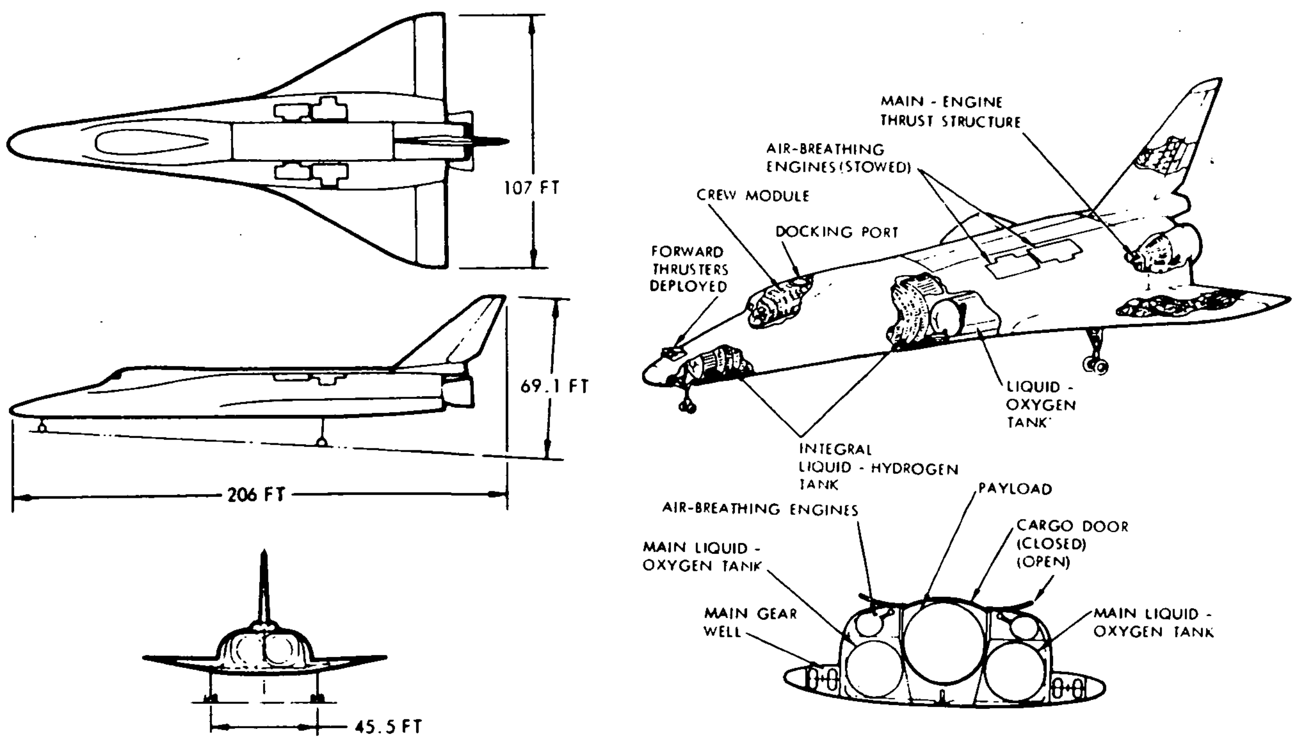

Figure 2-8. Orbiter Configuration

Extensive use of computerized control and data management permits full orbiter flight operation with a crew of two, commander and pilot. Two additional personnel are carried as cargo specialists when payloads are to be deployed, maintained, or taken aboard while in orbit.

Aerodynamic flight control is achieved with typical rudder and elevons, while exoatmospheric attitude control is sustained with a system of jet thrusters.

The main propulsion system consists of a pair of rear-mounted liquid propellant rocket engines which develope a vacuum thrust of 632,000 pounds each. The main engines are used to propel the orbiter from booster separation to the initial 50 by 100-nautical mile orbit only. Subsequent orbital transfers and deorbiting are accomplished with three smaller orbital maneuvering engines mounted above the main engines. Following entry, four air-breathing turbofan engines are deployed above the center fuselage to provide go-around and landing maneuver capability. The air-breathing engine system, when augmented with a fifth engine mounted beneath the fuselage, delivers sufficient thrust for horizontal takeoff and ferry flight when required.

Mass properties for the orbiter are shown in Table 2-5. Payload longitudinal center-of-gravity locations are shown in Figure 2-9.

Table 2-5. Mass Properties

Parameter	Ascent Burnout	Entry	On-Orbit Average
Weight (lb)	316,940	272,230	294,585
I_x Slug (ft^2)	2.725 $(10)^6$	2.495 $(10)^6$	2.610 $(10)^6$
I_y Slug (ft^2)	19.883 $(10)^6$	17.946 $(10)^6$	18.915 $(10)^6$
I_z Slug (ft^2)	21.495 $(10)^6$	19.351 $(10)^6$	20.423 $(10)^6$

The fully instrumented, environmentally controlled crew and passenger compartment is mounted atop the main hydrogen tank in the forward fuselage assembly. In the forward section are the commander's and pilot's stations with vehicle controls and displays. Also located in this compartment are accommodations for two cargo specialists, four of the ten passengers, general life support equipment, and personal stowage provisions. Immediately behind the crew compartment is an airlock with overhead docking port for transfer of crew and passengers between the orbiter and a space station or another orbiter. Two additional passenger seats are installed in this area. The docking port also is used for general personnel access while the orbiter is on the ground and as an ingress-egress hatch during extravehicular activity in space.

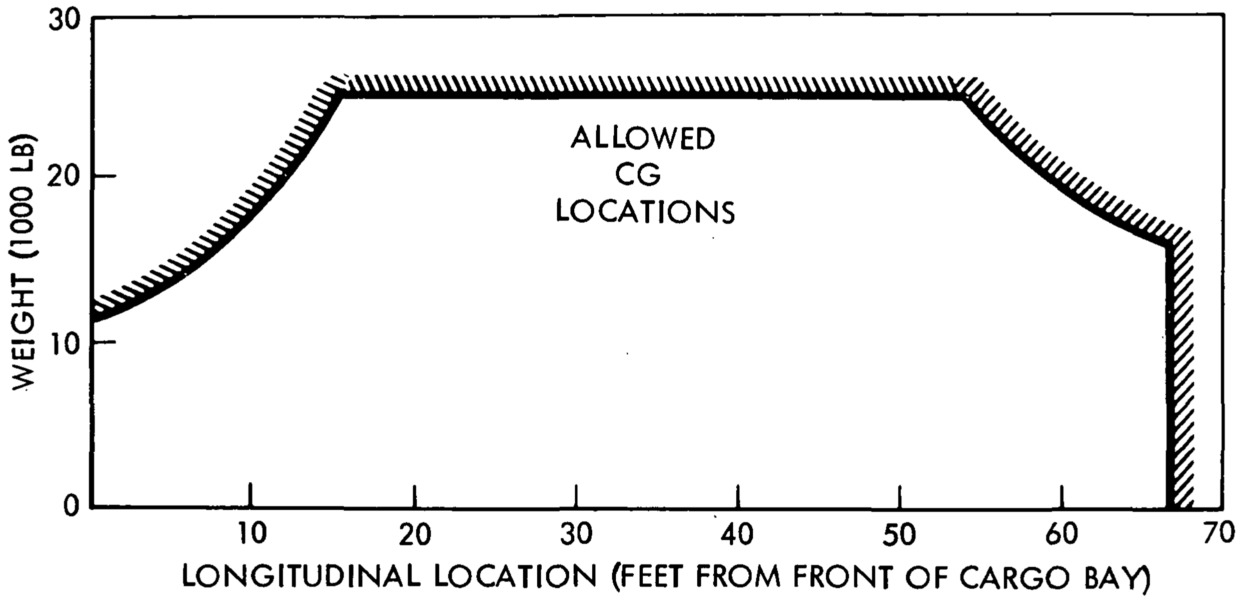

Figure 2-9. Payload Center-of-Gravity Envelope

The aft section of the module serves as an electronics bay. A center aisle through the electronics bay contains four passenger seats and leads to a tunnel connected with the cargo bay. Ready passage in a shirtsleeve environment is provided between all manned compartments. Emergency egress for the crew and passengers is through overhead hatches. Figure 2-10 illustrates the crew compartment.

The orbiter's docking and cargo-handling system (Figure 2-11) is designed to carry out the many unique functions associated with orbital operations and the manipulation of a variety of payloads in zero gravity. Major elements of the system are the cargo storage, restraint, and maintenance provisions; cargo handling subsystem; and docking subsystem.

The cargo bay is fitted with trunnions and latches for securing a wide variety of payloads. It is also equipped with floodlights and closed-circuit television monitors placed to achieve maximum visibility in all parts of the bay. The two full-length, hydraulically actuated cargo doors, when opened, permit completely unobstructed vertical loading and removal of payload packages.

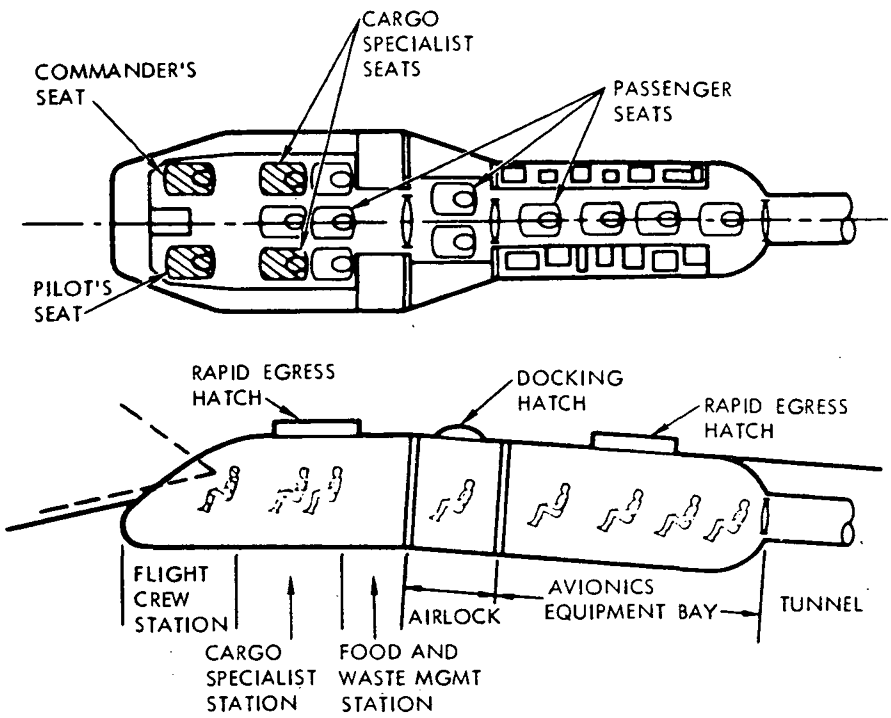

Figure 2-10. Orbiter Crew Module

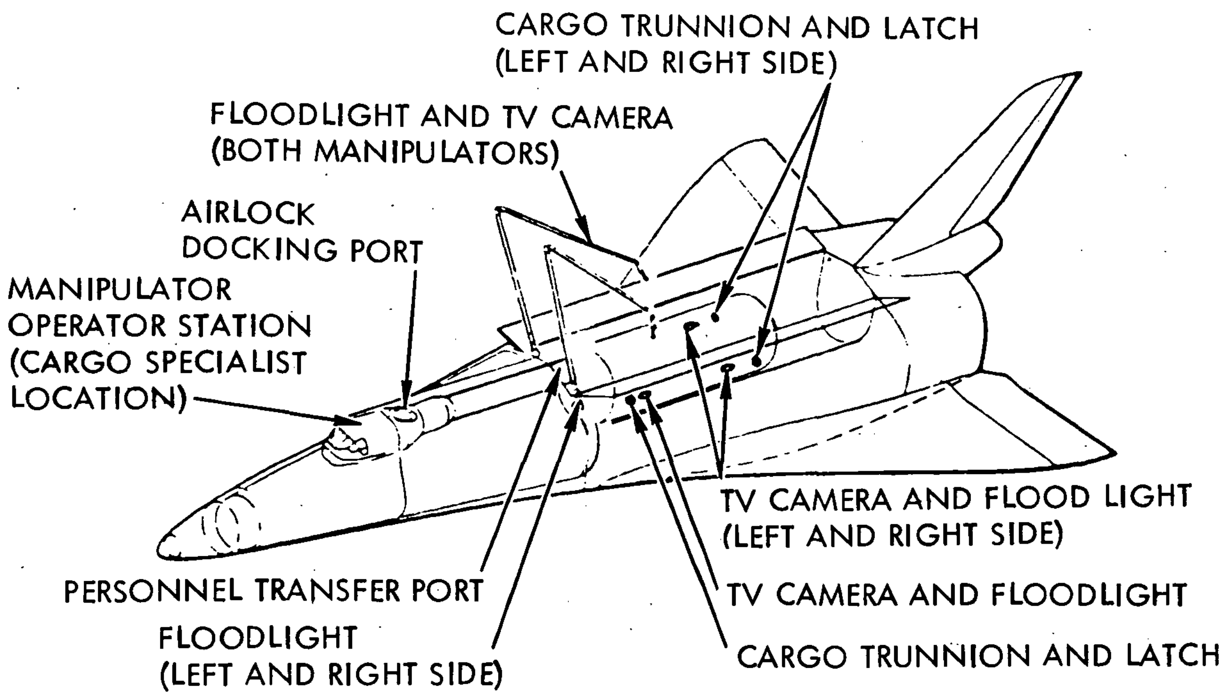

Figure 2-11. Docking and Cargo Handling System

Loading, unloading, and critical positioning of cargo modules are performed with a pair of jointed, electrically operated manipulator arms located on eiter side at the forward end of the cargo bay. Stowed inside the cargo compartment when not in use, the arms can be elevated, rotated, and extended to all corners of the bay. Precise control of the manipulators is exercised by a cargo specialist. The operator's station is equipped with all necessary television displays, communications outlets, and controls for maneuvering and emplacement of payloads.

The manipulators, in addition to serving as cargo-handling devices, perform a critical function during orbiter docking maneuvers. With the orbiter and the docking body stabilized at a distance of 25 to 50 feet, the arms are used to grasp the inert body, draw the two spacecraft together, and mate their docking ports as illustrated in Figure 2-12. When docking is performed with the space station, the manipulators are used to install a docking adpater before closure is performed.

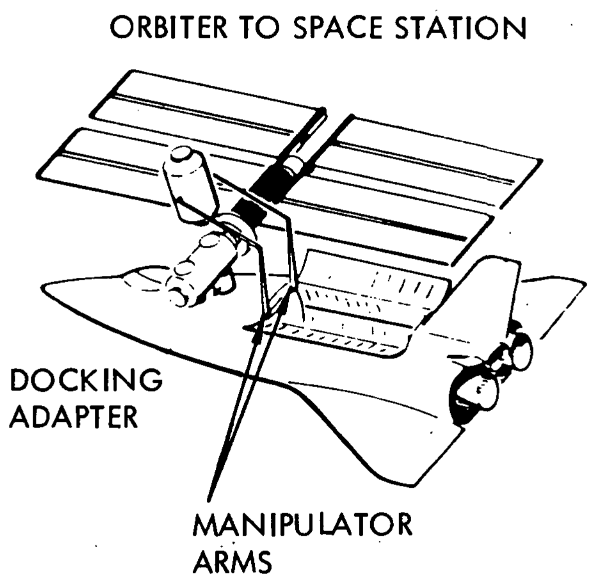

Figure 2-12. Docking Operations

Propulsion from the initial orbit established with the main engines is accomplished with three 10,000-pound thrust rocket engines mounted in the rear compartment just above the main engines. Using liquid hydrogen and liquid oxygen, these engines draw propellants from independent tankage installed in the aft section of the vehicle.

Attitude control is maintained by 29 thrusters located near the fore and aft ends of the fuselage. These 2100-pound thrust jets provide precision stabilization of pitch, roll, and yaw and are essential to maintaining proper orientation for lateral crossrange maneuvering during reentry. They also may be used as a backup deorbit system. The attitude control propulsion system (ACPS) and orbital maneuvering system (OMS), jointly referred to as the auxiliary propulsion system, draw their propellants from common tankage (Figure 2-13).

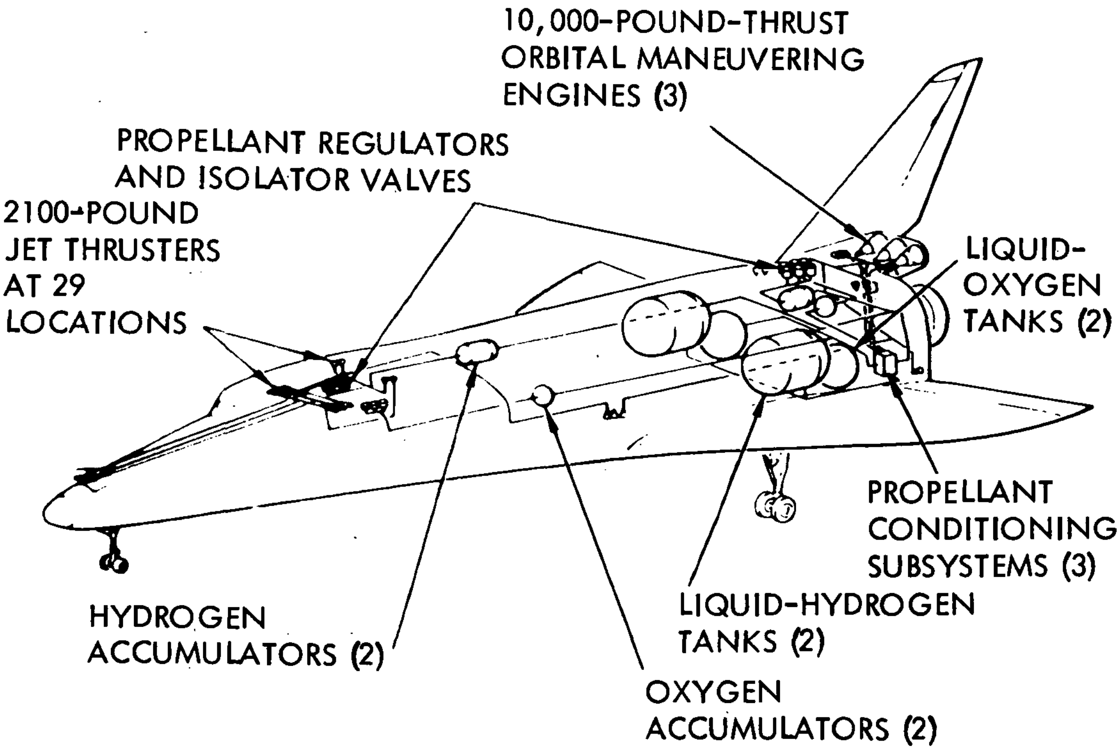

Figure 2-13. Auxiliary Propulsion System

The on-orbit propellant summary of Table 2-6 shows ACPS and OMS propellant requirements for the basic space station logistics reference mission. When not performing this function, the propellants budgeted for rendezvous, docking, stationkeeping, and redocking may be used for other purposes.

Table 2-6. On-Orbit Propellant Summary

Mission Phase	ACPS Usage (lb)	OMS		OMS + ACPS Usage (lb)
		ΔV (fps)	Usage (lb)	
Orbit injection	750.9	513.0	10,311.3	11,062.2
Rendezvous	1241.6	164.0	3,296.4	4,538.0
Docking	467.1			467.1
5-day stationkeeping	694.0			694.0
Redocking	621.7			621.7
Dorbit	254.0	435.0	8,743.5	8,997.5
Preentry	149.4			149.4
Entry	1200.0			1,200.0
Total	5378.7	1112.0	22,351.2	27.729.9

Note: 1. OMS ΔV contingencies not included
2. OMS propellant usage rate 20 lb/fps

Three 7/10-kilowatt fuel cells, located in the forward fuselage adjacent to the crew compartment, provide primary 28-volt dc power via three central main dc buses. Primary 115/200-volt, three-phase, 400-Hertz ac power is produced by three 20/30-kva ac generators (Figure 2-14).

The electrical power profile is shown in Figure 2-15. For the baseline profile, only 500 watts (average) of power are allocated to the payload. Total energy is 20 kilowatt-hours. For certain applications, however, additional power up to 5.2 killowatts can be made available at the expense of adding fuel cell reactants and tankage. Where a powered-up orbiter is required, additional reactants are required to maintain the vehicle in this status. For the seven-day mission the additional reactant and tankage weights are 800 pounds for powered-up orbiter and 920 pounds for increased power (5.2 killowatts).

Orbiter environmental control and life-support systems maintain a shirt-sleeve environment for a crew of four for seven days (or for 30 days with extra consumables). The overall system assures appropriate environmental control for manned areas. Environmental maintenance of electronics and other sensitive equipment is essentially limited to temperature regulation and heat dissipation. Among the life-support functions are control of temperature, humidity, air composition, air pressure, contaminants, bacteria count, odors, ventilation, and acoustics.

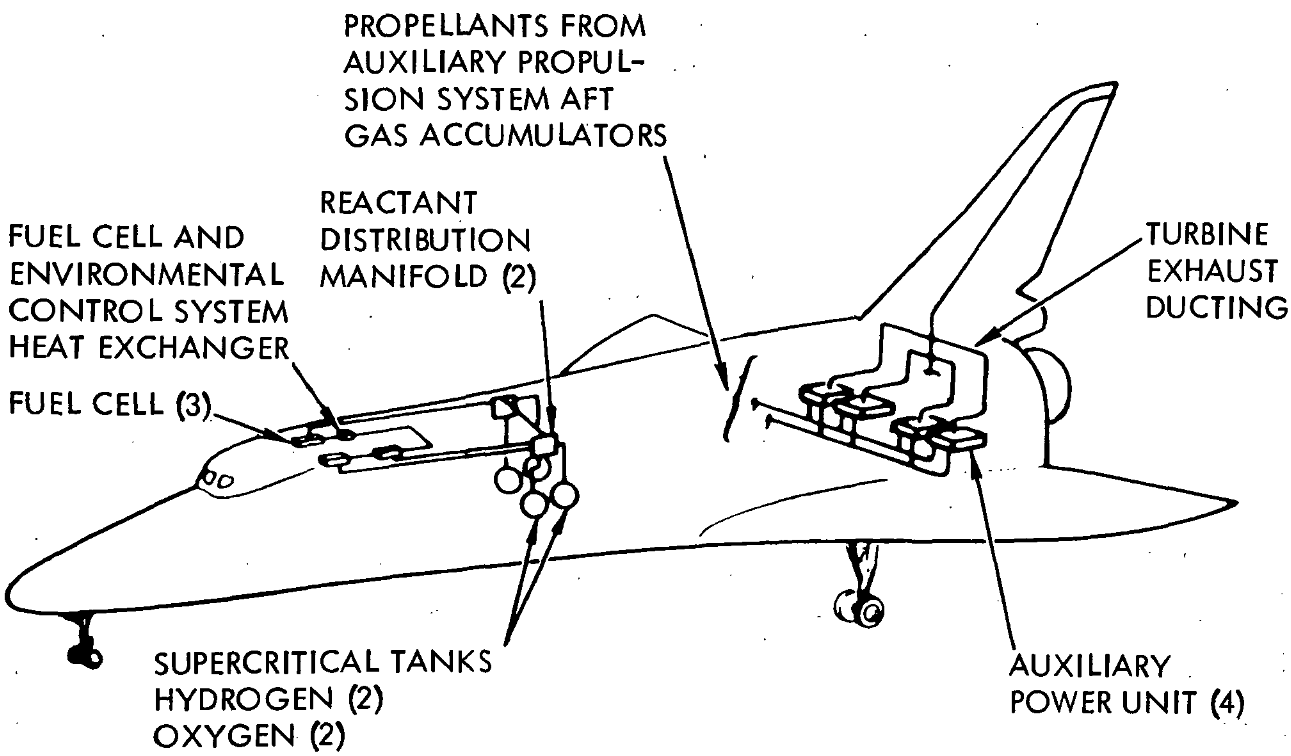

Figure 2-14. Power Generation System

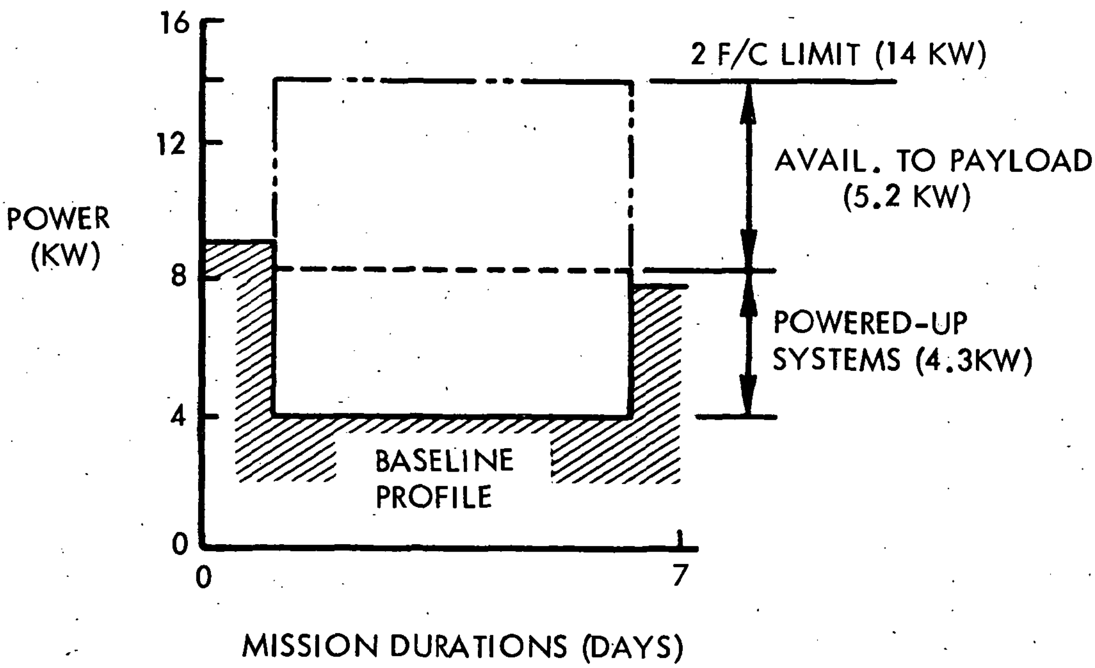

Figure 2-15. Electrical Power Profile

Air temperature within the manned compartments is maintained between 65 and 75 F under normal conditions and between 40 and 110 F during emergencies. Atmospheric temperature control is achieved with a heat exchanger and fan units through which cooled or heated water is circulated. The same water loop subsystem also supplies cooling water to the avionics compartment coldplates. Avionics coldplates in unpressurized locations are cooled by the Freon-loop subsystem. Cabin air pressure may be selected at any point between 10 psi and one atmosphere, depending on mission mode.

Gaseous and liquid wastes may be disinfected and dumped overboard, while solid wastes are decontaminated and retained in on-board storage tanks for removal during ground maintenance. Air contaminants, including bacteria, particulate matter, and odors, are removed from the cabin atmosphere with filters.

Food management incorporates a food packaging system for storage of food serving cans, dehydratables, and drink packages. A freezer-locker compartment is used for food storage.

The integrated avionics system is used to coordinate operation of all orbiter flight systems. Major subsystems governed by the data and control management system are guidance and navigation, communications, displays and controls, and power distribution and control. This system also performs the critical function of onboard checkout and fault isolation.

Sensor inputs for guidance and navigation are derived from three independent units: the inertial measurement unit, star tracker, and precision ranging system with onboard transceiver and ground and space station transponders. The inertial unit is the primary navigation subsystem; the star tracker and ranging system serve as corrective devices only.

The orbiter communications subsystem provides two-way voice and data transmission, range and range-rate data for space rendezvous, and information for atmospheric navigation and landing. A unified S-band system provides primary onboard voice and data intercommunication as well as two-way transmission with the space station and the manned spaceflight network. Additional voice and data communication with the ground is accomplished with a VHF-FM system via a stationary communications satellite, while two-way simplex voice transmission with civil and military air traffic control stations and with the booster vehicle is performed with UHF-AM equipment. Precision ranging system interrogators provide data for cooperative-target range and range-rate determination, on-orbit state vector updating, and atmospheric navigation and landing. A radar altimeter is part of the precision ranging system. Fifteen flush-mounted antennas are installed at various points on the orbiter fuselage. Antenna selection, as well as overall system checkout and control, is accomplished by the central data and control management system.

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3. INDUCED ENVIRONMENT

The environment induced on the payload while in the payload bay during transportation to and from orbit is described in the following paragraphs.

PURGE AND VENT

The cargo bay is purged with dry gaseous nitrogen (GN_2) prior to liftoff. The GN_2 dew point is -65 F; temperature 75 ± 5 F; pressure 15.2 ± 0.5 psia.

The cargo bay is vented during launch and entry and will be unpressurized during the orbital phase. The pressure differential between the cargo bay and the external environment will not exceed 2 psi.

FLIGHT LOADS

Orbiter flight load factors are presented in Table 3-1. These load factors are quasi-steady state and are equal to the total externally applied load divided by the total vehicle weight; factors carry the signs of the externally applied loads.

Table 3-1. Orbiter Limit Load Factors

Condition	Load Factor (g's)		
	X	Y	Z
Liftoff	1.4	±0.5	±0.5
High Q boost	1.9	±0.35	+0.5 -0.7
Booster end burn	3.0	±0.1	-0.5
Orbiter end burn	3.0	±0.1	-0.5
Entry	±0.25	±0.5	-2.5
Flyback	±0.25	±0.5	+1.0 -2.5
Landing and braking	+0.8 -1.0	±0.5	-2.5*
Crash**	-8.0	±1.5	-4.5 +2.0

*Consists of 1.0 g of aerodynamic lift, plus 1.5 g's of landing impact loads

**Crash load factors are ultimate, all others are limit

The load factors were computed using rigid-body analysis methods. Estimated dynamic magnification factors used to account for elastic body effects are summarized in Table 3-2.

Table 3-2. Dynamic Mangification Factors

Condition*	Magnification Factor	
	X	Y,Z
High Q boost	1.1	1.2
Booster end burn	1.1	1.1
Orbiter end burn	1.1	1.1
Landing	1.2	1.2

*For other conditions listed in Table 3-1, the dynamic magnification factors equal 1.0

TEMPERATURE

The internal wall temperatures for the cargo bay are presented in Table 3-3.

ACOUSTICS

The noise level in the cargo bay is 153 decibels. The associated acoustic spectrum is presented in Figure 3-1.

VIBRATION

The vibration environment in the cargo bay is (1) 18 g's rms for vibration aero-acoustically induced by the booster main engines, and (2) 22 g's rms for vibration mechanically transmitted from the orbiter main engines (where the mechanically induced vibration applies from fuselage station 1890 aft). No mass loading effects are included. The associated vibration spectra are presented in Figure 3-2.

SHOCK

Only the booster-orbiter stage separation will be initiated by pyrotechnic devices. Severe high-frequency transients are likely in the region of these devices. For normal staging, transient acceleration change during separation are 1.8 g's axially and 0.4 g normally. The associated time histories are presented in Figure 3-3. Landing shock is 1.5 g's in the minus Z direction. The landing shock criterion is presented in Table 3-4.

OUTGASSING AND EFFLUENTS

Effluent rates from the orbiter vehicle are listed in Table 3-5.

Table 3-3. Temperature Limits for Internal Walls of Cargo Bay

Payload External Surface Temperature (°F)	Prelaunch*		Launch		On-Orbit (Doors Closed)		On-Orbit (Doors Open)		Entry	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Cargo Bay Doors										
100	80	120	80	150	-100	150	N/A**	N/A**	-100	250
70	50	120	50	150	-100	150	N/A	N/A	-100	250
0	-20	120	-20	150	-100	150	N/A	N/A	-100	250
-300	-100	120	-100	150	-150	150	N/A	N/A	-150	250
-420	-100	120	-100	150	-150	150	N/A	N/A	-150	250
Other Cargo Bay Areas (sides, bottom, ends)										
100	80	120	80	130	0	130	0	130	0	200
70	50	120	50	130	-25	130	-25	130	-25	180
0	-20	120	-20	130	-75	130	-75	130	-75	160
-300	-290	120	-290	130	-300	130	-300	130	-300	150
-420	-290	120	-290	130	-420	130	-420	130	-420	150

*Cargo bay is purged with dry GN_2 for ground thermal conditioning. For bare LH_2 tanks, special provisions (e.g., He purging) will be required to prevent liquid air formation.

**The exposed surfaces of the payload will be subjected to the deep space environment which includes a black body radiation sink at 4 K and direct sun radiation.

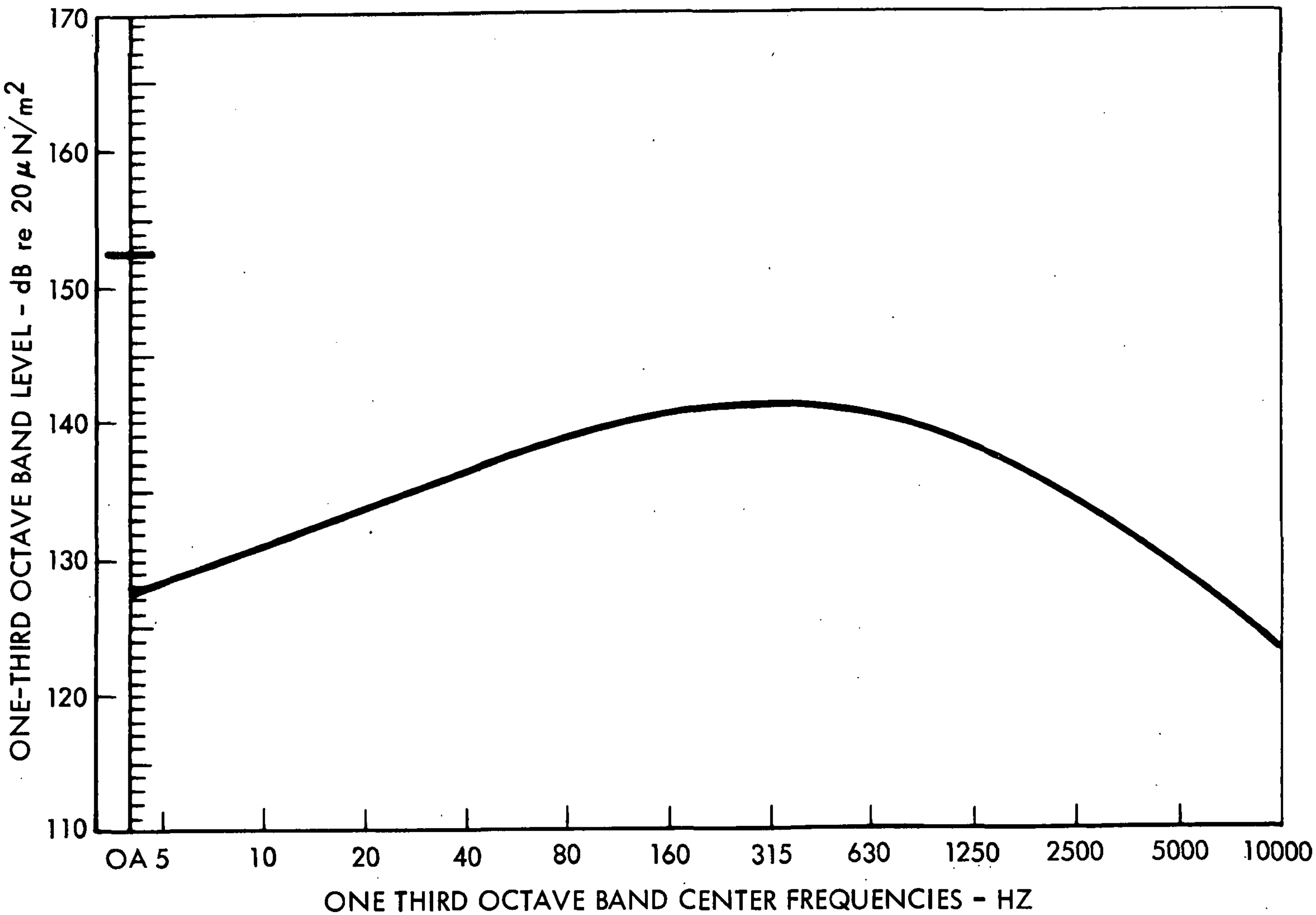


Figure 3-1. Cargo Bay Acoustic Spectrum

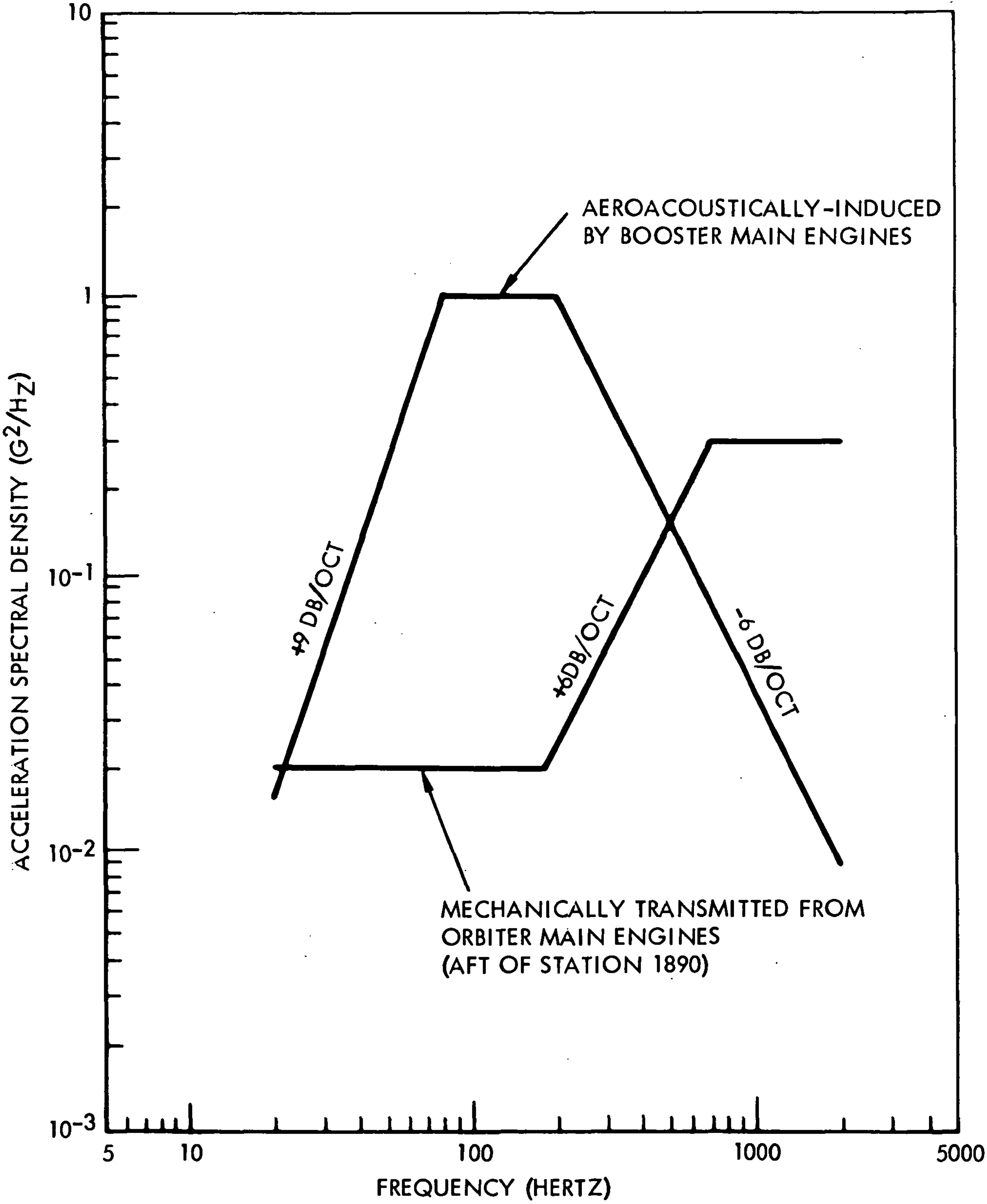


Figure 3-2. Cargo Bay Vibration Spectra

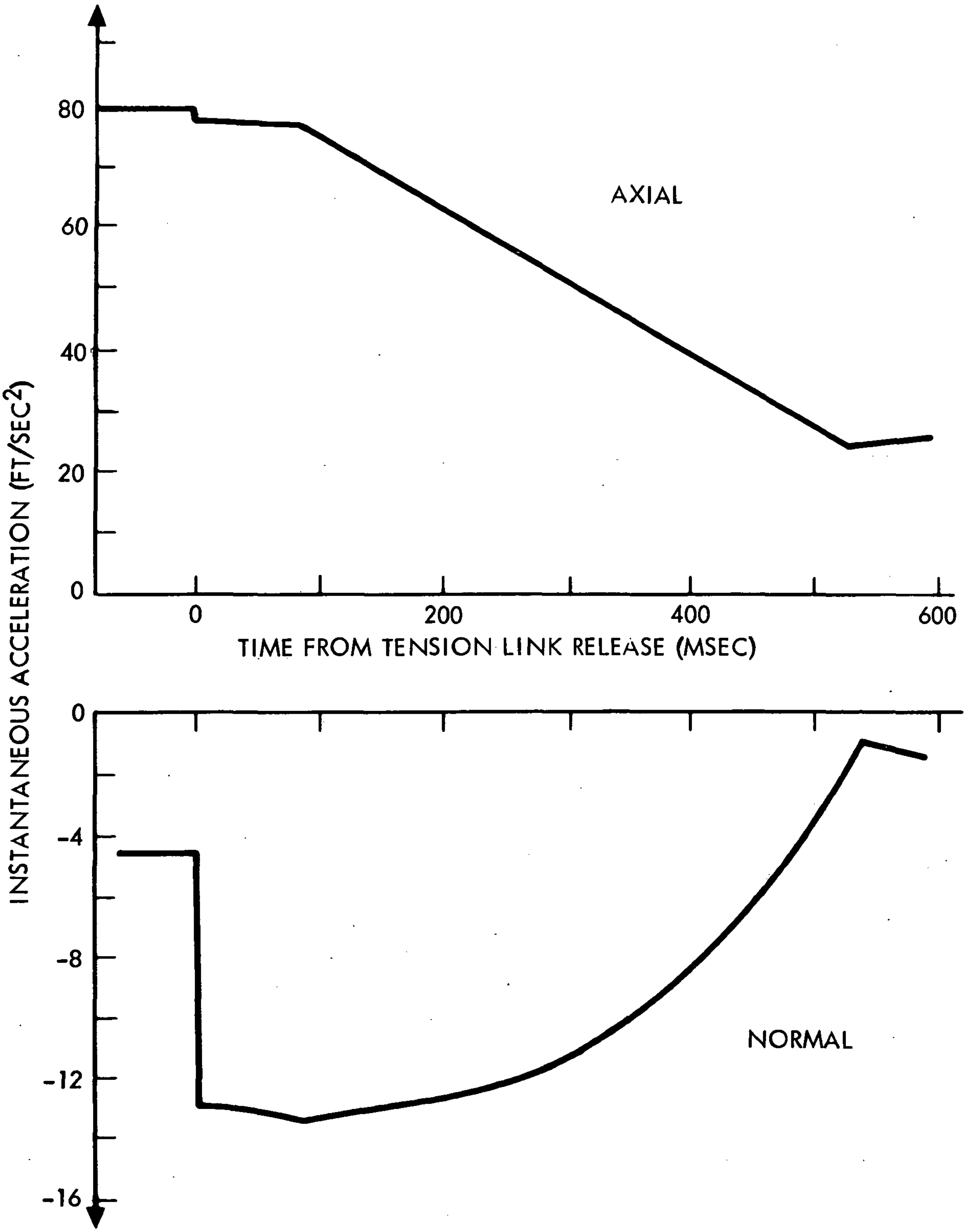


Figure 3-3. Orbiter Acceleration Time History for Booster-Orbiter Separation

Table 3-4. Landing Shock

Acceleration	Duration	Probability
0.23 g peak	170 m sec	0.18
0.28	280	0.29
0.35	330	0.26
0.43	360	0.15
0.56	350	0.08
0.72	320	0.03
1.50	260	0.01

Table 3-5. Maximum Effluent Rates

Component	Source	Rate	Remark
Water	Fuel cells	190 lb/day	All-up avionics; can hold for 24 hours
	ECLSS boiler Cabin leakage	220 lb/day 0.2 lb/day	Radiators looking at sun
	ACPS firings	280 lb/hr	±0.5° deadband
Hydrogen	Auxiliary propulsion Heat exchanger	0.4 lb/hr	Prevents boiloff
	Main propulsion venting	10. lb/min	360 lb. total residuals
	ACPS firings	50 lb/hr	±0.5° deadband
Oxygen	Main propulsion venting	6 lb/min	1800 lb. total residuals
	Cabin leakage	2 lb/day	
Nitrogen	Cabin leakage	7 lb/day	
Carbon dioxide	Cabin leakage	0.07 lb/day	
Urine	Waste management	3 lb/man-day	Can hold for 24 hours
Fecal vapors	Waste management	0.25 lb/man-day	Can hold for 24 hours

4. MISSION OPERATIONS

This section of the report describes both the ground and flight operation of the shuttle as related to the modular space station. The ground operation portion describes the launch complex, facilities, and the ground flow of the MSS. The orbital operations portion describes the overall flight profile from launch to landing. Also included is a description of the rendezvous and berthing operation during MSS buildup until initial manning. A mission sequence plan is presented which includes MSS module-by-module buildup, crew rotation flights, cargo flights, and experiment delivery.

GROUND OPERATIONS

Launch Site Description

The Kennedy Space Center (KSC) is described here in relation to the facilities required to support MSS launch activities.

KSC is a complete spaceport consisting of two primary operational elements and the necessary administrative and support capabilities to support space programs. The industrial area and launch complex (LC) 39 are the two primary operational elements.

The major components of LC 39 include the Vehicle Assembly Building (VAB), where the space shuttle is assembled and tested; the Launch Control Center (LCC), which houses display, monitoring, and control equipment for checkout and launch operations; the launch umbilical tower, upon which the space shuttle is erected for checkout, transfer, and launch; the crawler-transporter (CT), which transfers the space shuttle and the LUT to the launch pad; the crawlerway, a specially prepared roadway over which the CT travels to deliver the space shuttle to the launch pad; and the launch pad, from which the space vehicle is launched.

Major dedicated facilities at the operations site consist of the landing strip, post-landing safing area and equipment, maintenance and checkout building, mating installation, mated-vehicle transportation system, and launch pad.

One of the few new installations required at KSC is a landing strip for the orbiter and booster in reasonable proximity to the maintenance complex. Safing, because it is an operation peculiar to the reusable shuttle vehicles, also requires new installations adjacent to the landing strip. Primary functions of the safing operations are crew, passenger, and flight data removal; cooldown of the exterior thermal protection system; and nitrogen purging of propellant tanks and feed lines. Equipment is required for unloading personnel and any cargo that cannot remain aboard during the safing period. Also needed are ground utility services for avionics cooling, air conditioning, pressure and vacuum sources and service lines, and electrical supplies. The most extensive system associated with safing is that required for remotely controlled purging of tankage and disposal of hazardous fluids. A single safing facility serves both booster and orbiter.

Maintenance and preflight checkout is carried out in the existing VAB and a new hangar adjoining the north wall of the VAB. The new hangar is required to accommodate the booster vehicle, orbiter maintenance being carried out inside the VAB. Minor modification of the VAB doors is required for exit of the mated vehicles. On arrival at the maintenance hangar, the vehicle is positioned, service stands are installed, and the payload is removed with overhead cranes and transported to respective payload facilities. If deemed necessary, postflight checkout may be performed at this time. Preventive and corrective maintenance, as well as any required servicing, and modification are then accomplished, and the vehicle is secured for storage or released for immediate reuse. Figure 4-1 illustrates booster and orbiter maintenance accommodations.

Figure 4-1. Hangar Maintenance

A full complement of ground conditioning, pneumatic, and power service outlets is needed in the maintenance hangar. In addition, electronic and electrical checkout systems with automatic data acquisition and fault-isolation features are provided. Onboard computer-controlled, self-checkout and fault-isolation systems readily perform many functions formerly requiring special test devices and trained operators. Items of general mechanical equipment at the maintenance hangar include gantry cranes, jacking and handling gear, and precision alignment devices.

When the vehicles are assigned to a mission, payloads are installed in the orbiter and both vehicles are subjected to comprehensive premate checkout. These functions are carried out in the maintenance hangar using much of the equipment employed during post-flight maintenance and checkout operations. On satisfactory completion of subsystem checkout and verification of payload interfaces, the orbiter and booster interfaces are examined and the vehicles are released for mating.

The booster is first moved to the adjacent vehicle assembly building (VAB), where it is hoisted to a vertical position and mounted on the transportable launch umbilical tower. The orbiter is then hoisted and brought into position on the back of the booster. Attach fittings are secured, launch tower umbilicals are connected, and the vehicles are transported to the launch pad.

Comparable size and weight of the shuttle and the Apollo-Saturn vehicles permit use of existing major VAB, transportation, and pad facilities modified to accommodate dimensional differences. Pad services, in addition to the normal ground conditioning, pneumatic, and power supplies, include data and remote control systems and propellant loading. Figure 4-2 illustrates the KSC complex.

MSS Flow Plan at Launch Site

Figure 4-3 represents the launch operations master program plan from the facility preparation for the first MSS module through the mission operations with the growth station. This includes GSE installation and checkout, mission support vehicle (MSV) buildup, initial station module preparation and launch, cargo module preparation and launch, and growth station module preparation and launch.

Figure 4-4 represents a typical flow path for modules. The modules arrive at the launch site at the shuttle runway upon delivery from the factory or return from orbit. When returned from orbit, they are removed from the orbiter in the VAB and transported to the MSOB for servicing. Cargo is loaded in the cargo modules in the warehouse and weight and balance operations are accomplished in the MSOB. The modules are installed in the orbiter at the VAB, when the shuttle is transferred to the pad for launch operations.

The MSS modules (including cargo modules and RAM's) will be hoisted above the orbiter and lowered into the cargo bay with slings attached to the modules structure (Figure 4-5). After the module is fully lowered, the retention trunnions are engaged and secured for flight.

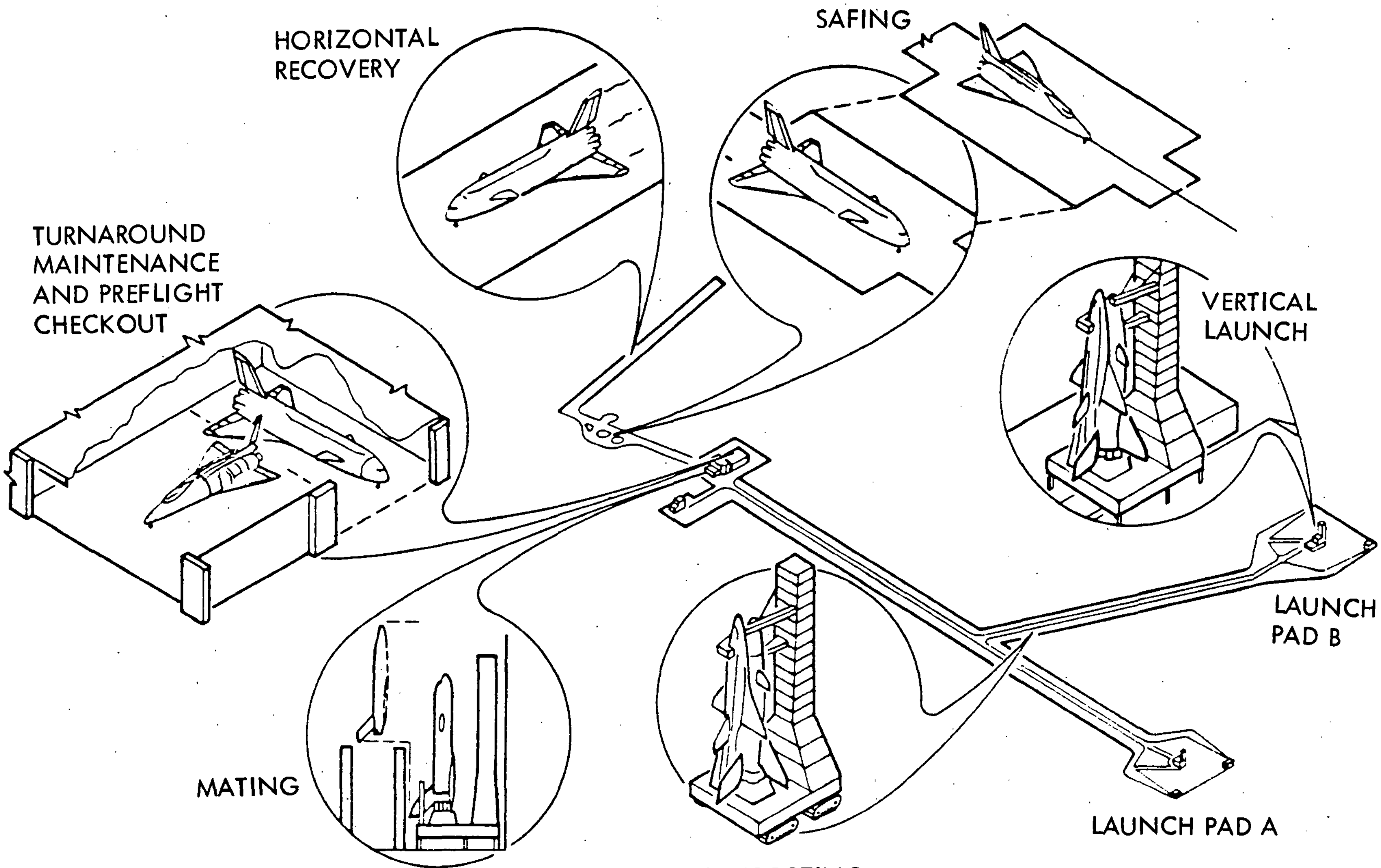


Figure 4-2. Launch, Recovery, and Turnaround Complex

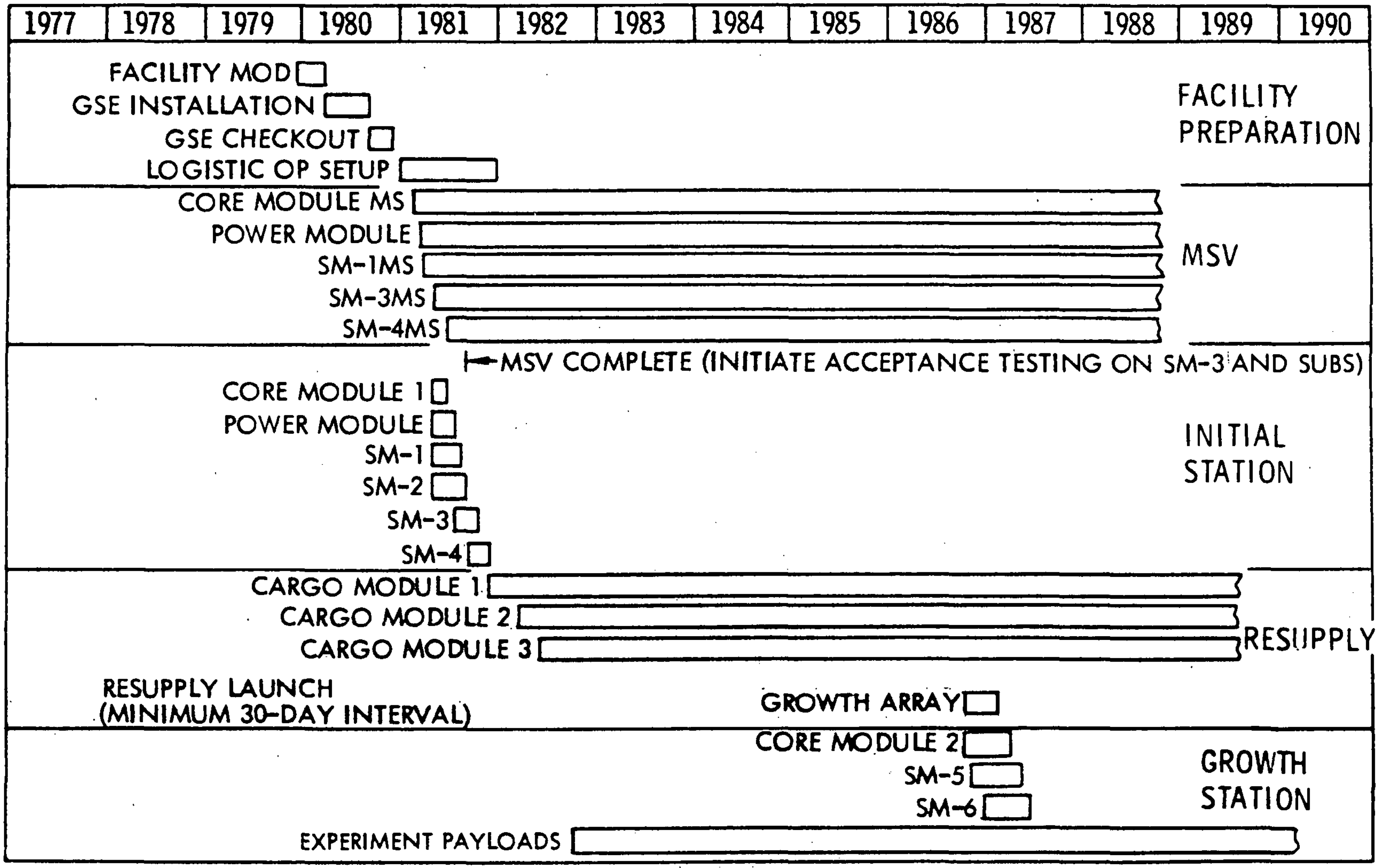


Figure 4-3. Launch Site MSS Program Schedule

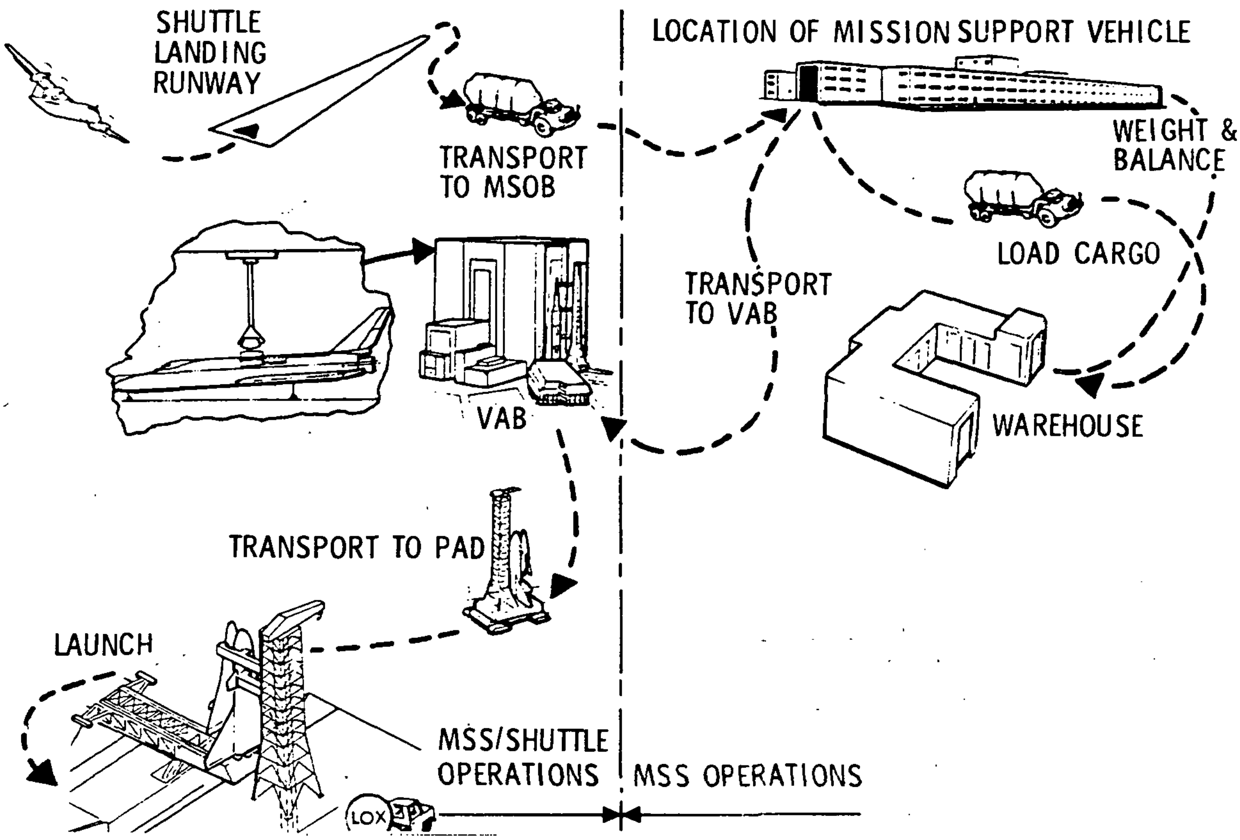


Figure 4-4. Typical MSS Module Flow at Launch Site

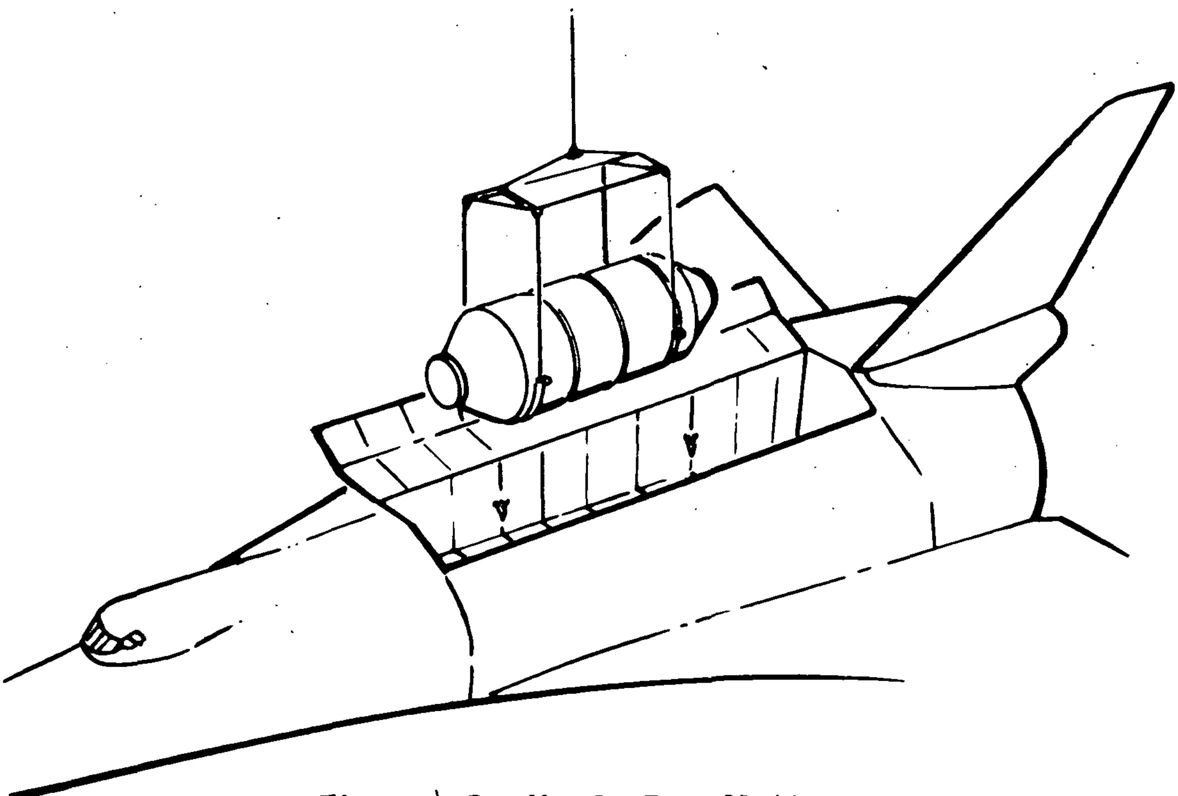


Figure 4-5. Module Installation

The module's caution/warning, power, and communication hardlines are then connected. The crew (cargo specialists) in the orbiter cargo specialist section will make all necessary checks of subsystems continuity and position indicators. After all checks have been made, the slings are removed and the bay doors closed. After installation operations have been completed, the access workstands will be removed and no further activity is planned until after the rollout is completed.

Launch Pad

The shuttle vehicle and LUT will be transferred to the launch pad by the crawler-transporter. At the launch pad, the LUT is secured to the pedestals, and shuttle-to-ground service connections are made. When electrical power is available, status checks will be made in preparation for the mission readiness test and the MSS modules checked for preflight readiness.

Launch operations begin with the loading of cryogenic propellants in the shuttle and the MSS module high-pressure gases. The launch pad area will be cleared of all personnel before loading propellants. Chilldown of transfer lines and shuttle tankage, venting, and transfer of propellants, replenishment, and termination are accomplished by an automated system with contingency pause and revert capability. After propellants and gases are loaded, the flight personnel board the vehicle. Final system activation and countdown operations are performed. Both airborne and ground systems are monitored for abort conditions that may occur anytime during launch operations.

The launch pad facility will have a rapid-lift elevator within the service tower to transport crew members, passengers, and the closeout crew to the boarding platform access arms.

The launch vehicles and the launch pad service tower design will incorporate emergency egress capabilities for the flight crews, passengers, and other personnel during launch operations. This capability will be sustained as close to launch as possible. In addition, the launch facility will provide personnel safing areas to protect the crew, passengers, tower, and rescue team personnel from possible hazards.

Launch Countdown

Airborne systems will be automatically scanned for proper configuration and readiness for launch. The range safety officer will verify that the range is clear for launch. The mission director will determine that all mission criteria have been satisfied and will issue the clearance to launch. The crew will then verify that the ready-for-launch summary is present from all subsystems.

The launch program will be initiated by the flight crew. The launch sequence will progress automatically from this point to liftoff.

ORBITAL OPERATIONS

The basic orbital operations of the space shuttle required to support the modular space station are discussed in this section. Basic considerations include the delivery and orbital assembly of the space station modules, logistics resupply, and delivery and return of the research and applications modules (RAM's). The majority of shuttle operations which interface with the modular space station occur on-orbit. For completeness, a summary of the reference shuttle mission profile, from launch to landing, is presented followed by a discussion of the space station buildup sequence. The space station support requirements are presented based on the mission sequence plan[1]. Brief discussions of shuttle rescue considerations and abort requirements are also presented.

Shuttle-MSS Sequence of Events

The sequence of events required for shuttle ascent is shown in Figures 4-6 and 4-7. The sequence shown in Figure 4-6 is valid only for the delivery of the initial space station module since rendezvous phasing is not required. The resultant time to final orbit circularization is approximately four hours. All subsequent shuttle launches require rendezvous with the on-orbit station and as a result require time for intermediate orbit (100 nautical miles) phasing as shown in Figure 4-7. Consequently, time from launch to rendezvous and circularization varies from 4.5 hours to a little more than 26 hours depending on the phasing time required.

A series of phasing and orbit transfer maneuvers are required for rendezvous with the space station during all shuttle missions except for the initial module delivery. Rendezvous operations commence immediately after insertion of the orbiter into the initial 50 by 100-nautical mile orbit. (For the initial space station module launch, no rendezvous is required and this phase is a continuation of the ascent-to-final orbit phase.) Two types of phasing are possible: natural (catchup) or high-altitude (catchback). The natural phasing technique is used as the baseline profile for space station operations; therefore, only this technique is discussed in this section. The high-altitude phasing technique, which can be used to reduce the time to rendezvous at the expense of performance, is discussed under rescue in a subsequent section.

Figure 4-8 presents the sequence of maneuvers and the ΔV requirements (from insertion to rendezvous) for the natural phasing technique. The total ΔV shown is the theoretical minimum and is the same for the variations of this rendezvous technique discussed. No allowance for dispersions have been included. Using this ascent phasing technique, the time from insertion to rendezvous can be as great as 22.5 hours for the worst case initial phasing. As shown in Figure 4-8, any required amount of phasing could be achieved in the 100-nautical mile circular orbit. Also, the time in the 100-nautical mile and 260-nautical mile circular orbits may be varied to accommodate rendezvous in daylight conditions with the sun angle oriented for pilot vision during the final braking maneuvers.

[1]See MSS Preliminary System Design, Vol. 2, SD 71-217-2 (DRL 68).

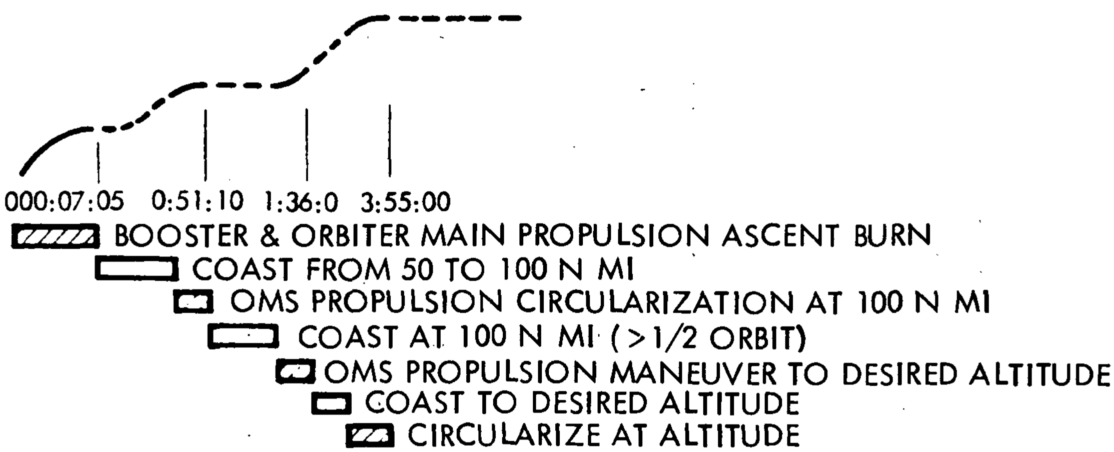


Figure 4-6. Sequence of Events, Core Module Delivery

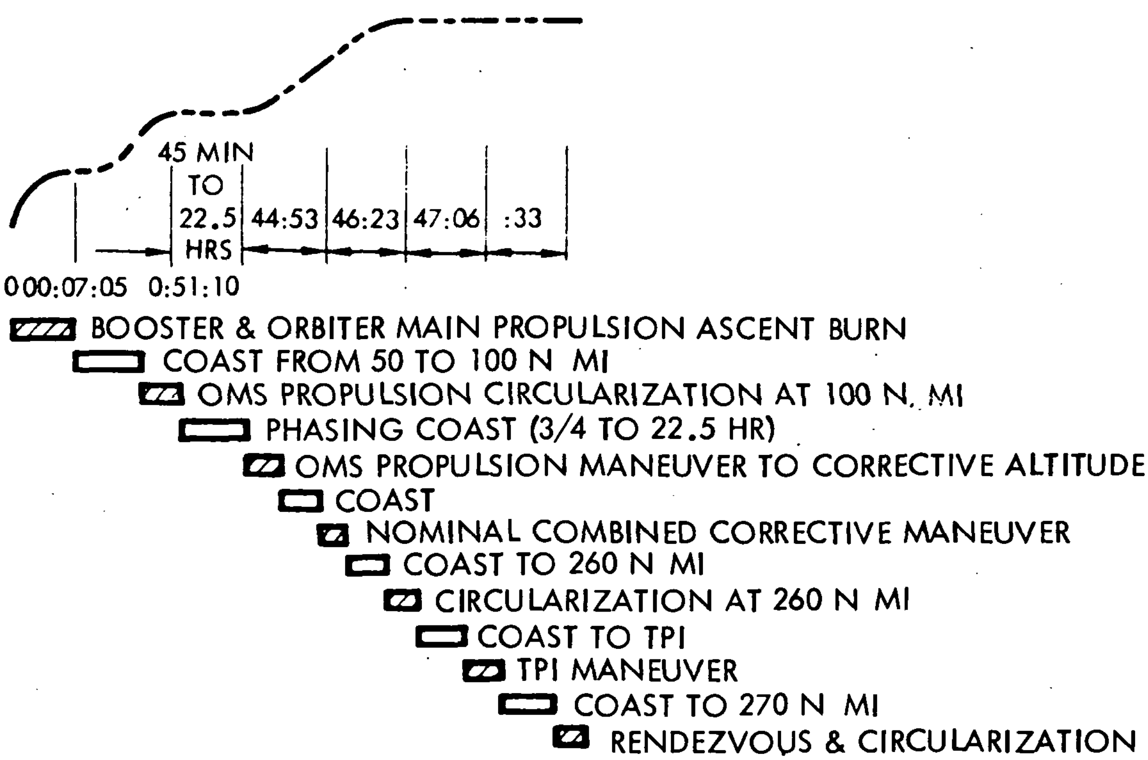
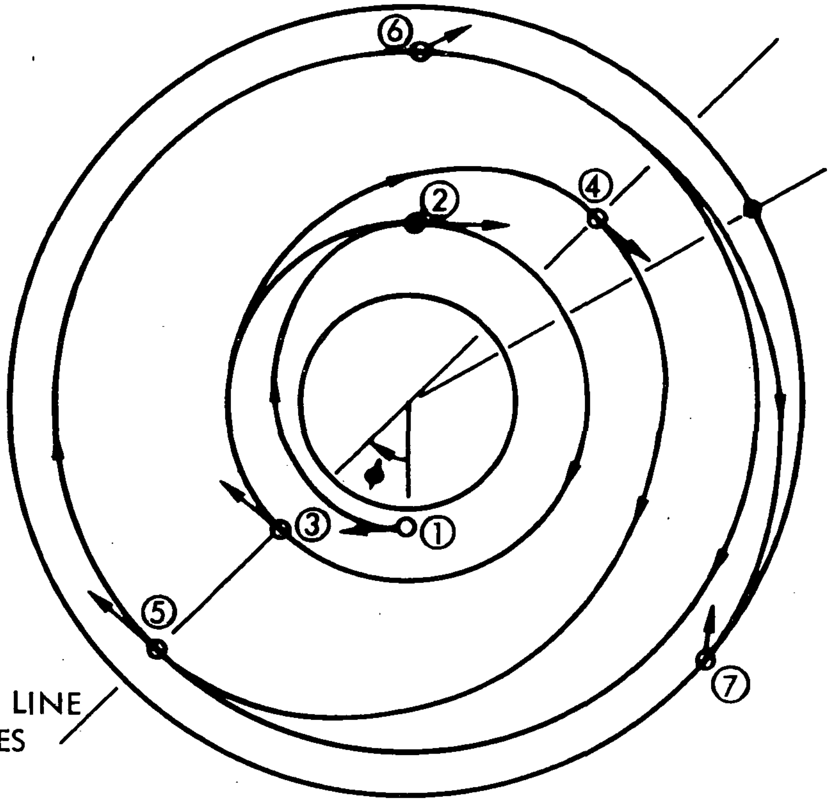


Figure 4-7. Power Module and Subsequent Modules Delivery



EVENT AFTER INSERTION INTO 50-100 N MI ORBIT	ΔV (FPS) ON-ORBIT ENGINES	RESULTING ORBIT (N MI)
1. CIRCULARIZE	91.0	100-100
2. PHASE ADJUSTMENT	142.3	100-180
3. COMBINED CORRECTIVE MANEUVER	279.1	180-260
4. CONSTANT DELTA HEIGHT MANEUVER	136.9	260-260
5. TERMINAL PHASE INITIAL MANEUVER	22.0	260-271
6. TERMINAL PHASE FINAL MANEUVER	27.0 (ACPS)	270-270
TOTAL	698.3	

Figure 4-8. Rendezvous Phasing Techniques

There are two basic variations of the maneuvers of Figure 4-8:

1. The altitude change from the phasing orbit at 100 nautical miles to the 260-nautical mile circular orbit may be performed by a single Hohmann transfer. This may be done as a part of expediting the rendezvous when there is very little change of phase angle needed.

2. The phasing orbit may be performed by multiple Hohmann transfers as shown in Figure 4-8. This variation is useful in achieving a required change of phase angle in a desired number of orbits.

Upon completion of the phasing orbits the shuttle performs a phase adjustment ΔV to transfer from 100 nautical miles to the final station orbit altitude. This transfer orbit is performed in two phases: an initial transfer to 180 nautical miles, where a combined corrective maneuver is performed for final transfer to 260 nautical miles.

The actual rendezvous function starts with the terminal phase injection (TPI) burn which puts the orbiter into a 260 by 271-nautical mile orbit. The apogee at 270 nautical miles is never realized because the terminal phase finalization maneuver (TPF) occurs at an altitude of 270 nautical miles after a 140-degree transfer as shown in Figure 4-9. The TPF is actually a series of braking burns by the ACPS which satisfy the braking gate criteria shown in Figure 4-10.

For the unmanned space station visits (i.e., during buildup) the orbiter will be self-targeting. Maneuver times and steering commands will be computed with only the knowledge of the present state vector of the orbiter and the ephemeris of the space station. During support of the manned space station, the station will receive updated time and position data and will be prepared to provide mission control and tracking support to the ground or to the shuttle. While the shuttle is in coelliptic orbit, prior to the terminal phase, the crew will initiate continuous open communication with the shuttle and tracking which will continue until completion of berthing. Crew time requirements in command and control for a shuttle minimum phase angle launch are one man, two hours continuous, plus one man, two hours in 20-minute segments. For a maximum phase angle shuttle insertion, it is two hours continuous plus three hours in 20-minute segments for one man.

The on-orbit operations commence with the completion of all major propulsive maneuvers and terminate with the initiation of deorbit operations. Since the majority of the space station-shuttle interfacing operations occur during this mission phase, they are discussed in the subsequent sections.

Because of the cross-range capability of the orbiter, there are at least two opportunities available during any 24-hour period to land at the primary (launch) site without the necessity of phasing maneuvers. The deorbit and entry mission phase begins with computation of the deorbit burn initiation time (OMS ignition) from inputs of orbiter position, orbital parameters,

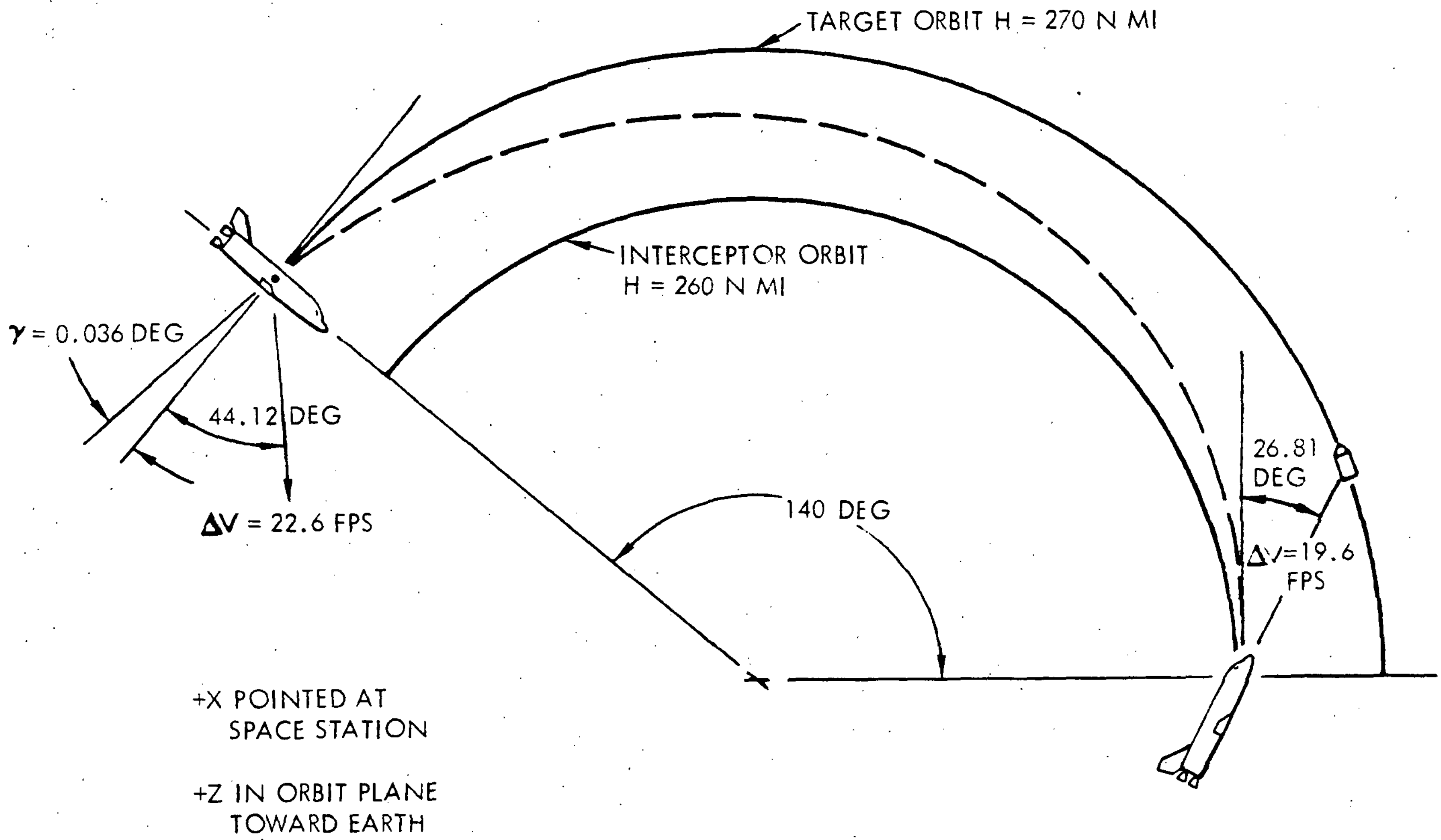


Figure 4-9. Terminal Phase Transfer

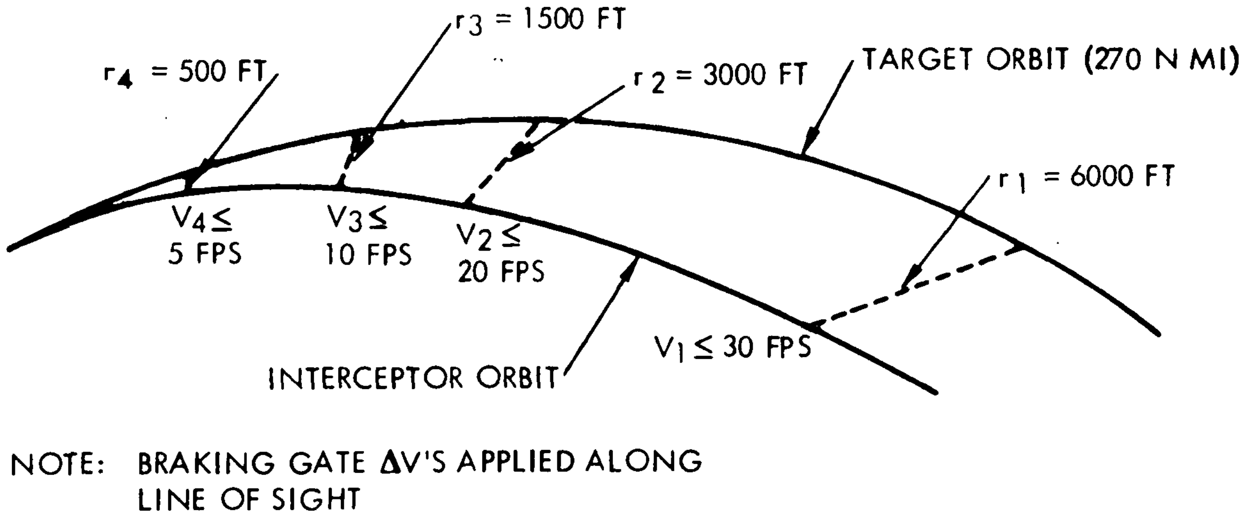


Figure 4-10. Terminal Rendezvous Braking Gates

landing site location, and predicted entry ranging characteristics. The vehicle is oriented to the proper burn attitude shortly before OMS engine ignition. After engine shutdown the orbiter is rotated to an entry attitude corresponding to the lateral range requirement.

Upon reaching the 0.05-g entry threshold, aerodynamic forces are used to direct the vehicle to the landing site located 5000 to 6000 nautical miles downrange. The entry maneuvers are classified in two categories: entry phase and terminal phase. During the entry phase, the objective is to reach trajectory coordinates near the landing field at an altitude of approximately 50,000 feet. At the completion of the entry phase, the orbiter performs terminal phase maneuvers to reach the final approach targeting coordinates at a 12,000-foot interface altitude, 10 miles from the runway. At an altitude of approximately 700 feet above the runway and a distance of approximately 3000 feet from the runway, a single 1.5-g exponential flare will be initiated, resulting in a "float" time of approximately 20 seconds from flare initiation to touchdown. The orbiter's landing velocity will be approximately 165 knots at runway contact with a sink rate of approximately 5 fps.

During final approach, should the orbiter not be in the proper approach pattern, the capability exists to perform a go-around using the air-breathing engine system (ABES).

Space Station Buildup Operations

The shuttle will be required to deliver modules and perform a number of on-orbit functions during buildup (both initial and growth) of the modular space station. The initial space station buildup phase begins with the shuttle launch and delivery to orbit of the first module and is completed when the station is first fully activated and manned by the initial six-man crew. The buildup sequence selected for the initial MSS consists of seven steps summarized in Figure 4-11. Since the assembly period is constrained by a shuttle launch frequency of one every 30 days, the overall buildup time associated with the selected sequence requires at least 180 days.

On Day 0, the initial module (core module) is delivered to orbit by the shuttle. It takes approximately four hours from launch for shuttle ascent to the operational altitude. Upon reaching the desired altitude, the core module is activated in the shuttle cargo bay. This activation includes energizing power buses, activating fuel cells, verifying ISS operation, ECLSS coolant loop operation, communications, IMU operations, and control functions. After the operational integrity of the core module subsystems has been verified, the interfaces between the module and the shuttle are disconnected. The core module is then deployed out of the cargo bay by the shuttle manipulator and positioned for final operational verification prior to release.

After the core module has been deployed, the special two-man crew aboard the shuttle conducts a final RF link and rendezvous aid check of the module, activates the core module reaction control subsystem, and then releases the module. After separation, the core module RCS will damp the separation transients and upon commands from the module IMU, stabilize the module in a gravity gradient attitude. Upon completion of these maneuvers, the shuttle crew prepares the core module for its quiescent operational mode. This includes shutting down the RCS and guidance and control subsystem by remote RF commands. This mode will be maintained until the module is awakened and its subsystems activated prior to the next module delivery, approximately 27 days later. After verifying the final operational status of the core module, the shuttle will remain on-orbit and station-keep in the vicinity of the core module for at least one day before returning to earth. This will enable the crew to observe and verify the attitude stability of the core module.

On Day 30, the power module is launched. Before launching this module, ground stations remotely awaken and verify the operational integrity of the operating core module subsystems. This includes activation of the core module RCS, G&C, and rendezvous aids. The time required from launch until the shuttle accomplishes on-orbit rendezvous with the core module can vary from 4 to 26 hours since phasing is required between the shuttle and core module. After the shuttle accomplishes rendezvous, the shuttle-MSS adapter is disconnected from the cargo bay mounts and, by use of the shuttle manipulator, deployed and berthed to the passenger docking port on the shuttle. The shuttle crew then commands the core module to maintain a stable initial attitude preparatory to retrieval and berthing. The shuttle then closes with the core module, the shuttle manipulator attaches to the core module, the module RCS and G&C subsystem are deactivated by RF commands and the module berthed to the adapter. The core module docking port used is on the +Z axis nearest

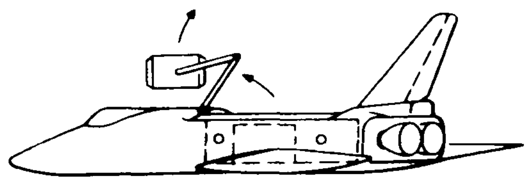
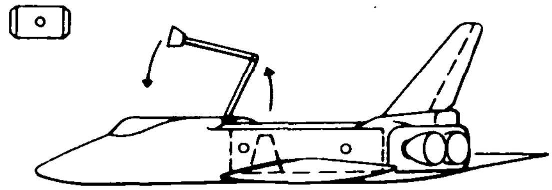
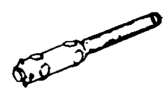
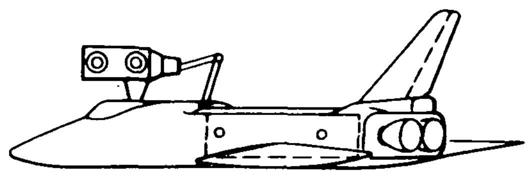
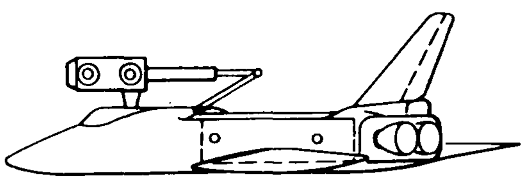
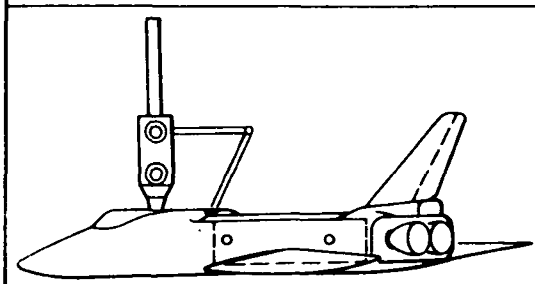
MODULE DELIVERED	PRINCIPAL OPERATIONS		ORBITAL CONFIGURATION
CORE		• ACTIVATE • CHECKOUT • DEPLOY	 CORE
POWER		• REMOVE AND BERTH STATION-SHUTTLE ADAPTER	 POWER
		• ATTACH MANIPULATOR TO CORE MODULE AND BERTH TO STATION-SHUTTLE ADAPTER	
		• REMOVE POWER MODULE AND BERTH TO CORE MODULE	
		• REBERTH CORE AND POWER MODULE CLUSTER TO STATION-SHUTTLE ADAPTER • DEPLOY MODULE CLUSTER	

Figure 4-11. Initial Space Station Buildup Sequence

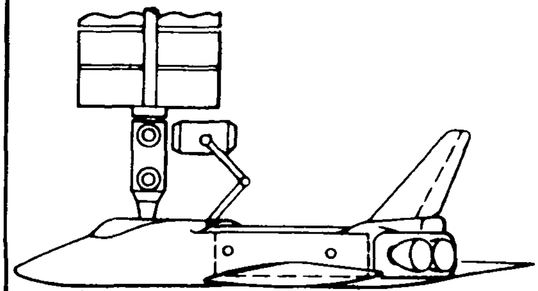
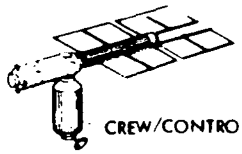
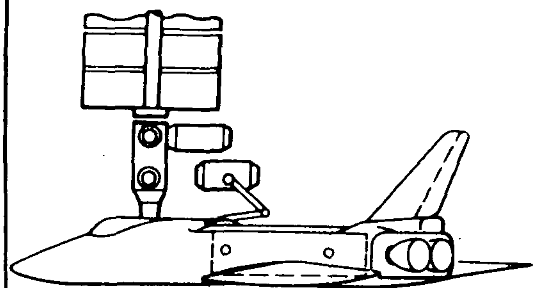
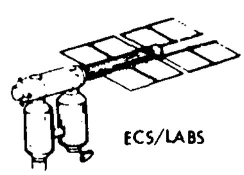
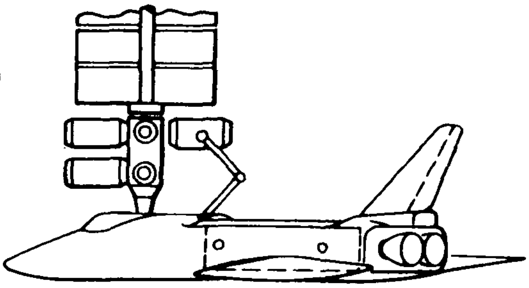
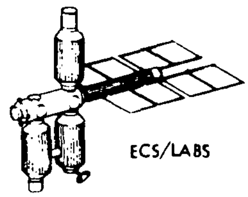
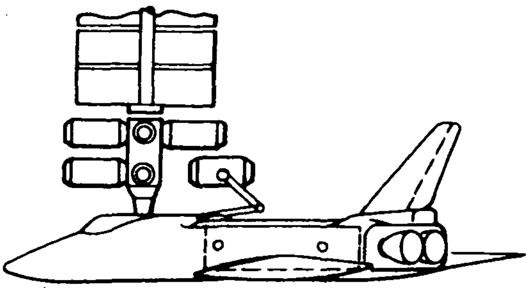
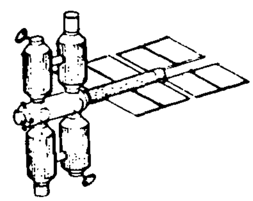
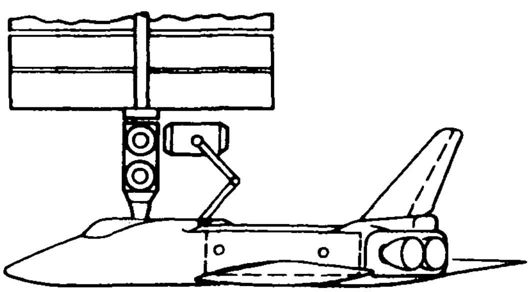
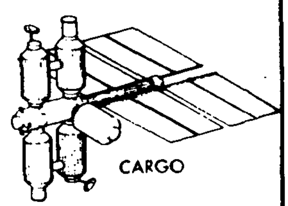
MODULE DELIVERED	PRINCIPAL OPERATIONS		RESULTANT CONFIGURATION
SM-1 (CREW/ CONTROL)		• BERTH CORE AND POWER MODULE CLUSTER • REMOVE SM-1 AND BERTH TO CORE MODULE • PARTIALLY ACTIVATE SM-1 • PARTIALLY DEPLOY SOLAR ARRAY (25%) • DEPLOY MODULE CLUSTER	
SM-2 (ECS/LABS)		• BERTH MODULE CLUSTER • REMOVE SM-2 AND BERTH TO CORE MODULE • PARTIALLY ACTIVATE SM-2 • DEPLOY MODULE CLUSTER	
SM-3 (ECS/LABS)		• BERTH MODULE CLUSTER • REMOVE SM-3 AND BERTH TO CORE MODULE • PARTIALLY ACTIVATE SM-3 • DEPLOY MODULE CLUSTER	
SM-4 (CREW/ CONTROL)		• BERTH MODULE CLUSTER • REMOVE SM-4 AND BERTH TO CORE MODULE • PARTIALLY ACTIVATE SM-4 • DEPLOY MODULE CLUSTER	
CARGO MODULE		• BERTH MODULE CLUSTER • FULLY DEPLOY SOLAR ARRAY • REMOVE CARGO MODULE AND BERTH TO CORE MODULE • FULLY ACTIVATE INITIAL SPACE STATION • DEPLOY INITIAL SPACE STATION • COMMENCE ROUTINE SPACE STATION OPERATIONS	

Figure 4-11. Initial Space Station Buildup Sequence (continued)

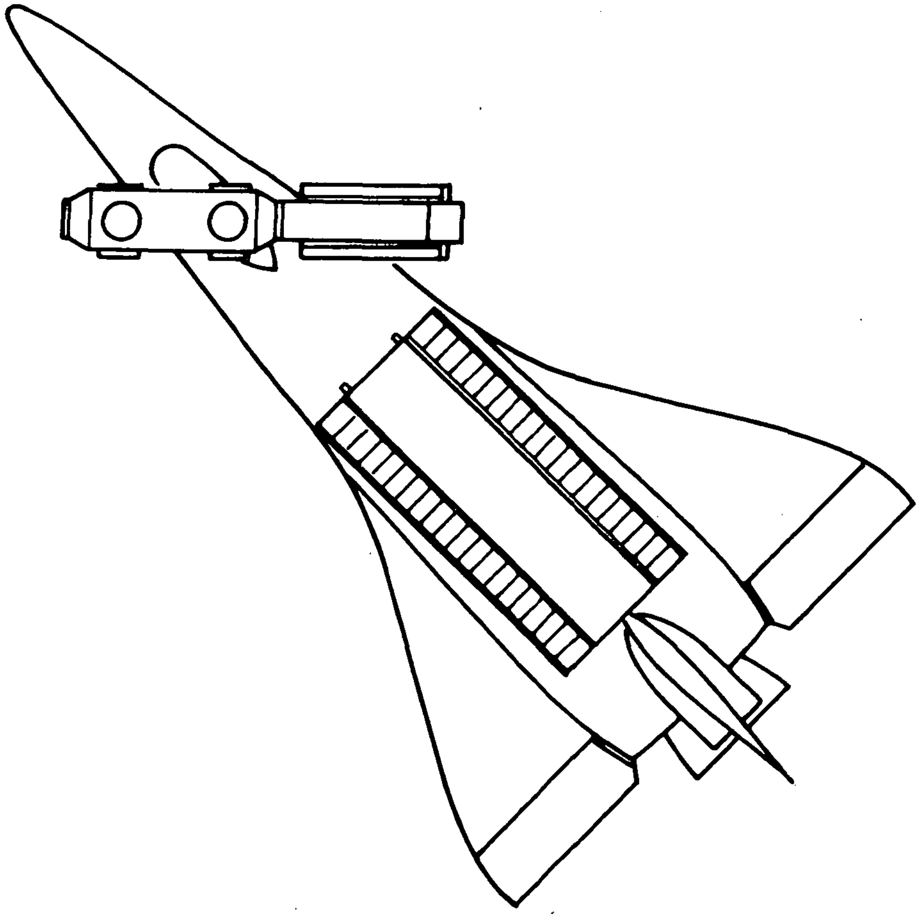
the power module-core module interface. Further, the core module is berthed so that its longitudinal axis is rotated 45 degrees relative to the shuttle longitudinal axis as shown in Figure 4-12. This unique berthing orientation is used to minimize manipulator reach requirements during berthing of the power module to the core module.

After the core module has been berthed to the adapter, the shuttle-adapter-core module interfaces and the core module environment are verified. The power module is disconnected from the shuttle cargo bay, deployed, and berthed to the +X axis port on the core module by the shuttle manipulator. The special crew (two men) enter the core module, connect and verify the power module-core module interfaces, and configure the assembly for detached operations (power module subsystems are not activated at this time). The special crew returns to the shuttle and the interfaces between the adapter and core module are disconnected. The shuttle manipulators are then used to detach the core module from the adapter. The core module-power module cluster is then rotated and reberthed to the adapter at the core module -X axis port. The adapter on the -X axis port of the core module will remain on-orbit with the cluster and is the designated shuttle-modular cluster berthing interface for the remainder of the buildup operations as well as for subsequent routine operations.

After the adapter-core module interface is verified, the adapter-core module-power module cluster is disconnected from the shuttle and positioned for final operational verification prior to release. Through RF links, the special crew conducts final checkout and activation of the core module subsystems and the modular cluster is released. The separation transients are dampened autonomously and the gravity gradient attitude mode attained by core module subsystems. The cluster is then configured for quiescent operations and its subsystem operational status verified by the shuttle crew before departure and earth return. This mode is maintained until the modular cluster is awakened and its subsystems activated prior to the next module delivery, approximately 26 days later.

Sixty days after the core module is launched, the third module, SM-1, is launched. Since phasing is required, the elapsed ascent time from launch to rendezvous can vary from 4 to 26 hours. The sequence of operations for delivery of SM-1 is summarized in Figure 4-13. This sequence is representative of the operations required during the delivery of all subsequent station modules.

After the shuttle accomplishes rendezvous, the core module-power module cluster is commanded to stabilize and maintain attitude and is configured for berthing by RF commands from the shuttle special crew. The shuttle then closes with the modular cluster and retrieves it using the shuttle manipulator. The core module RCS is deactivated and the cluster berthed to the shuttle passenger berthing port. For all station modules, cargo module, and RAM deliveries to the initial station, the berthed orientation of the core module Y and Z axes are skewed 45 degrees with respect to the longitudinal axis of the shuttle as shown in Figure 4-14. (This berthing orientation is used to minimize manipulator reach requirements during berthing or unberthing of modules as well as to provide manipulator arm (and elbow) clearance in the removal and replacement of modules in the cargo bay).



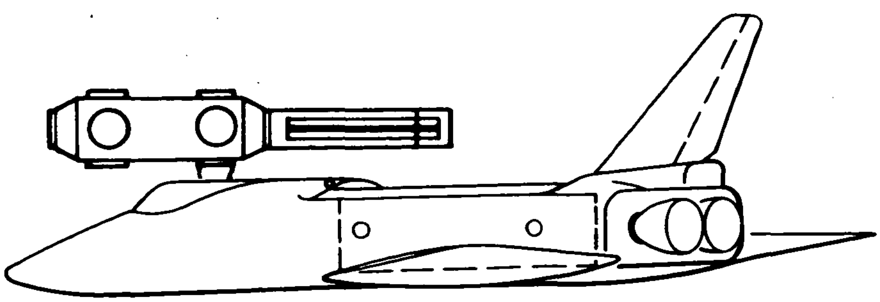


Figure 4-12. Power Module Berthing

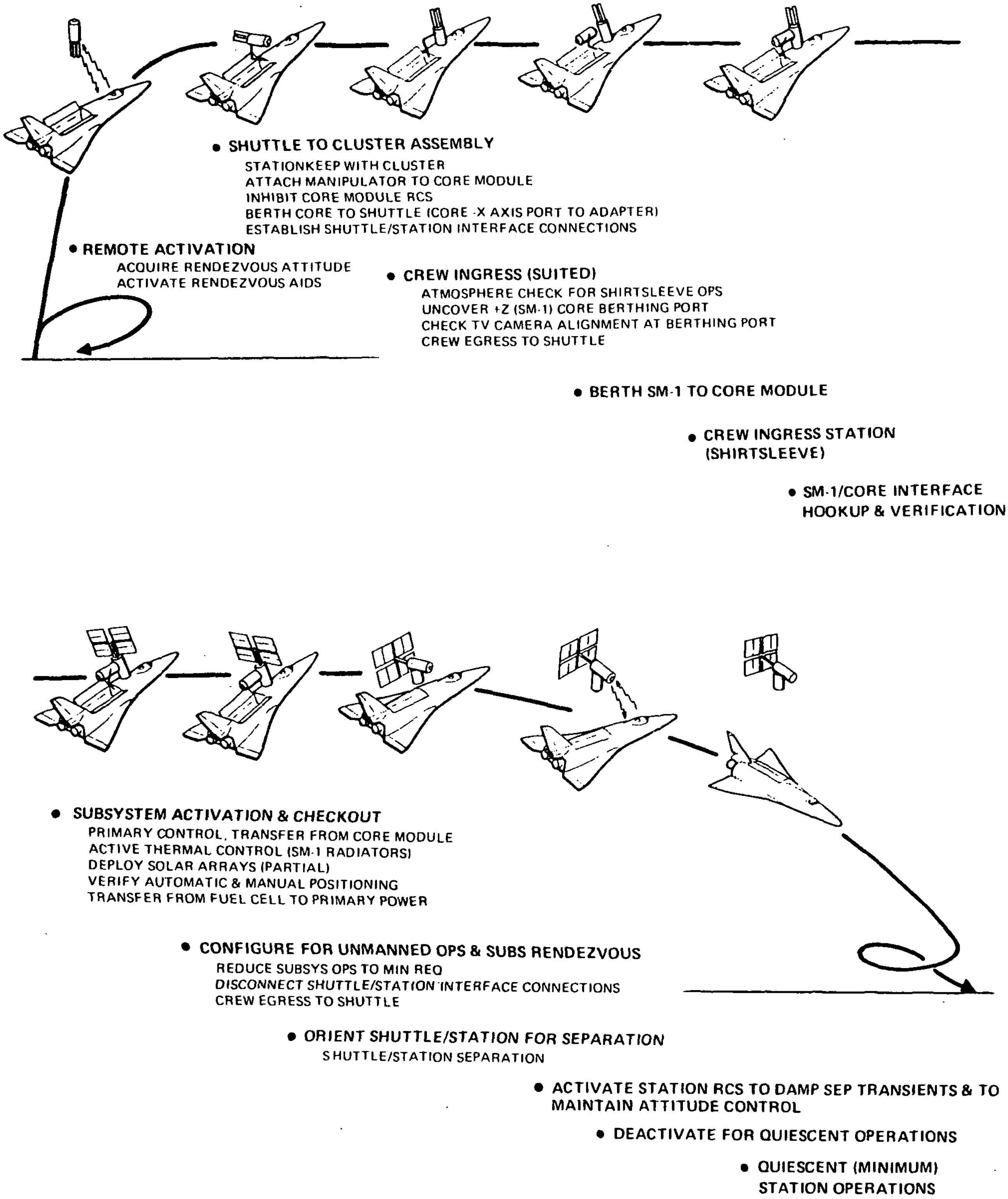


Figure 4-13. Typical Delivery Operations Sequence (SM-1 Delivery)

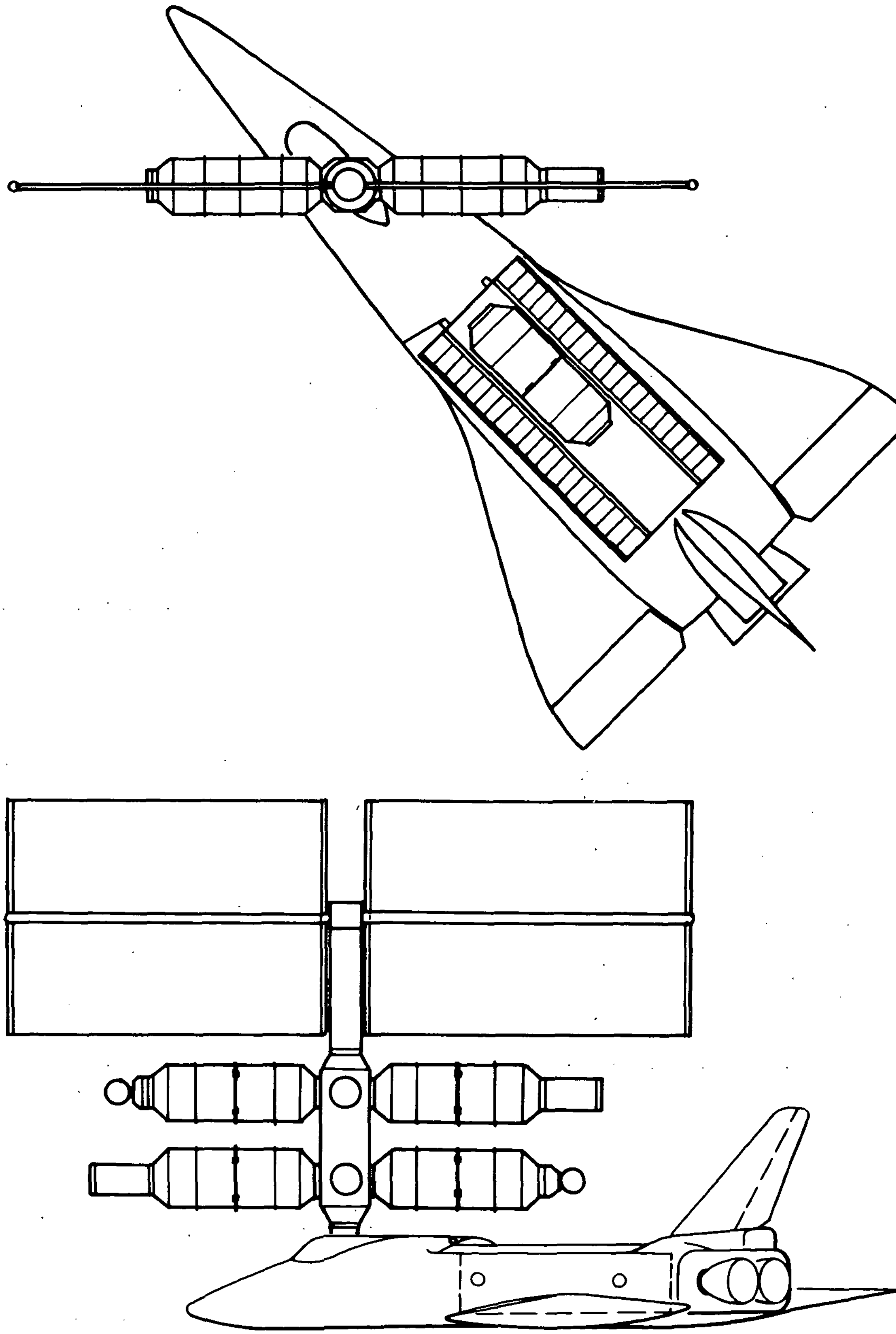


Figure 4-14. Shuttle Nominal Berthing Operations

The modular cluster-shuttle interfaces are verified and the MSS habitable environment established. The special crew then enters the berthed cluster and reconfigures it for SM-1 attachment to the forward +Z axis port on the core module. SM-1 is then disconnected from the shuttle bay and rotated out of the cargo bay and berthed to the designated port on the core module by the shuttle manipulator. The special crew enters the core module, assembles electrical and fluid interface connections with SM-1, and establishes and verifies a habitable environment in SM-1. The crew enters SM-1 and the control center is activated for modular cluster subsystem integration and checkout. The primary power buses are engaged and the solar array panels deployed 25 percent and their operation and electrical output (4.87 kilowatts) verified. Primary power is then transferred from fuel cells to the solar array. The electrolysis units (RCS and fuel cells) are activated and the cluster subsystem operation checked out.

The modular cluster is then configured for free flight, the shuttle-cluster interfaces disconnected, and the cluster deployed and positioned for relase by the shuttle manipulator. A final operability check on the modular cluster subsystems is performed, the RCS enabled, the solar array panels uninhibited, and the cluster released. Separation transients are dampened and a principal axis attitude flight mode established autonomously by the modular cluster. The principal axis attitude will be maintained for 25 days until the next shuttle visit when the module is commanded to fly an X-POP inertial attitude prior to berthing. The cluster is configured for quiescent operations and its status verified by the shuttle crew prior to departure and earth return.

Ninety days after the core module is launched, the fourth module, SM-2, is launched. Ascent time from launch to rendezvous may vary from 4 to 26 hours since phasing with the orbiting modular cluster is required. After the shuttle accomplishes rendezvous, the modular cluster is commanded to assume and maintain an X-POP inertial flight attitude, and is configured for berthing, which includes inhibiting the solar array panels.

The shuttle then closes with the cluster and the cluster is retrieved by the shuttle manipulators. The core module RCS is deactivated and the cluster berthed to the shuttle passenger berthing port. The modular cluster-shuttle interfaces are verified and a habitable environment established in the cluster. The special crew then enters the berthed cluster and configures it for SM-2 attachment to the aft +Z axis port on the core module by the shuttle manipulator. The special crew again enters the core module and its interface with SM-2 is completed. A habitable environment is established in SM-2 and verified. The crew enters SM-2 and the flexport is extended and connected to the flexport hatch on SM-1.

The modular cluster (now consisting of core module, power module, SM-1, and SM-2) is configured for free flight, its interface with the shuttle disconnected, and deployed and positioned for release by the shuttle manipulator. A final operability check on the modular cluster subsystems is performed, the RCS enabled, the solar array panels uninhibited, and the cluster released. Separation transients are then dampened and a principal axis attitude flight mode accomplished by the modular cluster. The principal axis attitude will be maintained for 26 days until the next shuttle visit. The cluster is configured for quiescent operations and its status verified using RF by the shuttle crew prior to departure and earth return.

SM-3 is the fifth module delivered to orbit and it is launched 120 days after the launch of the core module. The ascent, awakening, retrieval, berthing, attachment, interfacing, and other operations are similar to those previously described for SM-2 with the exception that the flexport extension and connection is not accomplished until SM-4 is delivered. SM-3 is berthed to the forward -Z axis port on the core module. The cluster will fly a principal axis attitude mode during its quiescent operations phase which lasts for 26 days.

SM-4 is the sixth and last of the modules which make up the basic initial station. This module is launched 150 days after the inital launch of the core module and is attached to the aft -Z axis port on the core module. The ascent, retrieval, berthing, and other operations are similar to those previously described for SM-2, including the flexport extension and attachment operation between SM-4 and SM-3. In addition, the second control center, similar to that on SM-1, is activated, connected to the data bus, and checked out. The unmanned modular space station will fly a prinxipal axis attitude mode during its quiescent operations phase which lasts for 26 days.

One-hundred-eighty days after the launch of the core module, the first cargo module and initial six-man station crew are launched. As before, the ascent time will take from 4 to 26 hours, the unmanned MSS subsystems are statused prior to shuttle launch, and subsequent to rendezvous the station is commanded to an X-POP inertial mode and its solar array panels inhibited in preparation for retrieval and berthing. After the unmanned station is retrieved and berthed to the passenger berthing port of this shuttle, the shuttle-station interfaces are verified and a habitable environment verified in the station. The initial manning crew then enters the station, the solar array panels are fully deployed, both control centers fully activated, and all subsystems brought onto line and checked out.

After the operational integrity of the station has been established, the cargo module-shuttle cargo bay interfaces are disconnected and the cargo module deployed and berthed to the station by the shuttle manipulator. The cargo module may be berthed to either of the forward Y-axis (+ or -) ports. The station-cargo module interfaces are secured and the shuttle prepares for earth return. The cargo module stays with the station and acts as a supply center as well as providing a 96-hour emergency life support capability. The shuttle-station interfaces are disconnected, the shuttle performs a separation maneuver from the station and configures for earth return.

At this time, approximately 185 days after the launch of the core module, the station is fully assembled, activated, manned, and capable of initiating routine operations. The resultant orbital configuration of the initial space station (Figure 4-15) consists of the core module, power module, four station modules, and the initial cargo module. During the period of routine station operations, research and applications modules are delivered and berthed to the aft Y-axis (+ or -) berthing ports as required to support experiment operations.

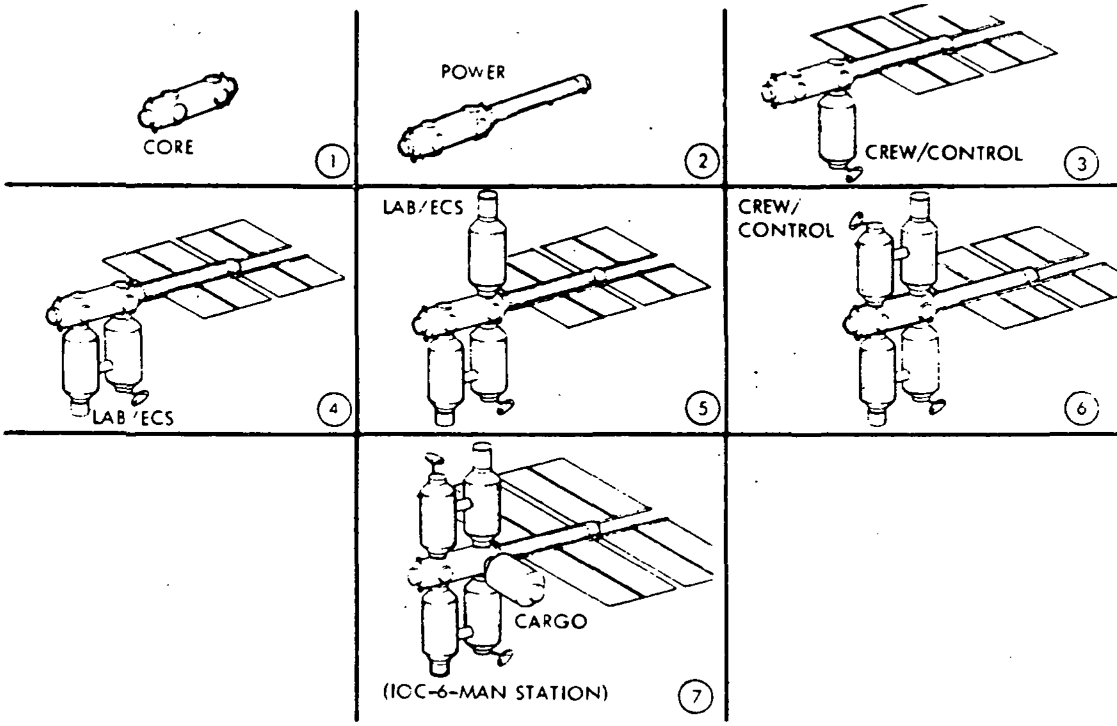


Figure 4-15. Initial Space Station Orbital Configuration

After five to six years of operations of the initial space station, additional modules are delivered to achieve a growth (12-man) space station capability. Growth capability is achieved by replacement of the solar array, addition of a second (short) core and the addition of two station modules with crew quarters and life support capability. Shuttle operations for the growth buildup phase are similar to those for buildup to the initial space station. The shuttle performs a rendezvous with the station, shuttle-station berthing is accomplished with the manipulator, and the station module is removed from the cargo bay and berthed to the appropriate station docking port. The space station configuration at each stage of the buildup is shown in Figure 4-16.

Shuttle Module Delivery Capability

The shuttle design reference mission (DRM) provides the capability to deliver a 25,000-pound payload to a 270-nautical mile, 55-degree inclination orbit. The capability also exists to return an equivalent payload (e.g., delivery and return of cargo modules). This capability is associated with routine space station operations and is, therefore, based on a shuttle mission profile which includes rendezvous and berthing operations. These operations are not required for delivery of the first space station module, resulting in a decrease in the on-orbit ΔV requirements. The reduced ΔV requirements decrease the propellant requirements (ACPS and OMS) by approximately 4725 pounds, permitting a corresponding increase in the first module

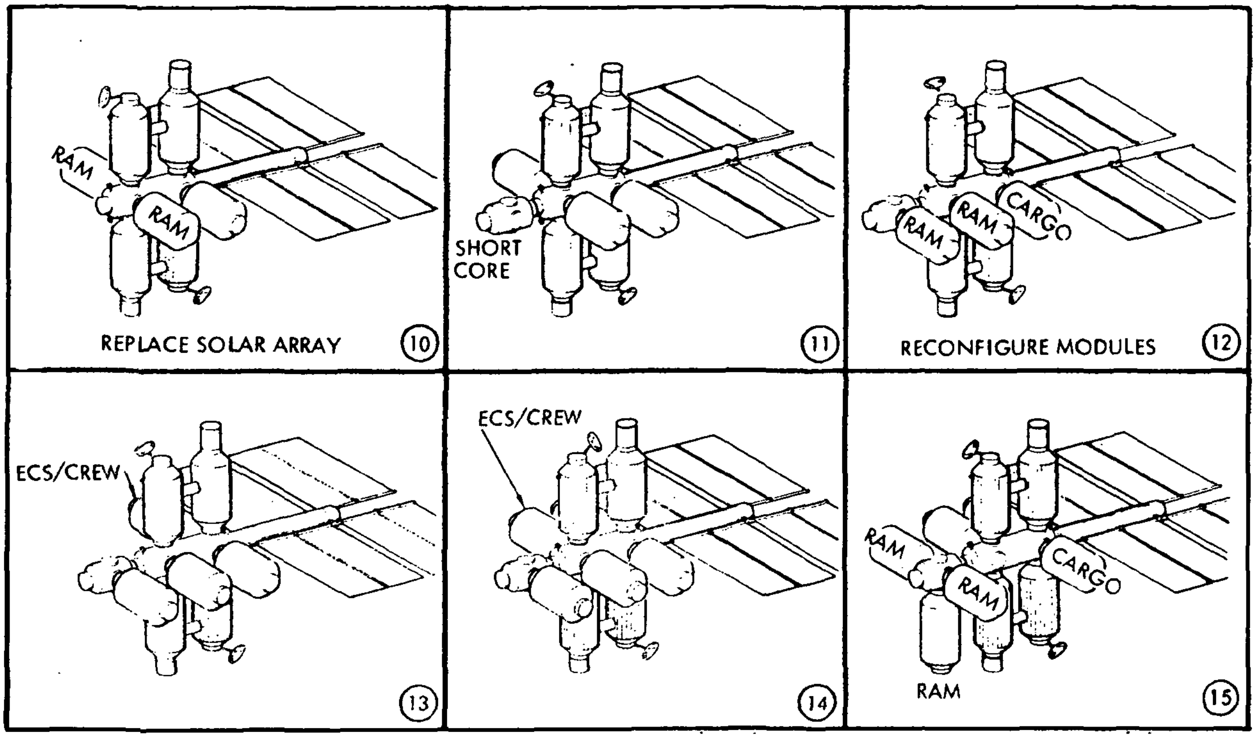


Figure 4-16. Growth Space Station Buildup

weight. The corresponding payload increase, illustrated in Figure 4-17, permits the delivery of a 29,725-pound payload on the first module launch (including shuttle tariffs and weight growth margin allowance).

The source of the propellant reduction is shown in Table 4-1, which shows the shuttle DRM on-orbit propellant requirements, discussed in Section 2, and the reduced requirements associated with the first module delivery. The total shuttle DRM propellant requirement is 27,730 pounds including 4538 pounds for rendezvous and 467 pounds for berthing. The propellant requirements for the first module launch is reduced to 23,005 pounds by the elimination of the rendezvous and berthing propellant requirements while increasing the orbit injection propellant requirement. The increased orbit injection propellant is required to permit delivery of the first station module to 274 nautical miles since orbit makeup is not performed during the early phases of space station buildup. The first module is delivered to 274 nautical miles and allowed to decay during the first three months of the buildup operations.

Additional propellant reductions, and thus payload increases, could be achieved by further reducing the on-orbit maneuver requirements. The capability for five days of stationkeeping was retained (694 pounds of ACPS propellant) although the baseline space station mission profile requires only one day. Also, the capability to retrieve and return the first module was retained to permit return of the module in the event it cannot be fully activated and its operability verified on-orbit. Elimination of this capability would eliminate the reberthing propellant requirement(622 pounds of ACPS propellant) and reduce the deorbit, reentry, and entry propellant requirements.

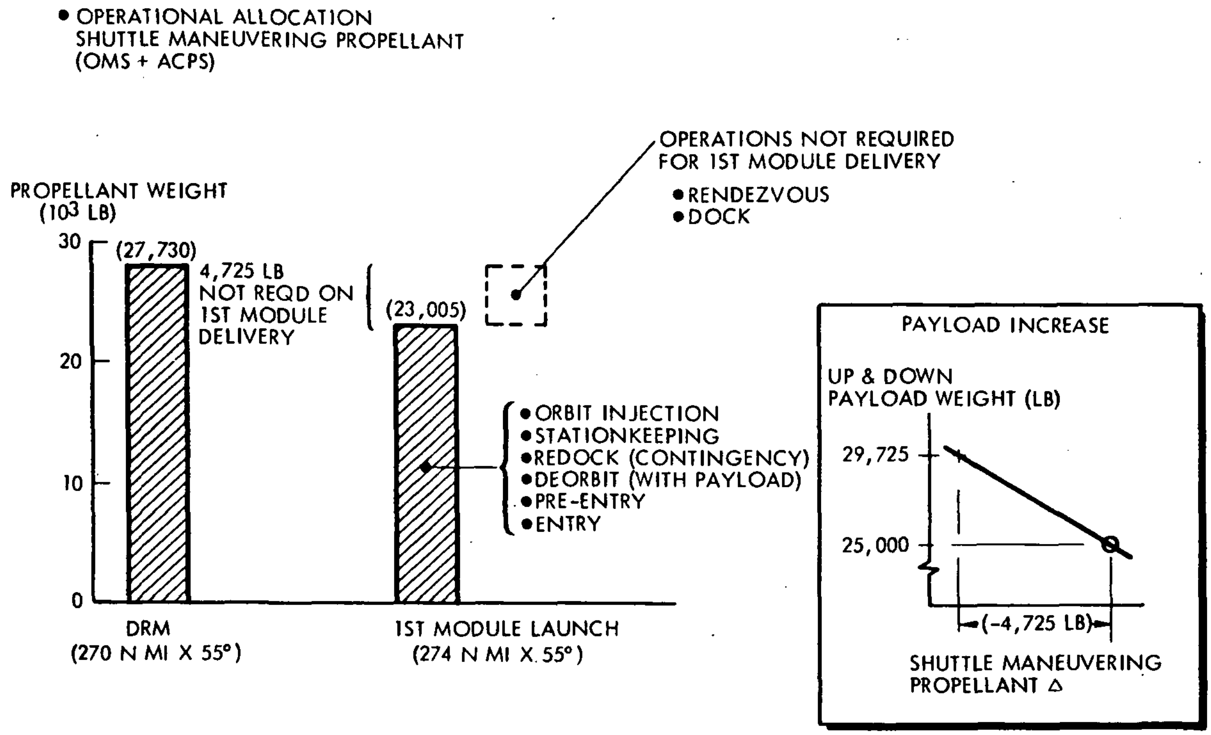


Figure 4-17. Shuttle First Module Launch Capability

Table 4-1. On-Orbit Propellant Requirements

Mission Phase	On-Orbit Propellant Requirements			
	Shuttle DRM			First Module Delivery
	ACPS (lb)	OMS (lb)	Total (lb)	Total (lb)
Orbit injection	751	10,311	11,062	11,342
Rendezvous	1,242	3,296	4,538	-
Berthing	467	-	467	-
Stationkeeping (5 days)	694	-	694	694
Reberthing	622	-	622	622
Deorbit	254	8,744	8,998	8,998
Preentry	149	-	149	149
Entry	1,200	-	1,200	1,200
Total	5,379	22,351	27,730	23,005

Associated with the delivery of the space station modules are support items which must be charged against the shuttle payload. During buildup of the modular space station, these tariffs vary from 1264 pounds for the core module to a maximum of 2764 pounds for the power module. The tariffs for all modules and the tariff items are defined in Table 4-2. These tariffs effectively reduce to shuttle payload since the identified items are not inherently provided by the shuttle. As an example, delivery of the core module imposes a 1264-pound tariff. The core module is the first station module for the selected buildup sequence. Therefore, the maximum allowable weight of the core module (including weight growth margin allowance) is 28,461 pounds. The corresponding maximum allowable module weights for all space station modules are also shown in Table 4-2. The weights shown, with the exception of the core module, are based on a 25,000-pound payload capability and, therefore, include any weight growth margin allowance.

Table 4-2. Shuttle Tariffs

Tariff Item	Tariff Weight (lb)					
	Core	Power	SM-1	SM-2	SM-3	SM-4
2 crew	400	400	400	400	400	400
2 crew provisions	300	300	300	300	300	300
2 PLSS and 2 PGA	354	354	354	354	354	354
Passenger provisions	63	155	190	160	160	166
Leakage makeup O_2 and N_2	0	165	180	210	210	210
Shuttle EPS reactants	50	365	495	383	383	405
Delta tank weight	97	425	425	425	425	425
MSS shuttle adapter	na	600	na	na	na	na
Total	1,264	2,764	2,344	2,232	2,232	2,260
Maximum allowable module weight (including growth margin allowance)	28,461	22,236	22,656	22,768	22,768	22,740

Space Station Support Requirements

The shuttle will be required to support routine operations of both the initial and the growth space stations once the respective buildup operations are completed. The required support operations include the delivery and return of space station crewmen, experiment equipment, consumables, spares, and RAM's. The scheduling of these operations depends on the scheduling of the space station operations defined by the mission sequence plan. The mission sequence plan, presented in Figure 4-18, provides the phasing of all program elements including the shuttle support requirements. The mission sequence plan also defines the schedule for delivery of the station modules, delivery and return of cargo modules, and delivery and return of space station crewmen. It also defines the scheduling of all functional program elements (FPE's) identified in the 1971 Blue Book. The logistics support

Figure 4-18. MSS Mission Sequence Plan

requirements, which will be discussed in further detail, are summarized as well as the scheduling of all shuttle launches.

The resultant operational program has a duration of approximately 16 years from the first space station module launch to the return of all crewmen after the completion of experiment operations. Six months are required for initial station buildup with IOC occurring in January 1982. The station operates at a six-man level for five years while experiments are conducted in six of the seven experiment disciplines. Initial operations are primarily conducted in the general-purpose laboratory (GPL); however, the first attached RAM is introduced midway into the first year of experiment operations and the first detached RAM is launched in the fourth year. The mission sequence plan as presented was developed assuming each FPE is operated for the minimum duration consistent with the achievement of significant objectives. In this manner, each FPE is accommodated at the earliest possible date.

The total logistics requirements for the space station operations and the experiment program defined by the mission sequence plan are shown in Table 4-3. Approximately 1900 pounds per month are required for basic operations of the initial space station, whereas 3600 pounds per month are required for the growth space station. Based on the experiment scheduling previously identified, approximately 1000 pounds per month are required for operations of the initial space station experiments and 1800 pounds per month for the growth space station. The experiment logistics requirements shown are an average value of the requirements for consumables and experiment equipment which must be delivered during the operation of the space station. An additional logistics requirement is imposed by the need for oxygen and nitrogen for emergency operations. The resultant cumulative requirements are shown in Figure 4-19, where the lower line represents the cumulative requirements for basic station operations and the upper line represents the total including experiment operations.

The resultant shuttle requirements for support of the space station are summarized in Table 4-4 and Figure 4-20 in terms of the missions required for the delivery of station modules, crew and cargo, RAM's and RAM support sections. Six shuttle missions are required for delivery of the initial space station modules and an additional four shuttle missions are required for buildup to the growth space station including one launch for replacement of the solar array. A total of 74 shuttle missions are required for the delivery of crew and cargo. The shuttle launch frequency for delivery of crew and cargo is dictated primarily by considerations of crew rotation since these missions occur at a frequency which permits the concurrent delivery of the cargo necessary for the support of the station and experiment operations. The logistics capability for crew and cargo delivery is based on a cargo module capacity of approximately 11,800 pounds per flight for shuttle missions which concurrently deliver up to six crewmen. As previously noted, the cargo requirements are approximately 2900 pounds per month for the initial space station and 5400 pounds for the growth space station.

Table 4-3. Average Cargo Requirements

Logistics Item	Resupply Requirement (lb, 30 days)	
	Initial	Growth
Clothing	76	152
Linens	62	124
Grooming	10	20
Medical	15	30
Utensils	56	112
Food	650	1300
Gaseous storage		
Oxygen	3	3
Nitrogen	247	377
Water	369	716
Special life support, LiOH	10	10
Water management	40	81
Atmospheric control	217	434
CO_2 management	57	113
Waste management	27	53
Hygiene	11	21
Spares	34	69
Subtotal	1884	3615
Average experiment resupply	1000	1800
Total 30-day average	2884	5415
Up-down emergency (96 hours)		
Oxygen	404	633
Hydrogen	23	36
Total emergency	427	669

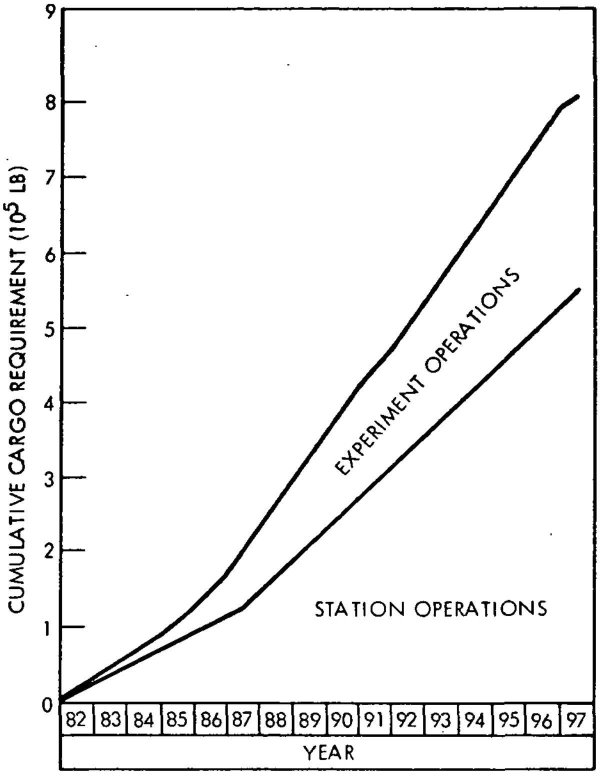


Figure 4-19. Cumulative Cargo Requirements

In addition to the shuttle missions required for the delivery of the station modules and for crew and cargo delivery, additional shuttle missions are required for the delivery of RAM's and the support sections necessary for the operation of detached RAM's. For the experiment program previously identified, only two support sections are required to support detached RAM operations. These support sections are returned to earth periodically for refurbishment and redelivered to orbit for further utilization.

The resultant total shuttle support requirement is 36 flights for the initial space station and 99 flights for the growth space station including the four shuttle launches for delivery of the station modules necessary for buildup to the growth space station. The resultant launch frequency is approximately one every eight weeks for the initial space station and one every six weeks for the growth space station.

Space Station Rescue

The space shuttle must be capable of reducing the space station crew within 96 hours (station design requirement) of notification that rescue is required. The time required for the shuttle to conduct rescue is a function of the launch preparation time, the time to the next available launch opportunity, the rendezvous time, and the time required to complete berthing and personnel transfer operations.

Table 4-4. MSP Statistical Summary

	Calendar Year																
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
Station Modules																	
Up	6						4										
Down							1										
Cargo Modules																	
Up		5	5	3	3	4	4	6	5	5	5	5	5	5	5	5	3
Down		4	5	3	3	4	4	6	5	5	5	5	5	5	5	5	4
RAM's																	
Up		1	1	1	2	1	3	4	4	1	3	1	2	1		1	
Down			2		1	1	1	4	3	3	3	1	1	1	1	2	2
Support Sections																	
SS-1																	
SS-2																	
Crewmen																	
Up	*	30	30	18	18	24	26	24	24	24	24	24	24	24	24	24	12
Down		24	30	18	18	24	20	24	24	24	24	24	24	24	24	24	24
No. Shuttle Flights	6	6	8	4	7	5	12	12	11	9	11	7	8	7	7	8	7

Initial Buildup | Initial Operations -6 Men | Growth Buildup | Growth Operations -12 Men

*Excludes crew for buildup.

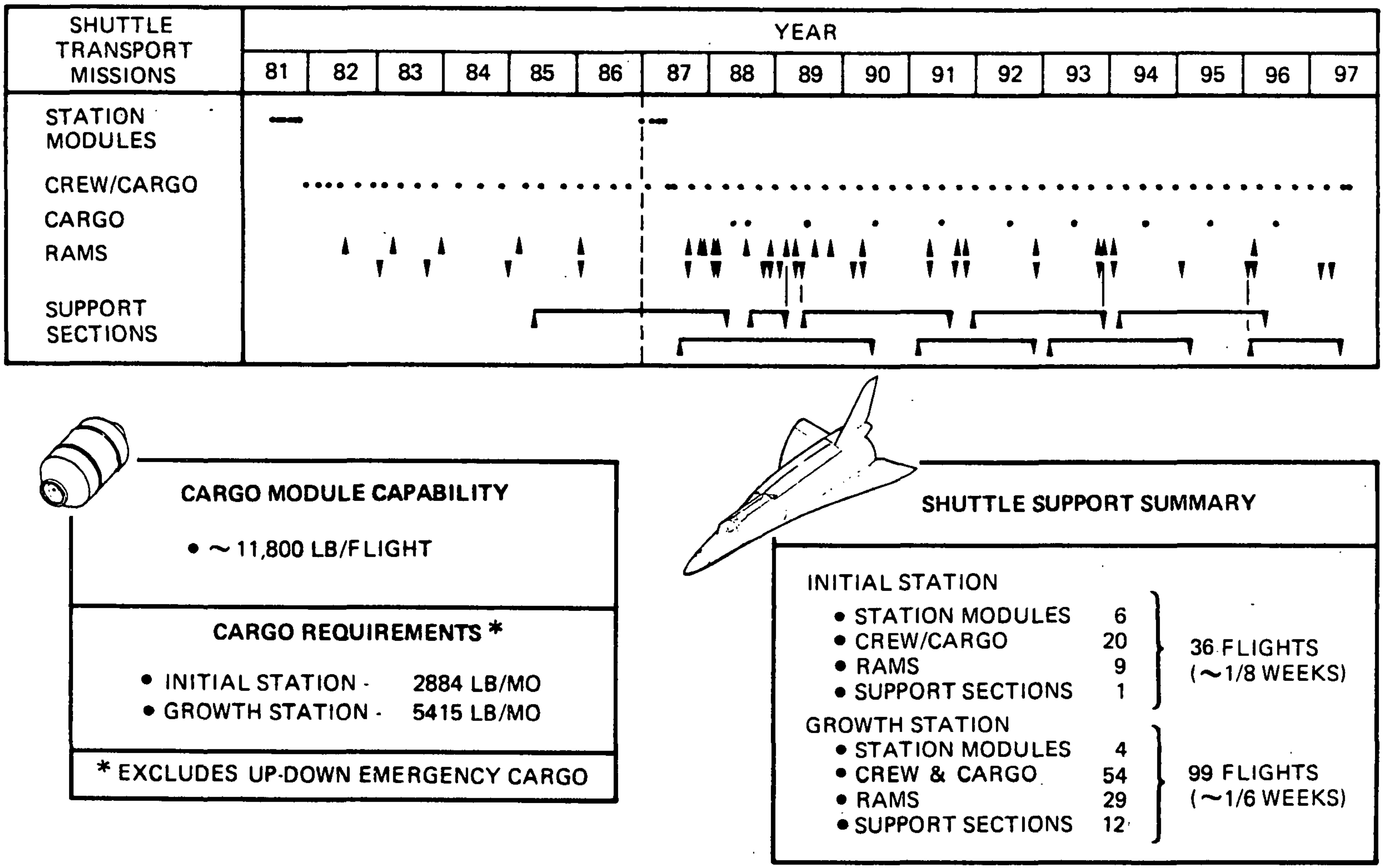


Figure 4-20. Shuttle Support Requirements Summary

The time to the next available shuttle launch opportunity, illustrated in Figure 4-21, depends on the time of notification of need. Two launch opportunities exist each day as the shuttle launch site passes through the space station orbit plane; a northeast launch opportunity followed by a southeast opportunity approximately nine hours later. If the southeast opportunity is missed, it is approximately 15 hours until the next (northeast) opportunity.

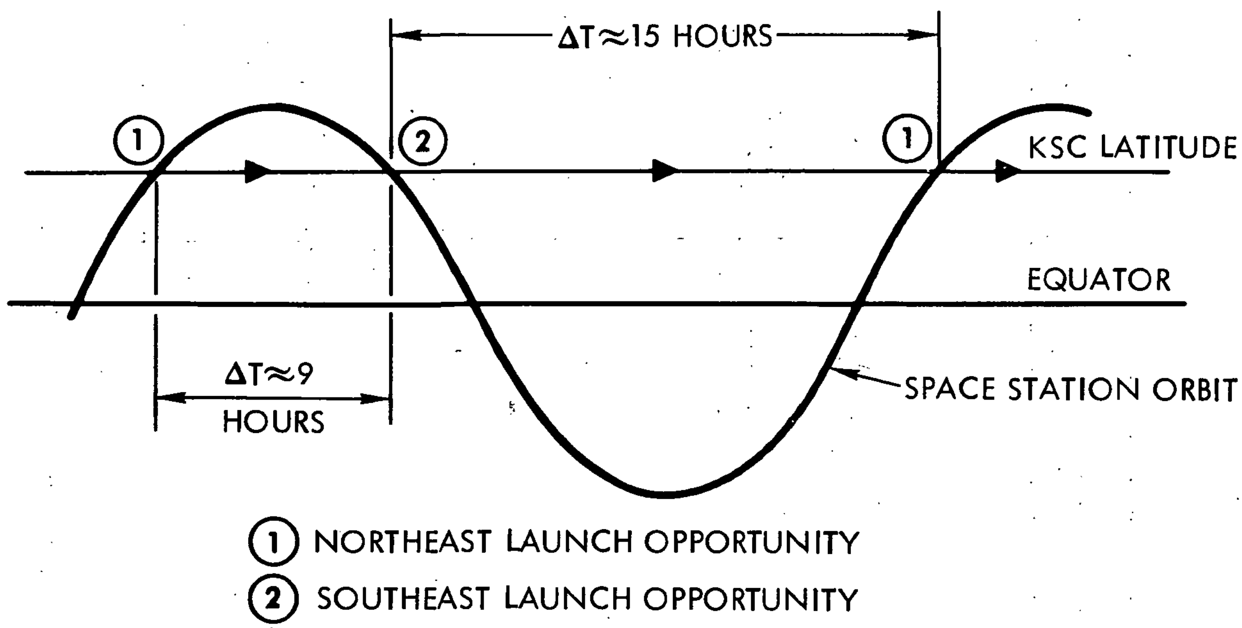


Figure 4-21. Shuttle Launch Opportunities

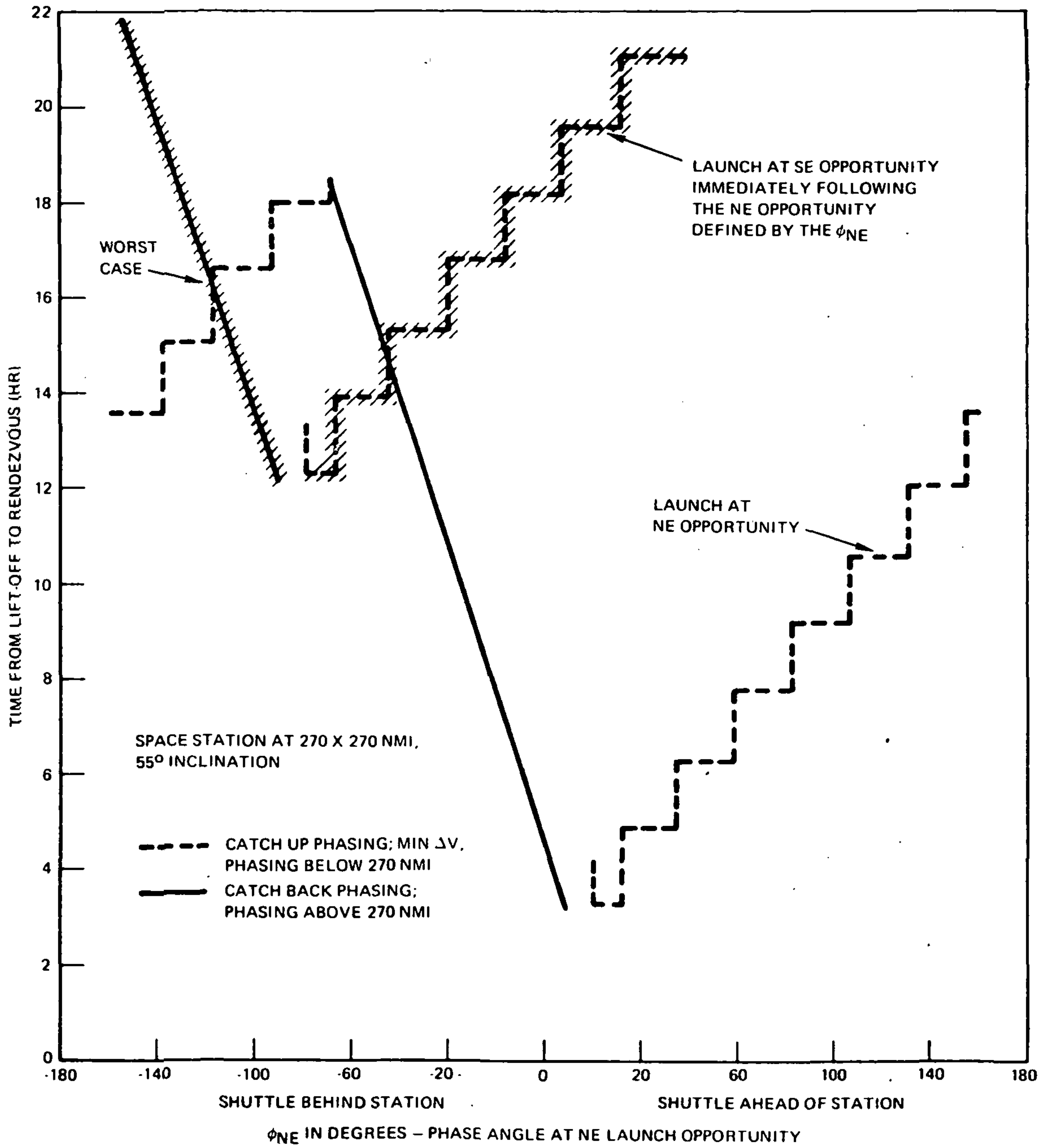


Figure 4-22. Time to Rendezvous Using Catchup and Catchback Phasing

The time to rendezvous depends on the space station phase angle (ϕ) at the time of shuttle launch. Two techniques of phasing and the resulting minimum time from liftoff through rendezvous for the worst-case conditions of phase angle between the shuttle and the space station at launch have been evaluated:

1. Natural (Catchup) Technique - The shuttle orbits in the same plane at an altitude lower than the target (space station) until it is in a position slightly behind the space station so that the necessary Hohmann transfer to the target altitude will result in rendezvous. This technique results in a worst-case time of 25.2 hours from liftoff to rendezvous.

2. High (Catchback) Phasing Technique - The orbiter spends ΔV to place itself in an orbit higher than the target (larger period of rotation) so that it can arrive at the desired phase for achieving rendezvous. This technique, used with natural catch-up, reduces the worst case to approximately 18.5 hours when 1865 fps on-orbit ΔV capability of the orbiter is used.

The catchup technique of phasing, which does not require any increase of OMS ΔV budget, can be employed on any shuttle mission to the space station with payloads not exceeding the maximum capability. Thus, it is always usable for a space station rescue. The catchback technique can be used on any mission including rescue if the required payload allows for carrying the increased amounts of OMS propellant needed for the ΔV for high phasing orbits.

To determine the time to rendezvous for rescue missions utilizing catchup or catchback phasing, time to rendezvous as a function of a given phase angle at launch was calculated for each phasing technique. From Figure 4-22, it can be seen that the worst-case rendezvous time requirement for a northeast launch opportunity is 16.2 hours with the utilization of the catchup or the catchback phasing techniques.

There is a possible reduction of time for the worst case that would result from launching at the opportunity immediately following the first launch opportunity. Waiting for this second opportunity would save time if the wait for the second opportunity plus the time from liftoff to rendezvous were less than the time from liftoff to rendezvous using the first launch opportunity.

Figure 4-22 illustrates how the rendezvous time for some values of ϕ can be reduced by waiting for the next launch opportunity. In particular, when the northeast launch opportunity is the first usable one, there is a reduction of time to be realized by waiting for the next southeast launch opportunity. For value of ϕ_{NE} between -138^o and -66^o it is beneficial to wait for the southeast launch opportunity. Also, the maximum rendezvous time is reduced from 18.5 hours at $\phi_{NE} = -90^o$, using the northeast launch, to 16.2 hours at $\phi_{NE} = 138^o$, using the following southeast launch.

When the southeast launch opportunity is the first usable one, there is no saving in rendezvous time achieved by waiting for the northeast launch opportunity, and the maximum or worst-case rendezvous time is 18.5 hours. This may be seen by extrapolation from the data of Figure 4-22. If the figure's abscissa were ϕ_{SE}, the lower curve would be for the southeast launch opportunity, and the upper curve would be for the northeast launch opportunity. However, the upper curve would shift up, not nine hours, but 15 hours, to wait for a northeast launch. Also, the upper curve would be shifted to the left 235° or actually 125° to the right. Thus, its minimum point would be at approximately $\phi_{SE} = 125^{\circ}$ and time to rendezvous 18 hours. No intersection of the two curves would occur; thus there is no advantage in waiting for the northeast launch.

Shuttle Abort

The shuttle abort capability depends on the mission phase during which the abort requirement occurs. Table 4-5 summarizes the abort mode as a function of mission phase and failure mode or hazard which produces the abort requirement. In some cases, the abort mode depends on where the abort requirement occurs during the mission phase. For these cases, the alternative abort modes have been identified.

During prelaunch, the abort mode is the rapid egress of the passengers via the access arm and launch tower. Egress time is a function of the access arm status (either in standby or retracted). Egress times are as follows:

	Prior to T - 2 min.	After T - 2 min.
Orbiter crew	$\leq$ 60 sec.	$\leq$ 110 sec.
Passengers	$\leq$ 85 sec.	$\leq$ 130 sec.

During mated ascent there are various abort conditions arising as a result of the time of failure of the booster. Basically, the orbiter (with cargo module or station module) will perform a flight to an alternative landing site located in the eastern United States.

Following mated ascent and the normal staging, the orbiter engines ignite with subsequent boost to orbit (50 by 100 nautical miles) injection. At staging, the critical abort mode is a condition with one engine out. At this point, there exists the capability for a once-around abort to an alternative landing site. A typical trajectory for a once-around abort from KSC is illustrated in Figure 4-23, which shows a once-around abort with orbiter landing in southern Texas; the location depends on the specific staging conditions. From this location, the orbiter must ferry itself back to KSC for subsequent refurbishment and launch. The ferrying operation is accomplished by use of the orbiter air-breathing engine system (ABES). The ferry operation requires the removal of the shuttle payload from the cargo bay at the once-around landing site. This imposes a requirement for payload ground support equipment at the site and the capability to transport the payload to a refurbishment site.

Table 4-5. Abort Capability Summary

Mission Phase	Failure Mode or Hazard	Abort Mode
Prelaunch	1 Major propellant leak or fire	Rapid egress
	2 Any functional subsystem failure	Egress
	3 Failure of any booster engine to ignite	Egress
	4 Explosion	Potential catastrophic loss of vehicle/ facility/crew
Mated Ascent	1 Leak or fire in booster or orbiter	Booster - recover at launch site Orbiter - recover at launch site OR Perform once-around abort to alternative landing site
	2 Subsystem failure to fail-safe level	Burn to booster propellant depletion
	3 Loss of booster engines	Complete mission OR Burn to booster propellant depletion OR Fly alternative ascent trajectory
	4 Total loss of booster thrust	
Orbiter Ascent	1 Leak or fire in orbiter	Once-around abort to launch site
	2 Subsystem failure to fail-safe level	Once-around abort OR Abort to orbit
	3 Loss of thrust or TVC from single orbiter engine	Once-around abort OR Abort to orbit
	4 Loss of TVC from two orbiter engines	
	5 Total loss of thrust	Catastrophic loss of orbiter OR Once-around abort with ACPS
On-Orbit/Entry and Atmospheric Flight	1 Fluid/propellant leak or fire	Terminate mission and perform deorbit OR Shuttle rescue
	2 Subsystem failure to fail-safe level	Terminate mission and perform deorbit OR Recover at landing site

Figure 4-23. Once-Around Abort Trajectory

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5. INTERFACE REQUIREMENTS

This section specifies the functional and physical interface requirements between the modular space station and the shuttle orbiter for ground and on-orbit operations. Ground operations interfaces include the structural attachments between the MSS modules and the cargo bay, payload power, and monitoring of payload caution/warning and subsystem status signals subsequent to insertion in the cargo bay. On-orbit operations interfaces include physical interfaces at the orbiter docking port and in the cargo bay, and operational interfaces between MSS subsystems and the orbiter. Safety and reliability criteria are defined for the MSS-shuttle operations.

GROUND OPERATIONS INTERFACES

The MSS ground interface requirements which have been considered are those which significantly affect ground operations or which are implemented as a direct result of ground operations requirements. These areas are identified in Table 5-1 and discussed in detail in the following paragraphs.

Table 5-1. Ground Interface Areas

Interface Areas	Core Module	Power Module	SM-1	SM-2	SM-3	SM-4	Cargo Module	RAM
Module installation	x	x	x	x	x	x	x	x
Retention	x	x	x	x	x	x	x	x
Command/control and monitor	x	x					x	x
High-pressure gas fill and vent	x	x					x	
Cryo loading								x
Perishable loading							x	
Interface verification	x	x	x	x	x	x	x	x
Servicing access	x	x					x	

Module Installation and Removal

Hoisting slings will be required to install all modules in the orbiter's payload bay. Removal is primarily required for the cargo module and the RAM's. The ends of the slings must be designed to attach to the module's trunnion support structure. A simple clevis and pin arrangement is envisioned for this function.

Payload Retention

Figure 5-1 shows the variation between the payload support locations provided by the shuttle orbiter and those required to support the MSS core and station modules in the orbiter bay. As these retention points do not coincide (except at the forward one) either an external beam that bridges between the middle and aft side supports or a reinforcement of the module structures to accept loads introduced at the shuttle-defined cargo support locations must be provided with its attendant weight penalty.

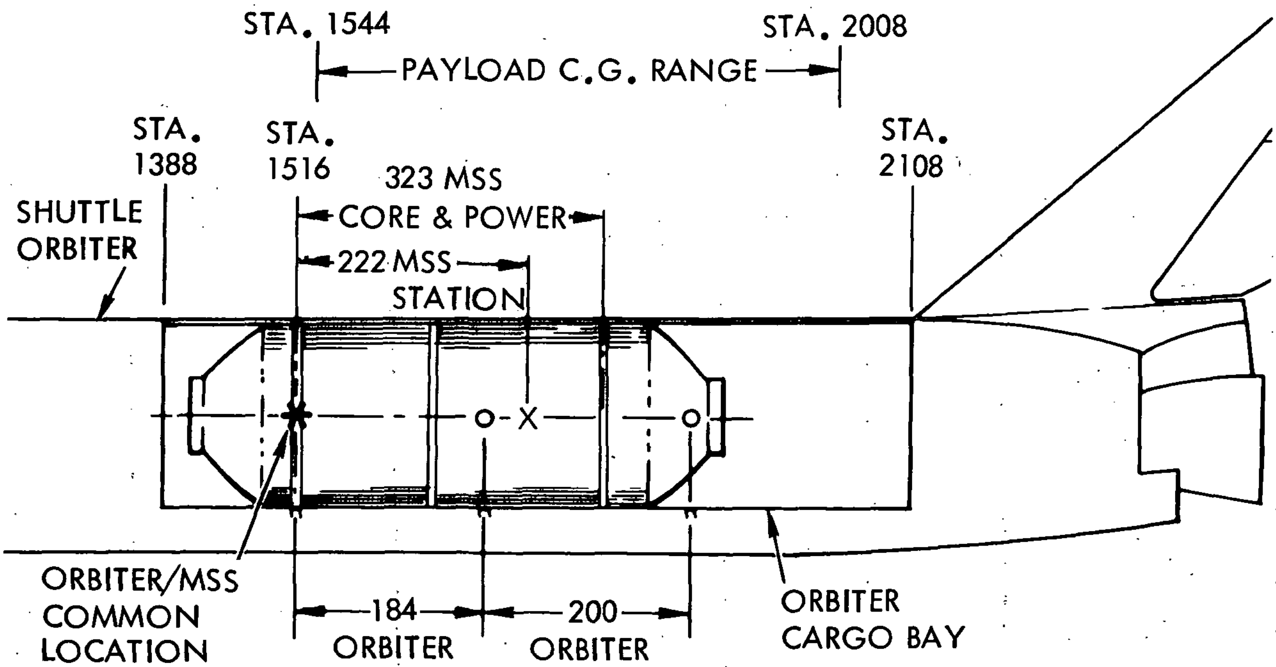


Figure 5-1. Variance Between Shuttle Cargo and MSS Module Support Locations

For the external beam concept, the weight penalty incurred will be about 320 pounds. Reinforcement of the MSS modules to accept the loads at the shuttle-defined support locations will result in an estimated weight increase of approximately 65 pounds for the station module and 466 pounds for the core module. Figure 5-2 illustrates the differences in the orbiter's payload retention system and that for the MSS module.

In the case of the MSS, the retention system reacts the major loads occurring in the X and Z directions during flight operations in a tangential direction to the pressure shell. Only the less significant lateral loads in the Y direction are reacted normal to the shell. However, the current shuttle orbiter has a three-point retention system that utilizes one center support located beneath the cargo with two side supports located on a common diameter. The orbiter bottom center support concept imposes a more severe loading condition on the station modules than does the MSS concept since flight loads are introduced into the pressure shells in a direction normal to the shell surface. The estimated structural weight increase for the single forward support concept is about 110 pounds.

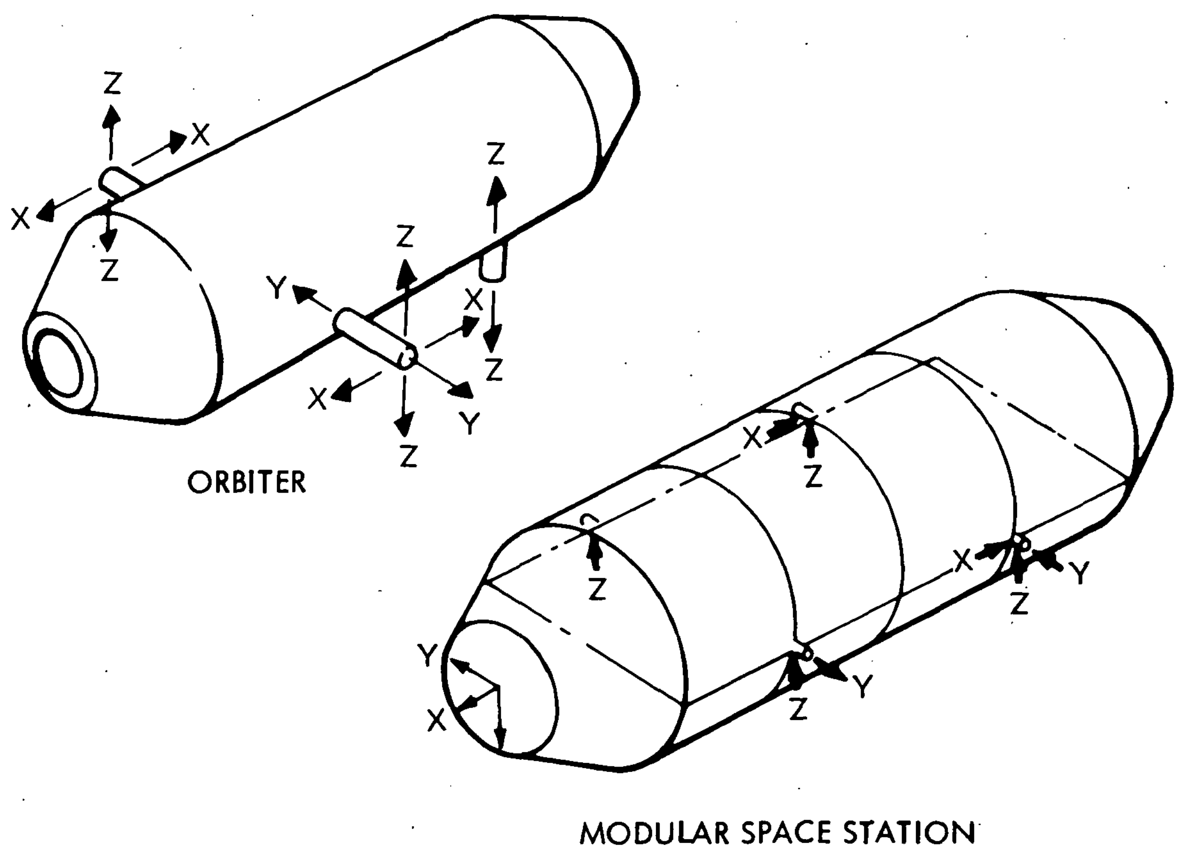


Figure 5-2. Payload Retention Systems

From these considerations, it may be concluded that:

1. The orbiter must provide multiple payload retention point locations to accommodate various payloads without imposing undue weight penalties.

2. The current three-point retention system adds unwarranted structural weight to the payload; hence, a four-point system should be adopted.

Payload Location

To retain the aerodynamic stability of the orbiter, the center of gravity of payloads must fall within prescribed limits while in the payload bay. For the NR orbiter, these limits, expressed in fuselage station numbers, are: station 1544 forward to 2008 aft. Referring to Figure 5-1, it is noted that the center of gravity for the MSS modules falls within these values and presents no problem to the orbiter.

Payload Retention Verification

Visual or remote verification that the payload trunnion retention latch mechanisms are in a flight safety condition is required. This may require special access panels in the orbiter structure or position indicator lights in the crew compartment.

Command Control and Monitoring

All MSS module interfaces for command control and monitoring will be implemented through the shuttle control system. The integrated command system will be checked out during VAB operations and will consist of a verification of the capability of the shuttle system to activate and operate the MSS modules. This will be the only verification for modules SM-1, SM-2, SM-3, and SM-4 since they will be launched dormant and will not contain any dangerous cargo.

Gas Tanks and Bottles

The power module and the core module do, on the other hand, contain gases which must be loaded at the pad. Fill and drain valves, vents, and circuits in these two modules will be monitored during the loading of hydrogen, nitrogent, and oxygen at the pad through the shuttle command and monitor system.

Interface Verification

In addition to the direct interfaces required for monitoring and control of active systems in the MSS modules, there are monitoring systems for the verification of the physical status of the module as it lies in the cargo bay. For example, tiedown latches, alignment indicators, and external gas detectors will be subject to periodic or continuous monitoring by the shuttle systems.

Servicing Access

Modules which have internal equipment which must be accessed during the time when the module is in the orbiter cargo bay presents an ingress-egress interface. The two modules principally involved in this requirement are the power and core modules. Basically, it is expected that situations may develop which will require access to the interior gas loading system. In such cases the installation must allow for the ingress and egress to these modules through the orbiter cabin. In addition, when this situation develops for any of the modules, the cabin air in the orbiter must meet the cleanliness requirements for the inside of the modules.

Normal operations will include the launching and retrieval of cargo and experiment modules. Ground interfaces during this phase will be similar to those related to the power and core module activities.

Additional requirements that will have to be accommodated will be the loading of perishables and the loading of cryogenics. Potential solutions include access provisions to these modules at the pad through the orbiter.

Common MSS-Shuttle GSE and Facilities

The common MSS-shuttle GSE and facilities have been analyzed to consist of the VAB, launch pad, shuttle safing area, and the cranes, elevators, and other servicing equipment utilized in these facilities. No MSS-peculiar requirements were identified. Specific usage of these GSE and facility items were discussed in Section 4.

ORBITAL OPERATIONS INTERFACES

Structures

The modular space station structural shell is required to withstand loads introduced at the end berthing ports due to an MSS-shuttle orbiter berthing operation. The shuttle orbiter velocity and alignment criteria for berthing to the MSS are shown in Table 5-2. Berthing interface load as a function of closing velocity is shown in Figure 5-3 for the MSS core and station modules.

Table 5-2. Shuttle Orbiter-MSS Berthing Criteria

Parameter	Berthing*
Centerline miss distance (in.)	±2.0
Miss angle (deg.)	±1.0
Longitudinal velocity (maximum) (fps)	0.05
Laterial velocity (maximum) (fps)	0.05
Angular velocity (maximum) (deg./sec.)	0.10

*Berthing is defined as employing a manipulator to bring the elements together slowly and thus requires no attenuation

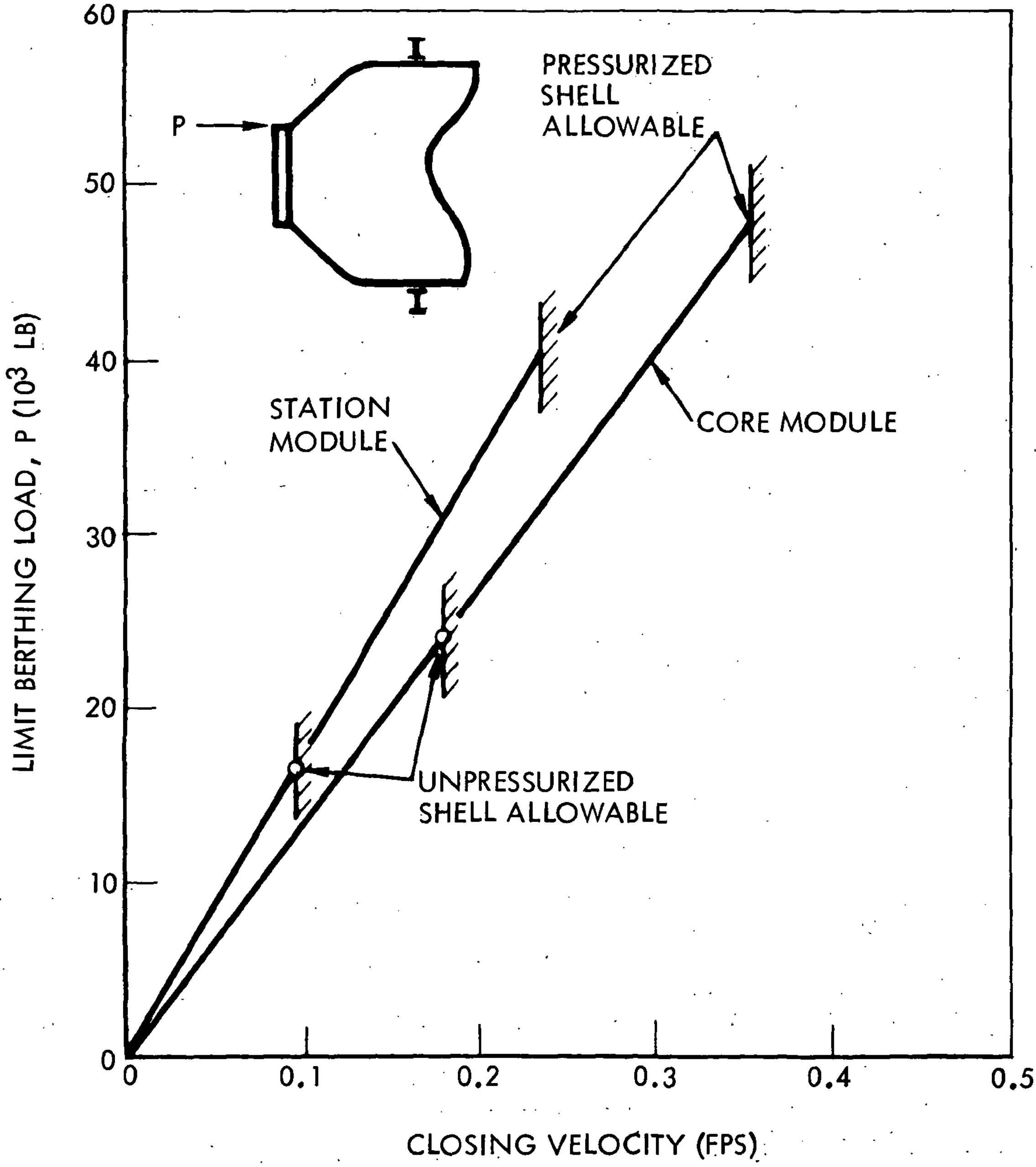


Figure 5-3. Berthing Load Versus Closing Velocity

The variation of berthing load with closing velocity was estimated using the axial stiffness characteristics of the structural shells. The capability of the modules to withstand berthing loads without buckling failure of the structural shell also is indicated in Figure 5-3 for both pressurized and unpressurized conditions. These allowables were estimated based on a misaligned berthing operation that introduces the berthing load over a localized region of the interface. From Figure 5-3 it can be seen that the velocities that will induce loadings equal to the structural capability are 0.095 fps and 0.235 fps for an unpressurized and pressurized station module, respectively, and 0.18 fps and 0.355 fps for the core module. All of these berthing velocity capabilities are well above those listed in the criteria of Table 5-2.

Although a berthing concept is incorporated into the preliminary MSS design, adequate space has been provided at each port to accept an attenuation system that will absorb higher energy levels associated with the docking closing velocities.

Another source of load application to the MSS during orbital operations while berthed to the shuttle orbiter results from activation of the shuttle attitude control propulsion system engines (Figure 5-4). Table 5-3 shows the interface loads[1] that result from firing two 2100-pound thrust shuttle orbiter ACPS engines. These interface loads induce a 20,000-pound ultimate load in the berthing port latches that retain the orbiter to the MSS. An additional 11,000 pounds per latch occur due to internal pressure to bring the total load per latch to 31,000 pounds. The load capacity of the current MSS berthing port latches is estimated to be about 13,000 pounds, thus a substantial weight increase would be incurred in the MSS to incorporate the higher loads.

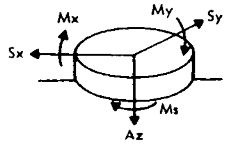
The maximum ACPS engine thrust level that will not induce berthing latch loads greater than their current design capacity is about 210-pound thrust per engine (two engines firing). As will be seen later, the level of 210-pound thrust per engine is more than adequate to perform the attitude control maneuvers required while the shuttle orbiter is berthed to the MSS.

Berthing Adapter

Figure 5-5 shows the adapter required to interface the 80-inch diameter MSS berthing port with the shuttle orbiter 60-inch diameter berthing port. The 32-inch adapter length is primarily required to accept the shuttle orbiter door which opens externally. The weight of the adapter is about 600 pounds. This figure includes the weight of structure, environmental protection, electrical power system, and environmental control system. Shuttle capability to vent the adapter to vacuum is required during station buildup. The adapter includes the necessary gas, fluid, and electrical lines, as illustrated in Table 5-4, to support the MSS during buildup. These same services must be provided by the orbiter at the berthing port.

[1] Space Shuttle System Loads and Dynamics Data Book, NR Space Division, DB 2 2.2-14000 (March 1971).

Table 5-3. Berthing Port Loads



Load Condition	Force x 10^{-3} (lb)			Moment x 10^{-6} (in.-lb)		
	Sx	Sy	Az	Mx	My	Mz
±X translation	∓2.33		±1.07		±1.03	
±Y translation		∓2.60		±2.62		±0.64
-Z translation	-1.05		2.45		1.16	
+Z translation	-0.46		-3.88		0.51	
±Roll rotation		∓0.50		±0.11		±0.09
+Pitch rotation	1.5		1.45		-1.66	
±Yaw rotation		∓1.08		±1.32		∓0.87

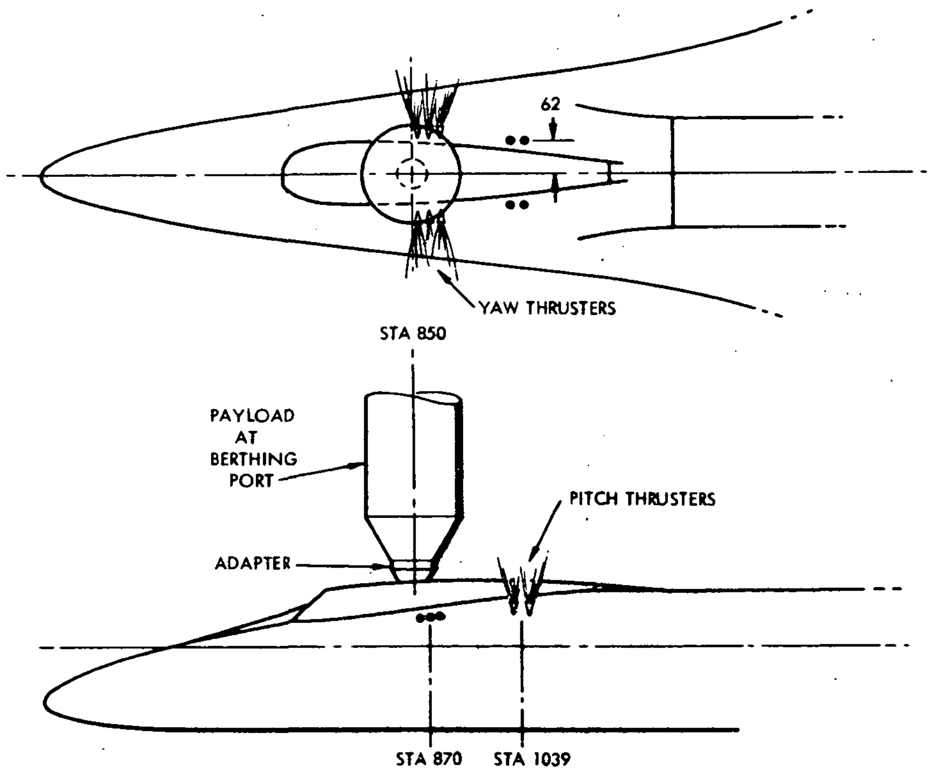


Figure 5-4. MSS-Orbiter ACPS Configuration

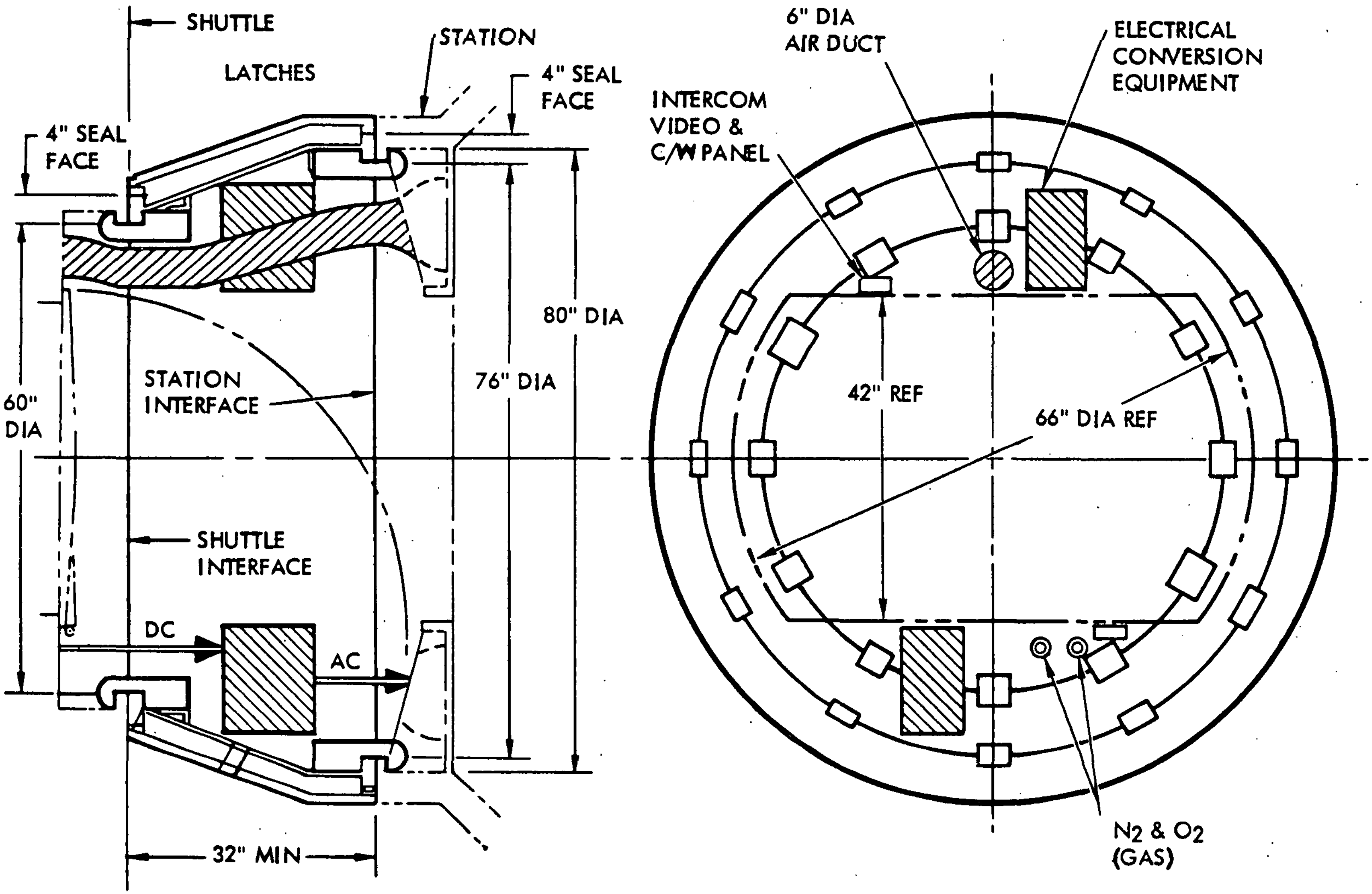


Figure 5-5. Station-Shuttle Berthing Adapter

Table 5-4. Adapter Interface Provisions

Item	Purpose
N_2 line	Supply MSS with repressurization gas from tanks in cargo bay
O_2 line	Supply MSS with O_2 for metabolic consumption and leakage makeup
Air duct	Six-inch air duct for MSS atmosphere recircularization and revitalization
Electrical power	Redundant electrical wiring to provide power and control of power supplied to MSS
Communications panel	Connects to shuttle interface unit for MSS caution/warning, voice, and CCTV, and for orbiter caution/warning signals

The method of manipulator attachment to the MSS modules is shown in Figure 5-6. Four equally spaced attachment points are located on a circumference at the midpoint of the modules. These attachments are to be designed to accept the manipulator end.

Environment Control/Life Support System (ECLSS)

Buildup Phase

The MSS requires ECLSS support from the orbiter during buildup primarily to allow manned shirtsleeve access for MSS checkout. Atmosphere revitalization, pressure control, support for suited operations, and monitoring interface requirements with the shuttle are described. Additional description of the MSS ECLSS buildup provisions is included in the MSS Preliminary System Design, Volume 4.

Atmosphere Revitalization of the MSS. The orbiter is required to provide atmosphere revitalization of the MSS to accommodate two men for checkout while berthed to the MSS for periods up to five days. The following revitalization functions are involved:

1. Carbon dioxide - 5.0 mm Hg partial pressure nominal, 2.25 pounds CO_2/man-day generation
2. Humidity - 8 to 12 mm Hg partial pressure, 3.4 pounds H_2O/man-day generation
3. Contaminants - 0.1 PPM* threshold limit value

*Parts per million by volume

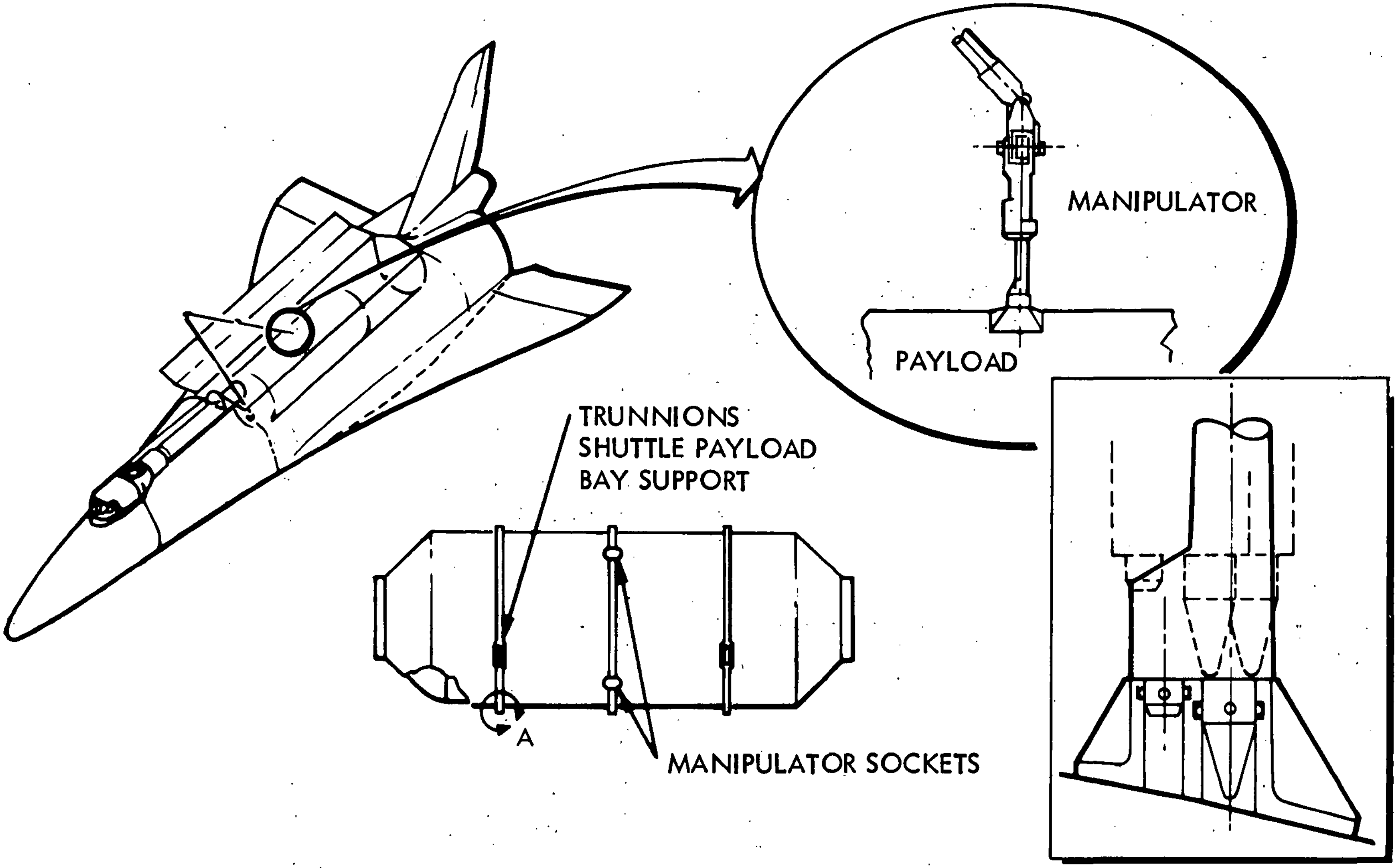


Figure 5-6. Representative Manipulator-Payload Attachment

Atmosphere revitalization support from the orbiter ECLSS is required while berthed to the MSS at each phase of the buildup of the initial MSS. The MSS atmosphere is supplied to the orbiter via a duct in the adapter at the airlock as shown in Figure 5-7.

The primary rationale for this interface is that the capability already exists in the orbiter ECLSS to accommodate the payload crew when they are in the orbiter. Hence this function can be provided to MSS at no penalty. Installation of LiOH and charcoal in the core module for this function would not be a significant penalty to the MSS; however, a condensing heat exchanger for humidity control would be significant.

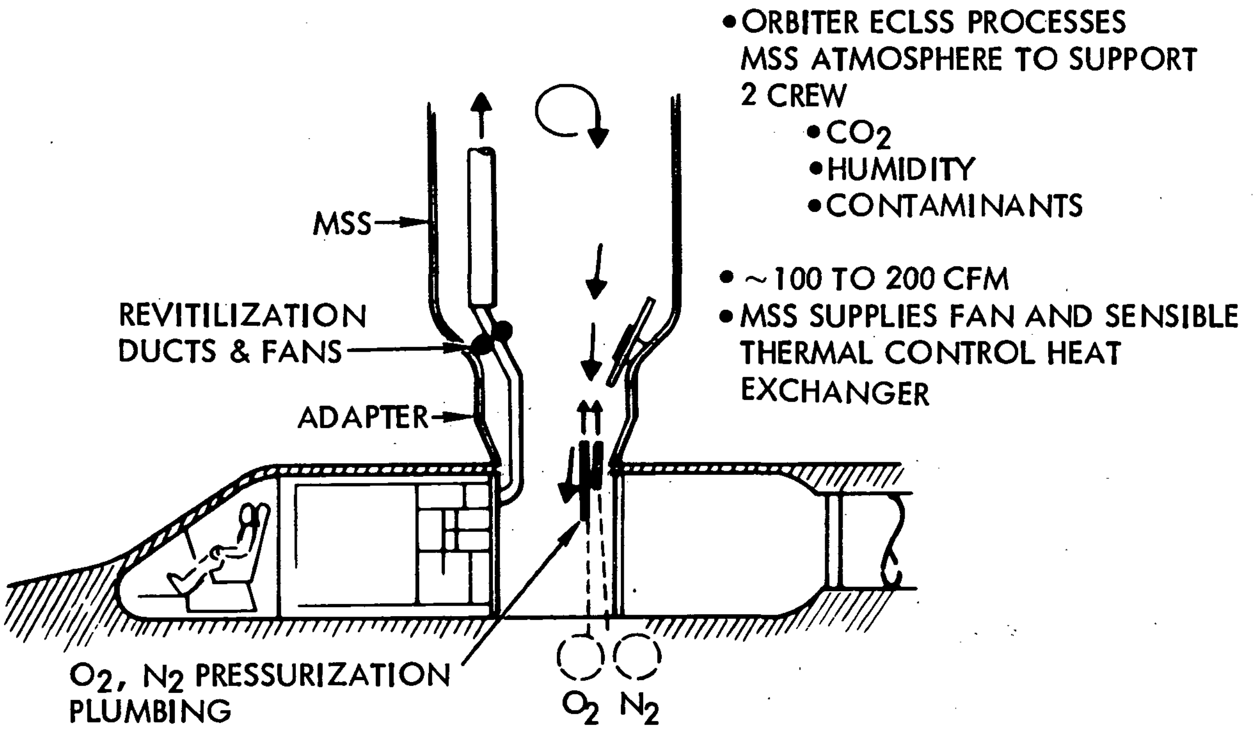


Figure 5-7. Atmosphere Revitalization of MSS

Crew Life Support. Food, water, hygiene provisions, and fecal, urine, and trash collection are required to support the two MSS crewmen for periods up to seven days. Since these facilities exist on the orbiter, the orbiter can provide them, but the expendable weights must be charged against the MSS payload. The MSS design values for this support are:

1. Food, package - 2.7 pounds/man-day
2. Water, metabolic - 6.32 pounds/man-day
3. Water, hygiene - 4.0 pounds/man-day
4. Feces, wet - 0.33 pound/man-day
5. Urine - 3.45 pounds/man-day
6. Trash - 2.0 pounds/man-day

Pressure Control - Gas Supply. The orbiter and MSS atmosphere are combined for periods up to five days during MSS checkout. Both the orbiter and the MSS atmosphere oxygen and nitrogen composition must be controlled to the following values:

1. Oxygen, partial pressure - 3.1 to 3.5 psia
2. Total pressure, N_2 diluent - 14.7 $\pm$ 0.3 psia

Two pressure regulator systems (one in the orbiter and the other in the MSS) cannot simultaneously control the same air volume without exceeding the design point tolerances. The orbiter pressure control system should be considered dominant until the MSS is built up and MSS operation is verified.

The MSS modules decay by leakage in the 30-day intervals between delivery of MSS modules as summarized in Table 5-5. Pressurization of the MSS at the time of shuttle visit is recommended as opposed to continuous leakage makeup to reduce complexity and improve reliability of the MSS. Pressurization to 14.7 psia is accomplished via piping installed at the orbiter berthing hatch using gas stores which are charged against the payload. If the high-pressure gas stores are installed in the cargo bay, oxygen and nitrogen plumbing to the berthing port would be required. Installation of the gas tanks temporarily near the berthing port would minimize the amount of plumbing in the orbiter. Approximately a 20-inch diameter oxygen tank and 33-inch diameter nitrogen tank would be required. Installation of the gas stores in the delivered MSS module was not selected because an automatic pressure control system with remote control capability would be required for each module.

The orbiter also provides oxygen for metabolic consumption to accommodate two MSS crewmen for periods up to seven days. The MSS leakage consumable weights for the maximum five-day visit period are charged to the MSS payload, but provision for connecting this gas supply to the orbiter pressure control is required. Oxygen usage is:

1. Metabolic oxygen consumption - 1.84 pounds/man-day
2. MSS oxygen leakage - 1.16 pounds/day
3. MSS nitrogen leakage - 3.84 pounds/day

Table 5-5. Gas Storage Requirements for Buildup

Configuration	Initial Leak Rate (lb/day)	Pressure at 30 Days (psia)	Repress. to 14.7 psia (lb)	5-Day Leak (lb)	Gas Total (lb)
Core	5.5	8.0	134	27	161
Core, Power Boom*	5.5	8.0	134	27	161
Core, Power Boom, SM-1	6.0	11.6	152	30	182
Core, Boom, SM-1, SM-2	6.5	12.5	177	32	209
Core, Boom, SM-1, SM-2, SM-3	7.0	12.4	172	35	207
Core, Boom, SM-1, SM-2, SM-3, SM-4	7.5	13.2	197	37	234
Full-up MSS**	10.0	14.7			
Total	269 pounds O_2 plus 885 pounds N_2 = 1154 lb				

Leakage Allocation: Core berthing ports - 5 lb/day
Module leakage - 0.5 lb/day

*Power boom volume excluded as it remains unpressurized

**Includes two RAM's and 1 to 2 cargo modules

Pressure Suit Operations. The requirement for pressure suit operations is caused by the need for maintenance of the MSS, and a safety requirement that the crew has two routes for return to the orbiter. Maintenance of the MSS during the buildup phase would be required in the event of a seal failure, meteoroid puncture, or a failure which causes loss of the MSS shirtsleeve atmosphere. The two routes for return of the crew to the orbiter is illustrated in Figure 5-8.

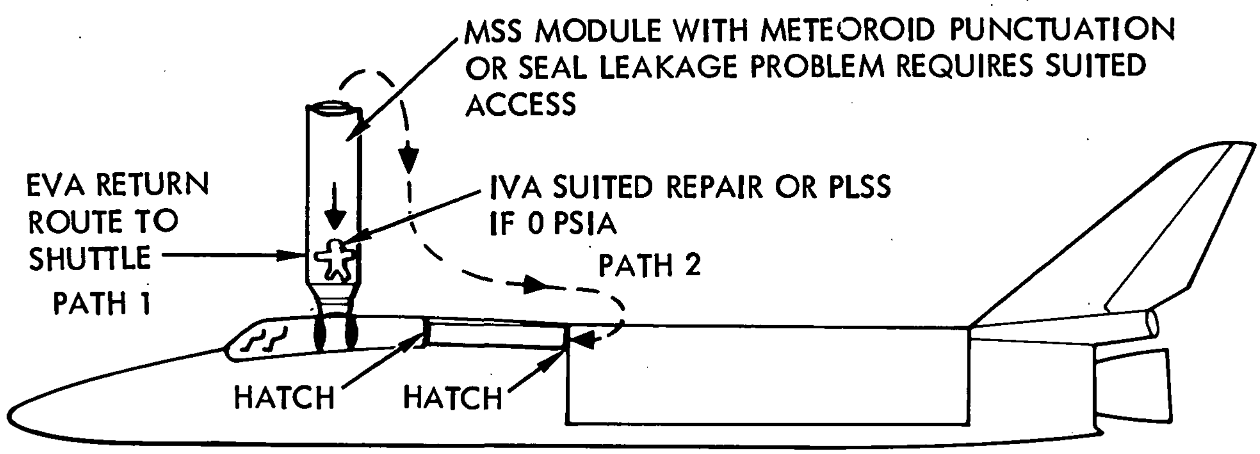


Figure 5-8. Orbiter-MSS EVA/IVA Provisions

Safety Monitoring. The ability to transfer data from the MSS payload to an MSS payload display unit located in the orbiter compartment for safety-related ECLSS measurements is required. The ECLSS measurements and the applicable mission phase are:

1. Total pressure of MSS payload - ascent, on-orbit, descent
2. Total pressure of shuttle cargo bay - ascent, on-orbit, descent
3. Oxygen partial pressure of MSS payload - on orbit
4. Pressure of pressure vessels and pressure and temperature of cryogenic stores - on orbit
5. Fire detection and control - ascent, on-orbit, descent
6. Explosive atmosphere - ascent, on-orbit, descent
7. Toxic atmosphere - on orbit
8. MSS payload internal temperatures - on orbit

Normal Operations Phase

The MSS provides atmosphere revitalization and pressure controls of the orbiter during crew exchange or cargo delivery to the MSS. Metabolic oxygen for two flight control crewmen and orbiter gas leakage will be provided by the MSS while the orbiter is hard-docked. The orbiter CO_2 partial pressure will be controlled to 3 mm Hg by the MSS.

Contamination can affect the thermal properties of the thermal control coatings on the exterior surface of the MSS. The orbiter should not vent products which contaminate, condense, or cause excessive heating on the surfaces of the MSS while located in the payload bay, during emplacement, or while berthed to the MSS.

Electrical Power

Electrical power is provided to payloads from the shuttle orbiter EPS. An electrical energy allowance of 20 kilowatt-hours is specified in the form of regulated dc power. Availability of energy in excess of the 20-kilowatt-hour is mission-dependent.

The docking interface between the space shuttle and the MSS payload should be selected after consideration of possible standardization on one umbilical connector design. A standard docking interface must have redundant power and control connections, manual mating, and requirement coordination between shuttle and MSS payload of voltage regulation allowance, point of control, grounding provisions, and fault isolation.

Buildup Phase

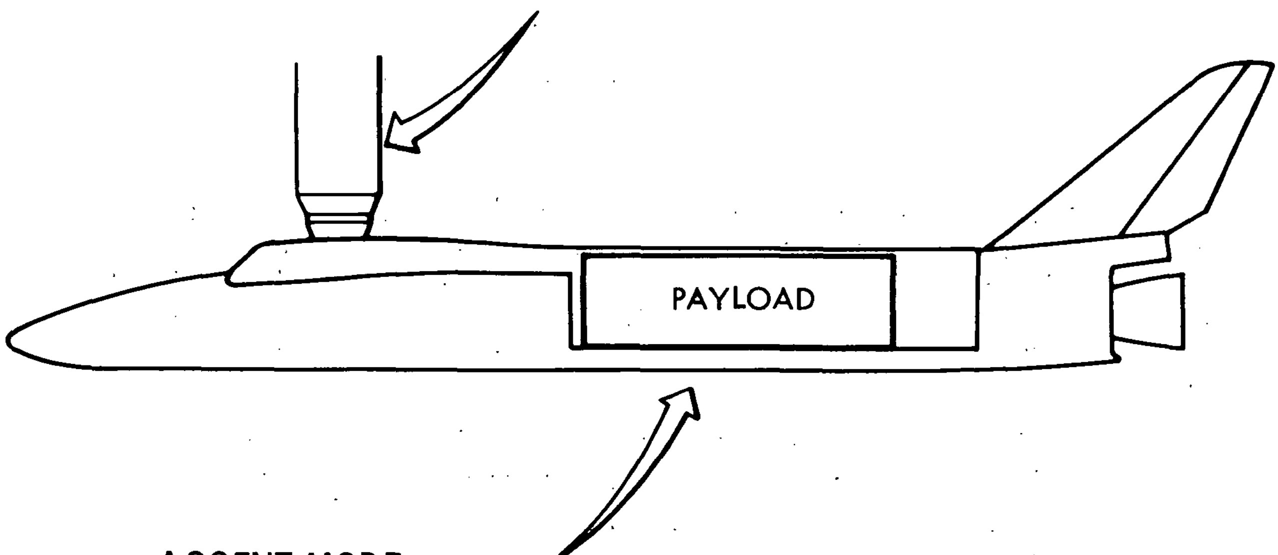
To complete the MSS buildup sequence, shuttle power for control and support will be required at the docking interface and in the cargo bay as illustrated in Figure 5-9. The initial core module will contain high-pressure gas storage and continuous pressure and temperature monitoring will be required. Shuttle power will be required for core module fuel cell activation. It will be necessary to check out all core module subsystems before fuel cell activation (i.e., ISS, G&C, thermal control, and EPS). In addition to the specified 20 kilowatt-hours at 500 to 800 watts, reserve shuttle power up to approximately 2 kilowatts will be required for MSS use through SM-1 activation on a short-term, demand basis. Shuttle power must be supplied to MSS caution/warning and status sensors.

Normal Operations Phase

Shuttle power must be supplied continuously to MSS cargo modules and RAM's in the cargo bay to provide power for caution/warning and status sensors. There is no requirement for shuttle power provisions at the docking port interface during normal operations.

ON-ORBIT MODE

- BUILDUP PHASE
  - ORBITER SUPPLIES 28 VDC REGULATED POWER FOR:
    - LIGHTS, FANS, CONTROLS
    - ACTIVATE FUEL CELLS, CHECKOUT
    - ENVIRONMENTAL CHECK
    - CAUTION/WARNING
  - PAYLOAD SUPPLIES POWER CONDITIONING



ASCENT MODE

- BUILDUP AND NORMAL OPERATIONAL PHASES
  - ORBITER SUPPLIES 28 VDC REGULATED POWER FOR:
    - CAUTION/WARNING
    - HEATERS, CONTROLS, ETC.
  - PAYLOAD SUPPLIES POWER CONDITIONING

Figure 5-9. Electrical Power Interfaces

Guidance and Control

Buildup Phase

Attitude Control of Docking Configuration. During the buildup phase, before continuous manning of the station, it is expected that the orbiter will provide stabilization and control of the combined vehicle. This will allow the orbiter to provide an orientation that is suitable from a thermal standpoint. It will also eliminate station impulse requirements.

The impulse requirement for five days of stabilization are:

Axis	Propellant (lb)
Roll	380
Pitch	370
Yaw	240
Total	990

The shuttle attitude control propellant budget for the space station mission is summarized in Table 5-6. Note that the budget includes almost 700 pounds for stationkeeping and slightly more than 600 pounds for redocking. If the shuttle remains attached, these quantities can be used for attitude control and are more than adequate considering the 990-pound requirement.

Table 5-6. Shuttle ACPS Budget - Station Mission

Mission Phase	Propellant (lb)
Orbit injection	750.9
Rendezvous	1241.6
Docking	467.1
5-day stationkeeping	694.0
Redocking	621.7
Deorbit	254.0
Preentry	149.4
Entry	1200.0
Total	5378.7

Rendezvous Guidance and Navigation. The station will provide tracking and ranging aids including transponders and an optical beacon to support the terminal phase of rendezvous. The orbiter will perform all translation maneuvers necessary to execute the rendezvous.

Docking and Undocking. It is expected that the docking or berthing transient will be damped by the orbiter. The station will inhibit attitude control immediately following orbiter manipulator contact. Any translation maneuvers required for undocking and separation will be provided by the orbiter.

The station is not expected to have docking sensors. Docking aids such as the standoff cross or equivalent will be provided on the station.

Stationkeeping Operations. Any translation maneuvers required for stationkeeping will be provided by the orbiter.

Normal Operations Phase

Attitude Control of Docked Configuration. During normal station operations, following the completion of buildup, it is expected that the orbiter will provide stabilization and control if the stay time is short - on the order of a few hours. If the orbiter stay time is long - on the order of five days - it may be desirable for the station to provide control of the combined vehicle in order to minimize the impact on station operations. The station fuel budget includes the propellant necessary to provide this control.

Rendezvous Guidance and Navigation. After the continuous manning point, the station navigation function will be initiated. Station state vector data will then be available to support the initial phase of rendezvous operations. The station will provide tracking and ranging aids including transponders and acquisition lights to support the terminal phase of rendezvous.

It is expected that the orbiter will perform all translation maneuvers necessary to execute the rendezvous. The station will track the orbiter to monitor these maneuvers.

Orbiter inertial alignment data and deorbit and trajectory data for earth return will be supplied or verified by the station.

Docking and Undocking. The docking and undocking operation and aids during normal operation are identical to those previously described for the buildup operation.

Stationkeeping Operations. Any translation maneuvers required for stationkeeping will be provided by the orbiter. The station will monitor the position of the orbiter for safety purposes. If the orbiter exceeds prespecified position-velocity bounds, a warning will be transmitted. Corrective action will be taken by the orbiter as the station cannot perform an evasive maneuver.

Information Subsystem

The interface between the MSS information subsystem and the orbiter is completed either by hardline or RF means. Hardline interfaces are required at both the orbiter docking port and in the cargo bay.

Buildup Phase

Rendezvous. The shuttle orbiter must have the ability to rendezvous with the on-orbit, unmanned, MSS assembly. The first module (core) delivered on-orbit will contain the RF equipment to provide turnaround ranging (S-band) for orbiter final rendezvous. The ISS will make provisions so that the equipment aboard the MSS (i.e., lights, targets, transponders) required for orbiter rendezvous can be activated by the orbiter.

Berthing. Before the orbiter manipulator contact, the MSS assembly must be capable of being commanded by the orbiter to be in an attitude-stabilized condition and also be able to deactivate the attitude control mechanism immediately upon manipulator contact.

An RF link between the orbiter and the unmanned MSS assembly will provide the means to accomplish these activities in addition to providing MSS subsystem response data to orbiter commands for display purposes.

MSS Status and Control. Payload status and subsystem control is required to assure orbiter crew safety during delivery and to assure that the on-orbit MSS assembly environment is habitable before crewman entry.

During the payload delivery phase with the module in the cargo bay, an interface is required between the payload subsystems and the orbiter interface unit to provide MSS subsystem status and crew safety parameters to the orbiter data management subsystem.

During the on-orbit phase, in a detached mode, the MSS assembly will provide subsystem status data, upon orbiter command, via an RF link to the orbiter for decoding and display.

In the attached mode (MSS assembly attached to orbiter docking port), an interface between the MSS subsystems and the orbiter interface unit is required to provide the orbiter with subsystem status and caution/warning data in addition to crew voice communications after crew entry. Communications to ground will be via the orbiter RF system. While crewmen are temporarily in the MSS assembly, caution/warning signals from the orbiter will be provided as audible tones injected on the MSS intercom link.

Normal Operations Phase

Rendezvous. An RF link for simultaneous transmission and reception of MSS-orbiter up and down data and turnaround of a ranging signal will be provided. Both station and orbiter will be capable of serving as cooperative ranging targets. A two-way duplex voice RF link will be provided between the orbiter and station. The ISS will control the operation of MSS equipment (i.e., lights, transponders) required for orbiter-station rendezvous.

Berthing. Before orbiter manipulator contact with the station, subsystem status data exchange is required via an RF link with emphasis on attitude stabilization parameters. The station will monitor and provide warning signals to the orbiter for evasive action as required. For further berthing activities after orbiter-station hard mate, the station will provide a closed-circuit TV signal to the orbiter manipulator operator station via the MSS telephone/video bus as illustrated in Figure 5-10.

It must be noted in Figure 5-10 that only one manipulator is used to perform the berthing while the other manipulator provides lights and CCTV to the manipulator operator. In case of manipulator failure, the additional viewing function would be lost and all viewing would come from the station TV camera in the window as shown.

MSS Status and Control. During the payload delivery phase with the module in the cargo bay, an interface is required between the payload subsystems and the orbiter interface unit to provide MSS subsystem status and crew safety parameters to the orbiter data management subsystem.

Orbiter Status. During on-orbit operations with the orbiter mated to the station, a hardline interface is required at the orbiter docking port. This interface is between the station telephone/video bus, the station intercom link, and the orbiter interface unit. Orbiter caution/warning signals are provided as audio tones on the station intercom link. Two-way voice intercom between the station and orbiter is provided. Station generated closed-circuit TV signals are provided on the telephone/video bus to the orbiter to aid the manipulator operator during berthing operations.

Crew Habitability

Buildup Phase

Crew Provisions. The orbiter will provide seating accommodations for two station crewmen. The orbiter also will provide emergency gear and associated stowage space to accommodate all flight emergencies. Capability for station crewmen ingress and egress will be provided in a similar manner to the flight crew. Medical care provisions also will be provided by the orbiter.

Crew Transfer. After hard mate between the orbiter and the unmanned MSS assembly, the orbiter will perform all functions required to secure the docking interface, enable access between the orbiter and MSS assembly, attach all umbilicals and connectors, and activate the MSS subsystems required for the mated configuration. Normal crew transfer will be accomplished in a shirt-sleeve environment via the orbiter EVA/IVA airlock through the payload adapter into the MSS assembly. Handholds, handrails, and lighting must be provided along all routes and at each hatch to facilitate crew movement.

Normal Operations Phase

Crew Provisions. The orbiter will provide seating accommodations, emergency gear and associated stowage space, and medical provisions for six station crewmen during launch and landing phase only. Capability for station crewmen ingress and egress will be in a similar manner to the orbiter flight crew.

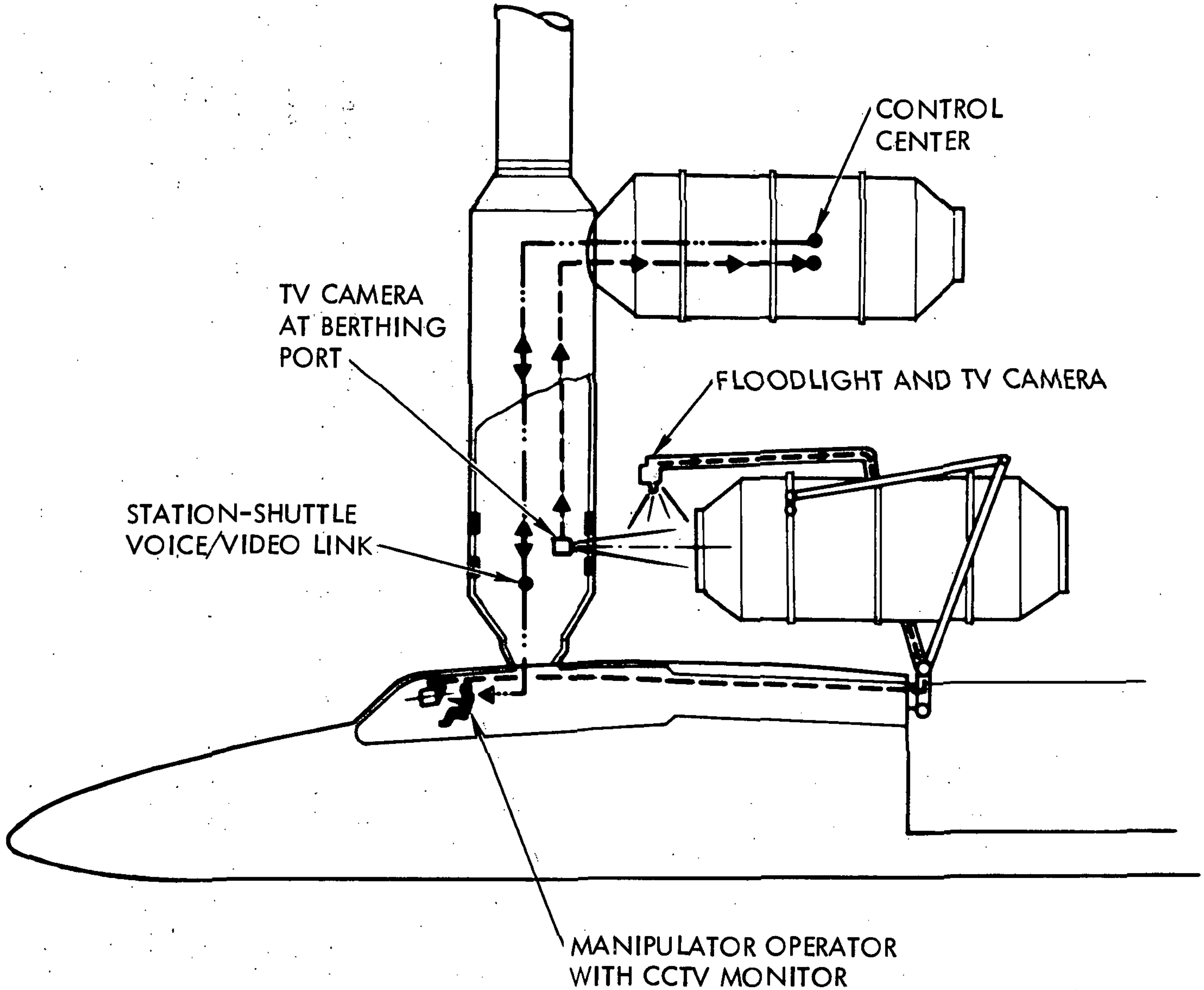


Figure 5-10. ISS-Orbiter CCTV Interfaces

Crew Transfer. After hard mate between the orbiter and the station, the station will perform all functions required to secure the docking interface, enable access between the orbiter and MSS, and attach all umbilicals and connectors required for the mated configuration. Normal crew transfer will be accomplished in a shirtsleeve environment via the orbiter EVA/IVA airlock through the adapter into the station. Handholds, handrails, and lighting must be provided along all routes and at each hatch to facilitate crew movement.

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6. SAFETY AND RELIABILITY CRITERIA

Requirements were established for monitoring potential payload hazards by the shuttle crew while a MSS module is located in the shuttle cargo bay. The requirements are limited to those particulars which are necessary to provide crew safety and to protect the shuttle from damage by a failure or accident within a module during transportation.

The following requirements and associated rationale apply during ground operations and ascent-to-orbit phases of the mission.

1. For MSS modules which contain hydrogen pressure vessels, monitoring of tank pressure and hydrogen leak detection is required. Remote dumping capability of a leaking hydrogen tank is desirable. Leak detection is required to determine potential explosive atmosphere. This allows for a decision by the shuttle crew. To determine which tank is leaking, pressure indication is required; this also allows for verification of leak detection signal. Remote tank dumping is desirable since a small leak in a tank or associated lines would result in a continuous hazardous atmosphere once on orbit and causes maintenance to be performed in a hazardous condition.

2. A module fire detection system is required with remedial measures for fire extinguishing. This requirement applies when fire potential within a module can be determined such as active power or hazardous gases.

In establishing requirements for the shuttle manipulator interface, it was necessary to identify potential credible malfunctions or accidents in the candidate manipulator operations which would result in single-point failures to the program. As a result of the analysis, the following single-point failures were identified as critical to the program during buildup of the MSS (i.e., the buildup cannot be completed if these failures occur):

1. Shuttle manipulator failure.

2. Failure of the manipulator grab mechanism on the shuttle.

3. Failure of any one berthing port on the station where a redundant one is not available.

4. Failure to berth or unberth by the shuttle.

5. Failure to berth or unberth the shuttle docking adapter to and from either the shuttle or the station.

Any of these failures which could not be circumvented by backup functions would become a single-point failure to the program; however, adequate redundancy has been provided to assure program success.

Analysis shows that there are potential means to prevent program failures. The asterisk indicates requirements which prevent single-point failures leading to loss of a single module rather than a program loss. The safety requirements are:

1. Provide backup means for returning module to shuttle cargo bay in the event of shuttle manipulator failure.*

2. Provide backup release on shuttle manipulator (also required for shuttle safety).*

3. Provide continuation of buildup following damage to or malfunction of power module berthing port.

4. Provide a backup berthing port on the station at each stage of buildup which allows shuttle berthing and a continuation of buildup.

5. Provide continuation of buildup following damage to or malfunction of core module berthing port for berthing to power module.

   a. Provide two berthing ports (for power module) on core module.*

   b. Provide capability to maintain berthing port and mechanism (for power module) on core module in orbit.*

   c. Provide backup core module in program and design power module to survive until it can be brought up to orbit.

   d. Design power module to survive until core module can be returned to earth, repaired, and returned to orbit.*

6. Provide continuation of buildup following damage to or malfunction of berthing port on a station module.

   a. Provide for survival of each stage of partially builtup station until module can be returned to earth, repaired, and brought to orbit again.*

   b. Provide backup of each station module in program, and design for survival of each stage of partially builtup station until backup module can be brought up to orbit.

   c. Design station modules for berthing at either end (i.e., two berthing ports per module).*

d. Provide capability to maintain ports and mechanisms on station modules in orbit.*

7. Provide continuation of buildup following damage to or malfunction of berthing port on core module.

   a. Provide one more berthing port on each pressure-isolatable volume of the core module than is required for normal buildup, capable of berthing any planned station module. Provide an emergency pressure-tight cover for damaged, leaking core module docking ports.

   b. Provide capability to maintain berthing ports and mechanisms on core module in orbit.

8. Provide for survival of station until backup shuttle arrival in orbit.

9. Provide backup means for release of berthing ports.

In arriving at these requirements, it was assumed that a failure of a particular shuttle mission does not constitute program failure, and that the abandonment of any one MSS module in orbit is highly undesirable. If abandonment of one module is acceptable, the requirements identified with an asterisk are not needed.