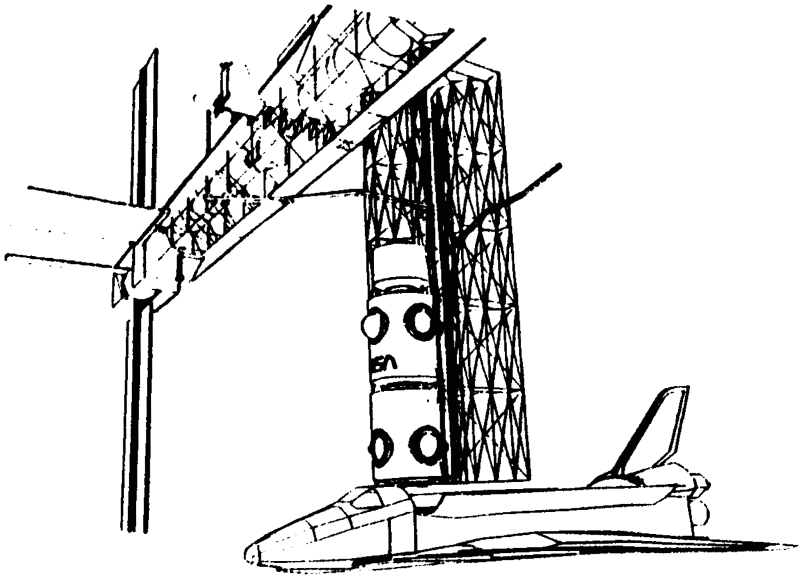
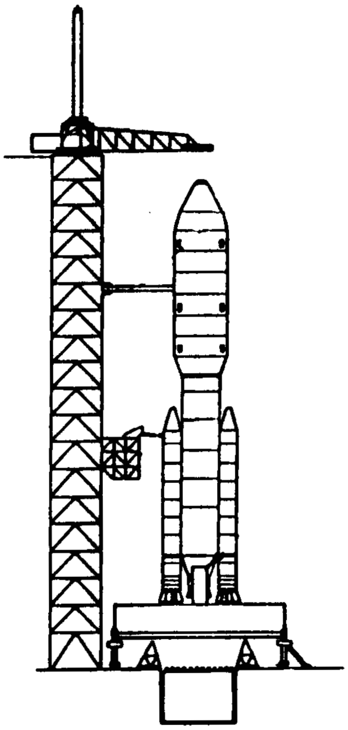
NASA Technical Memorandum 100604



SPACE STATION HEAVY LIFT LAUNCH VEHICLE UTILIZATION

L. J. DeRyder

APRIL 1988



National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

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CONTENTS

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1.0 HLLV UTILIZATION STUDY BACKGROUND

OBJECTIVES

The Space Station Preliminary Design Definition is based on dedicated use of the STS for assembly, verification, outfitting, logistics, resupply, crew rotation, and return of experiments and refuse to ground. Since the 51-L accident, however, a large number of postponed Shuttle flights -- some of vital interest to our national security -- has created a mission planning backlog of non-Space Station missions. The Shuttle's performance with respect to payload delivery to orbit has also been downrated. Therefore, the need for additional launch vehicles has become apparent to accommodate national needs during the decade of the 1990's when Space Station launch needs must compete with those of both science missions and national defense.

The 1986 NASA Mixed Fleet Study, which compared requirements with capabilities, showed that a combination of Shuttle flights with missions flown by other launch vehicles would reduce Shuttle demands and minimize the shortfall caused by use of the Shuttle alone. The larger lift capacity (both weight and volume) offered by HLLVs is attractive to consider with respect to Space Station assembly because it presents the ability to launch more fully integrated and outfitted subsystems, modules, and servicing facilities. The objective of this study is therefore to examine in detail the use of HLLVs and to assess their utility for Space Station assembly/deployment, logistics, and resupply.

HEAVY LIFT LAUNCH VEHICLE (HLLV) UTILIZATION

OBJECTIVE

ASSESS THE USE OF HLLV'S FOR

1. SPACE STATION ORBITAL ASSEMBLY/ DEPLOYMENT
2. SPACE STATION LOGISTICS & RESUPPLY

HLLV ASSESSMENT TEAM

The HLLV Utilization Study team was composed of participants that represented key NASA systems, subsystems, and mission operations disciplines from the Langley Research Center (LaRC), George C. Marshall Space Flight Center (MSFC), Lewis Research Center (LeRC), John F. Kennedy Space Center (KCS), Lyndon B. Johnson Space Center (JSC) and the Washington, D.C. NASA Headquarters (HQ).

Heavy Lift Launch Vehicle Study

HLLV ASSESSMENT TEAM

RAY HOOK JOE TALBOT AMOS SPADY PAT TROUTMAN BUDDY DeRYDER KAY MILLEN LAURA WATERS	LARC
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DON SCHULTZ	LERC
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VANCE BRAND CHARLES ARMSTRONG JERRY BELL DOUG COOKE DENNIS WEBB DAVE HOMAN	JSC
BRYANT KEITH DICK OTT PHIL SHANAHAN	HQ

SPACE STATION PROGRAM BACKGROUND

The current Space Station concept is based on the premise that the Shuttle will be available exclusively for Station delivery and support purposes in Earth orbit. The Station design derivation is driven in a large measure by the Shuttle configuration performance. Furthermore, the Shuttle is the only available means of transporting both humans and cargo to, and returning them from, Earth orbit.

The current Space Station design and operational requirements need to have a permanent presence of eight crew. The current Shuttle crew passenger limit of 4 and the maximum on-orbit staytime limitation of 90 days per crewman requires 8 Shuttle flights per year just to operate and logistically resupply the Station. Other dedicated payload flights, such as science platforms, require additional launches.

SPACE STATION PROGRAM BACKGROUND

PREDICATED ON DEDICATED SHUTTLE AVAILABILITY

- CONFIGURATION GEOMETRY DEFINITION DRIVER
- REQUIRED FOR INITIAL MANNED ASSEMBLY AND PERMANENT MANNED CAPABILITY (PMC) OPERATIONS
  - MAJOR CONSTRAINT ...... NO OTHER MANNED TRANSPORTATION SYSTEM EXISTS
- ONLY AVAILABLE DOWN CARGO CARRIER

CURRENTLY REQUIRES > 8 FLIGHTS/YEAR

- PLATFORM NEEDS ADDITIONAL TO CREW ROTATION

KEY SPACE STATION PROGRAM CONSIDERATIONS

The first step in conducting the HLLV study was to identify key Space Station Program (SSP) concerns that the HLLV would be expected to alleviate.

One major issue for the SSP is minimizing the demands on the Shuttle in order to reduce risk and to create Shuttle availability for other missions.

Another area for study is increasing the percentage of Station assembly and verification performed prior to launch. This also will minimize program risk and maximize crew safety. EVA time, which was baselined to be 24 hours per seven-day mission by the 1986 NASA Space Station Critical Evaluation Task Force (CETF) study, will be reduced even further as the number of Shuttle flights is decreased, due to the increased prelaunch assembly and integration opportunities offered by HLLV utilization.

KEY SPACE STATION PROGRAM CONSIDERATIONS

IDENTIFY SPACE STATION CONFIGURATION OPTIONS THAT ADDRESS KEY PROGRAM CONCERNS

- MINIMIZE THE NUMBER OF REQUIRED SHUTTLE FLIGHTS
- MAXIMIZE PRE-LAUNCH SUBSYSTEM INTEGRATION/ VERIFICATION
- MINIMIZE HEAVY DEPENDENCE ON EVA FOR STATION ASSEMBLY
- IMPROVE HAB/LAB MODULE OUTFITTING LOGISTICS
- ENHANCE EARLY ATTACHED PAYLOAD SCIENCE ACCOMMODATION

KEY SPACE STATION PROGRAM CONSIDERATIONS
(cont.)

The utilization of HLLVs for launching Space Station components will require integration of two additional system elements into the flight assembly and operations process. Because SS design is based upon the STS, to maintain launch vehicle integration compatibility, the HLLV must provide a payload (P/L) carrier for Station elements that is compatible with the Shuttle cargo bay. In an unmanned launch mode, the HLLV P/L carrier must provide stabilization of its payload after separation of the main booster engines to permit rendezvous with either the STS or the SS.

The integration of the Orbital Maneuvering Vehicle (OMV) which adds a second system element to the SS infrastructure can be considered for the function of orbital stability and control of the HLLV P/L carrier. Use of the OMV would require no additional systems development cost to the SSP for this function. Conceivably, the OMV can be integrated with the HLLV P/L carrier to provide a spacecraft utility bus for orbital attitude stabilization, station keeping, command and data handling, and communication and tracking of assembly payloads. Of key importance is the OMV's ability to provide close-in, unmanned rendezvous and docking maneuvering capability to the SS.

Unmanned, automated rendezvous and docking operations in close proximity to the Space Station have not been considered in the current SS design definition with respect to launch vehicle interfaces. Currently, the Orbiter pilot in the loop method is envisioned for rendezvous/docking proximity operations. Unmanned automated rendezvous and docking of HLLV P/L's to the SS would require the development of additional systems and hardware. It would also require a Space Flight demonstration of this operational process and of the flight hardware as a precursor to the assembly of the SS in earth orbit.

KEY SPACE STATION PROGRAM CONSIDERATIONS

HLLV UTILIZATION ADDS TWO NEW SYSTEM ELEMENTS TO SPACE STATION SYSTEM INFRASTRUCTURE

- HLLV ORBITAL PAYLOAD CARRIER FOR UNMANNED RENDEZVOUS
- OMV FOR ASSEMBLY FLIGHT RENDEZVOUS/PROXIMITY OPERATIONS

AUTOMATED/UNMANNED RENDEZVOUS & DOCKING REQUIRES SPACE FLIGHT DEMONSTRATION PROGRAM

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2.0 HLLV CHARACTERIZATION

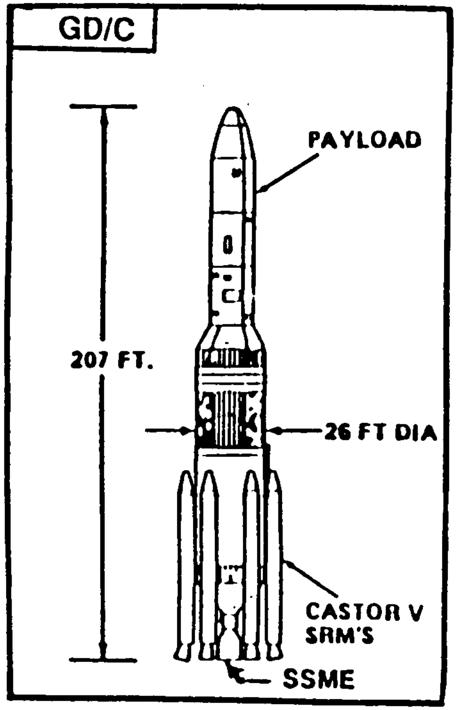
HLLVs POTENTIALLY AVAILABLE BY EARLY 1990's

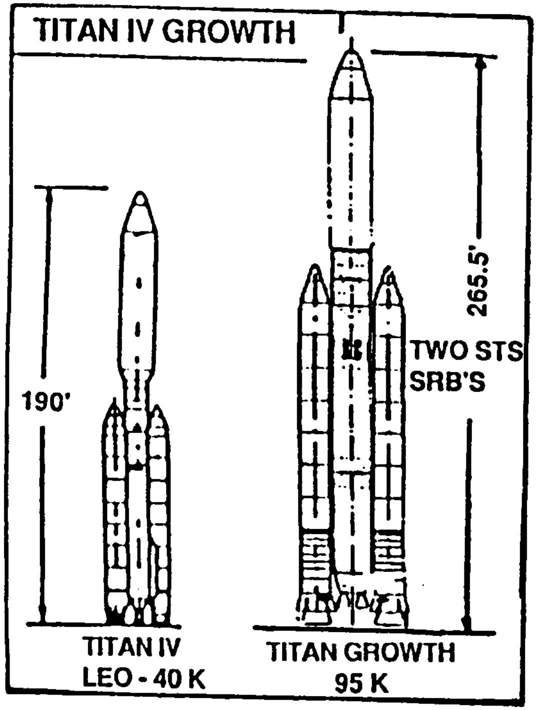
There are three candidate HLLV options which can be considered as a development possibility by the early 1990's. The General Dynamic Centaur (GD/C) candidate is being considered by private industry, and TITAN IV growth is being investigated by the Air Force.

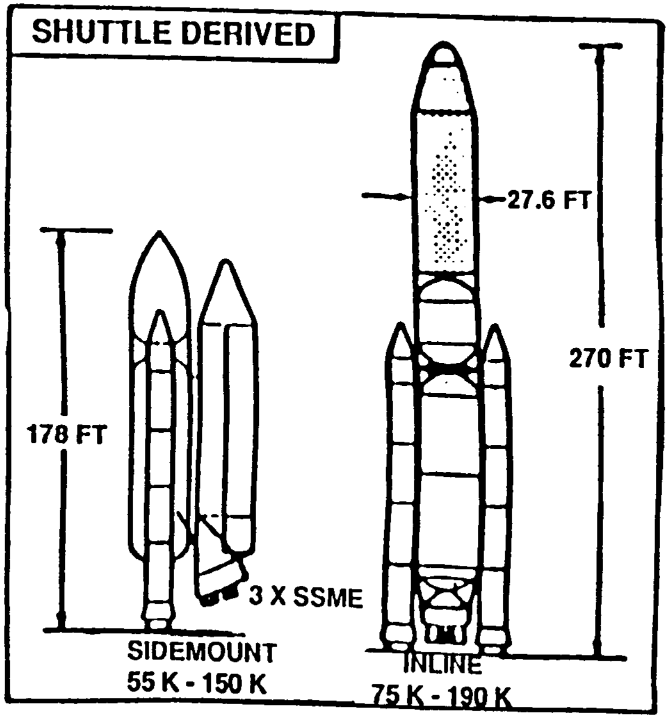
The third option is NASA's candidate: a HLLV based on STS design, also known as a Shuttle Derived Vehicle (SDV). This would allow two possible configurations, in-line or side-mount, and would provide the most assurance of STS/HLLV dual compatiblity.

Heavy Lift Vehicle Study

HEAVY LIFT VEHICLES POTENTIALLY AVAILABLE BY EARLY 1990'S







SHUTTLE DERIVED LAUNCH VEHICLE CONCEPTS

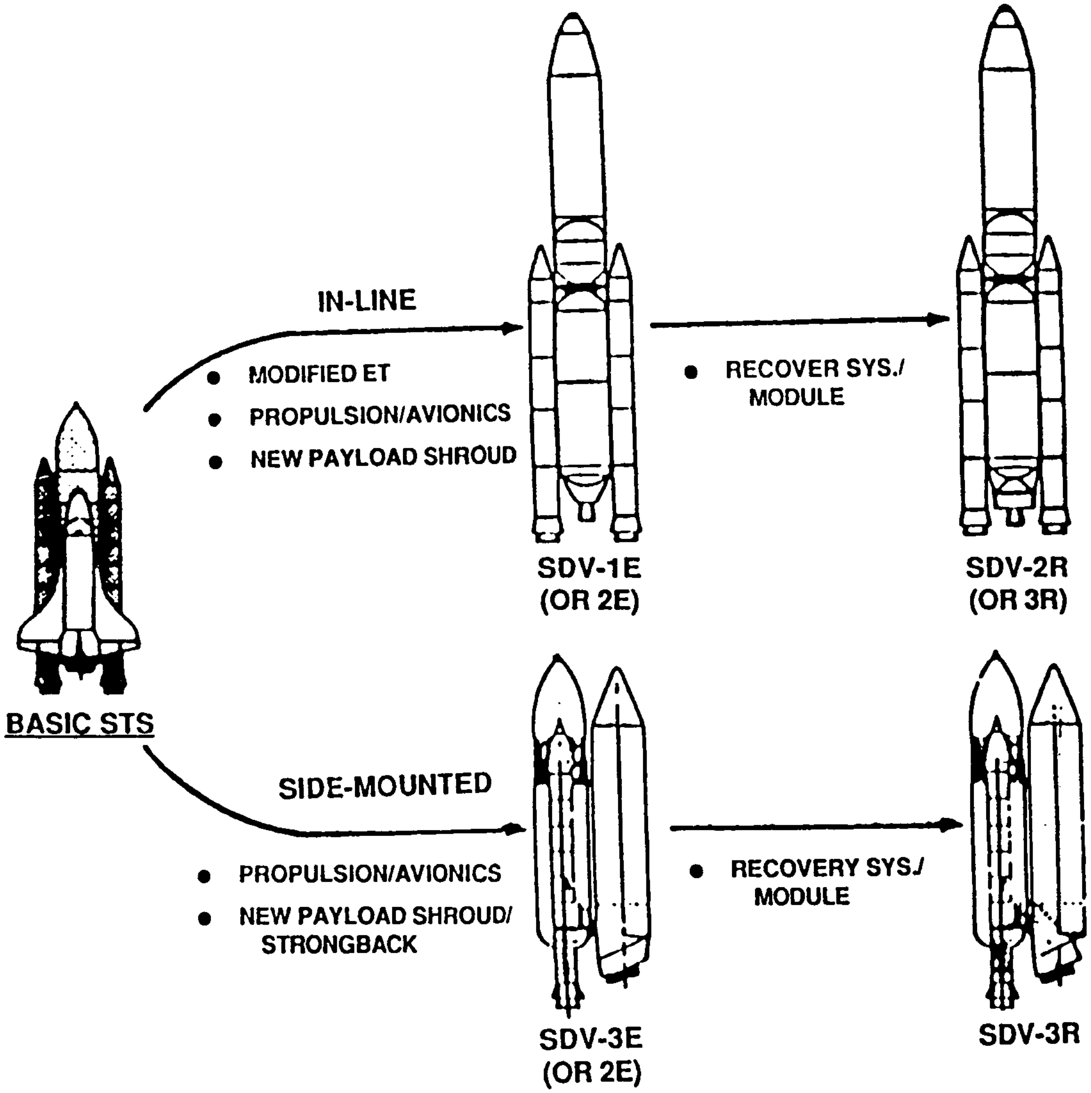
Both the in-line and the side-mount SDV concepts retain a great deal in common with STS. This will reduce development costs, development time, and program risk. It should be noted that only the side-mount version would be directly compatible with STS launch pads.

Some of the variables involved in the SDV design are the location of the payload carrier, the number of Space Shuttle Main Engines (SSMEs) used, and SDV recovery capability. Components requiring design integration are the Orbital Maneuvering Vehicle, the payload shroud, propulsion/avionics, and the recovery system/module. The avionics and OMV will demand the greatest amount of design integration effort, since the HLLV will be unmanned and the OMV will provide the orbital rendezvous and docking capability with the SS for payload deployment.

Heavy Lift Launch Vehicle Study

SHUTTLE DERIVED LAUNCH VEHICLE CONCEPTS

PROGRAM OPTIONS



BASIC STS

IN-LINE

- MODIFIED ET
- PROPULSION/AVIONICS
- NEW PAYLOAD SHROUD

SDV-1E
(OR 2E)

- RECOVER SYS./
  MODULE

SDV-2R
(OR 3R)

SIDE-MOUNTED

- PROPULSION/AVIONICS
- NEW PAYLOAD SHROUD/
  STRONGBACK

SDV-3E
(OR 2E)

- RECOVERY SYS./
  MODULE

SDV-3R

COMMON FACTORS W/STS

FACILITIES
- ASSEMBLY BUILDINGS
- TRANSPORTATION
- LAUNCH PADS (SIDEMOUNT)
- R&D, TEST & VERIFICATION SITES

STAGES
- TANKS
- INTEGRATION HARDWARE
- TRANSPORTATION MODES

MAJORS ELEMENTS
- ENGINES
- THRUST STRUCTURE
- NOZZLES
- PAYLOAD FAIRINGS

COMPONENTS
- AVIONICS
- CAVOLINES, VALVES, INSULATION

OPERATIONS
- ASSEMBLY
- TRANSPORTATION
- LAUNCH
- ORBITAL

HEAVY LIFT CAPABILITY SELECTION

Although the use of multiple SSMEs creates additional cost and development effort, the added capabilities make it desirable, if not necessary. While one SSME has a lift capacity of 50-75,000 lbs. which is sufficient to launch SS modules and to perform logistics missions, two SSMEs will allow the launch of pre-integrated SS structures. This consideration allows ground-based subsystem integration and verification, reduces EVA time which minimizes program risk. The addition of the third SSME not only increases capacity to 150-190,000 lbs., if needed, but also provides redundancy (engine out) for SS assembly flights. For maximum flexibility and minimum risk, three SSMEs should be used.

HEAVY LIFT CAPABILITY SELECTION

SPACE STATION APPLICATION (220 N.M.)

SHUTTLE DERIVED VEHICLE (Number of SSMEs)	RATIONALE
ONE ENGINE (50 K - 75 K)	PERMITS FULLY OUTFITTED LABORATORY AND HABITABILITY MODULES TO BE ORBITED
TWO ENGINE (100 K - 125 K)	PERMITS LAUNCHING SPACE STATION TRANSVERSE BOOM IN A SINGLE FLIGHT (9 FT TO 10 FT BAY SIZE)
THREE ENGINES (150 K - 190 K)	PROVIDES DESIRED PERFORMANCE WITH ENGINE OUT CAPABILITY

DESIGN PHILOSOPHY:

- DESIGN SHUTTLE DERIVED VEHICLE TO FLY WITH EITHER ONE, TWO, OR THREE SSMES
- FLY HIGH VALUE PAYLOADS E.G. SPACE STATION ASSEMBLY FLIGHTS WITH ONE ENGINE OUT CAPABILITY
- LAUNCH POLAR PLATFORMS ON ONE OR TWO ENGINE SDVS DEPENDING ON LIFT CAPABILITY NEEDED
- UTILIZE ONE ENGINE SDV FOR SELECTED SPACE STATION LOGISTICS MISSIONS

SDV PERFORMANCE CAPABILITY

(Expendable)

Seven expendable SDV configurations were evaluated as to payload capacity. The figures for 220 NM and Eastern Test Range launch (28.5 degrees) apply to Space Station assembly and operations. The calculations were based on the assumption that the SSMEs would be operating at 104% of rated power. For the HLLV study, only side-mounted options were used; in-line configurations are included below for comparison.

The key result of this evaluation is that using three engines more than triples capacity for both in-line and side-mount configurations, as well as providing redundancy for one or two engine options.

Heavy Lift Launch Vehicle Study

SDV PERFORMANCE CAPABILITY

(EXPENDABLE)

(I) = INLINE
(S)= SIDE MOUNT

CONFIGURATION	220 NM @ 28.5°	160 NM @ 98°	445 NM @ 98°	PAYLOAD ENVELOPE
1 X SSME				
● SDV-1E (I)	76 K	58 K	46 K	25' X 60'
● SDV-1E (S)	55 K	38 K		15' X 60'
2 X SSME				
● SDV-2E (I)				
● SDV-2E (S)	100 K	72 K	52 K	25' X 90'
3 X SSME				
● SDV-3E (I)				25' X 90'
● SDV-3E (I)	189 K			36' (OD) X 90'
● SDV-3E (S)	153 K			27' (OD) X 90'

104% SSME

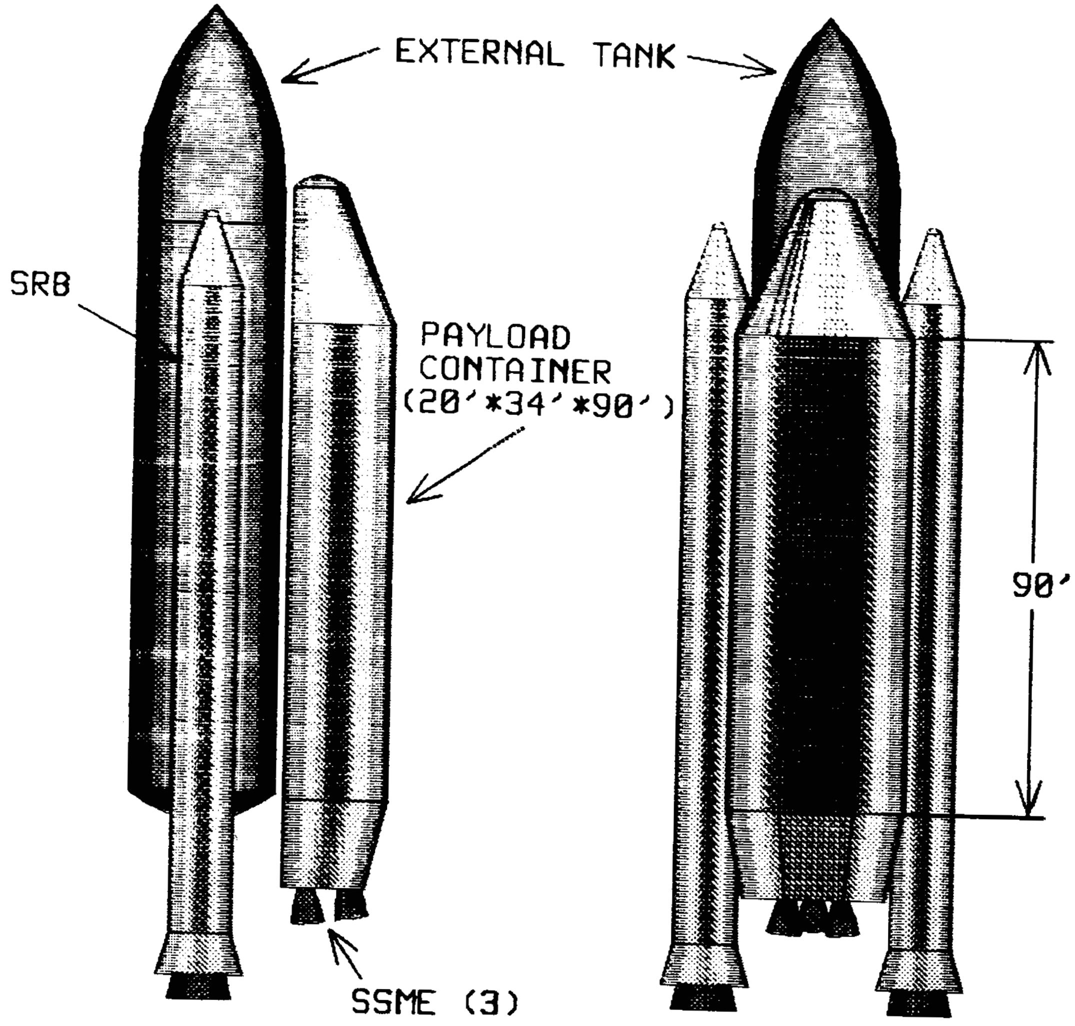
SDV: 3 ENGINE, EXPENDABLE, SIDE-MOUNT

A three engine expendable side-mount vehicle concept provides several attractive features. The three engines add capacity and redundancy; expendability reduces design efforts and costs; and the side-mount option requires the least modification to existing launch facilities.

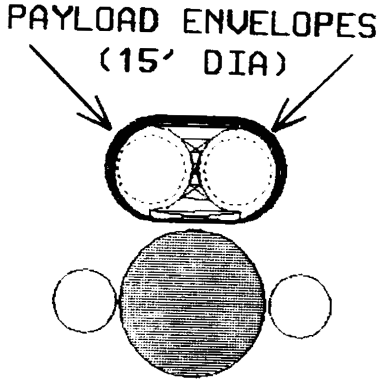
The HLLV/SDV payload envelope could be configured to provide a cargo container geometry representative of two 15' diameter shuttle cargo bays 90' long in a side-by-side (or back-to-back) arrangement. The shroud volume provided for Space Station components is nearly the equivalent of 4 Shuttle cargo bays (the full 60' of Orbiter cargo bay cannot be utilized for Station assembly because the volume near the forward bulkhead must be kept clear for either EVA egress/regress or the pressurized docking module when the Shuttle docks to the Station).

Heavy Lift Launch Vehicle Study

SHUTTLE DERIVED VEHICLE CONCEPT
3 ENGINE, EXPENDABLE, SIDEMOUNT



SHROUD VOLUME
ACCOMODATES
EQUIVALENT OF 4
SURROGATE SHUTTLE
CARGO BAYS.



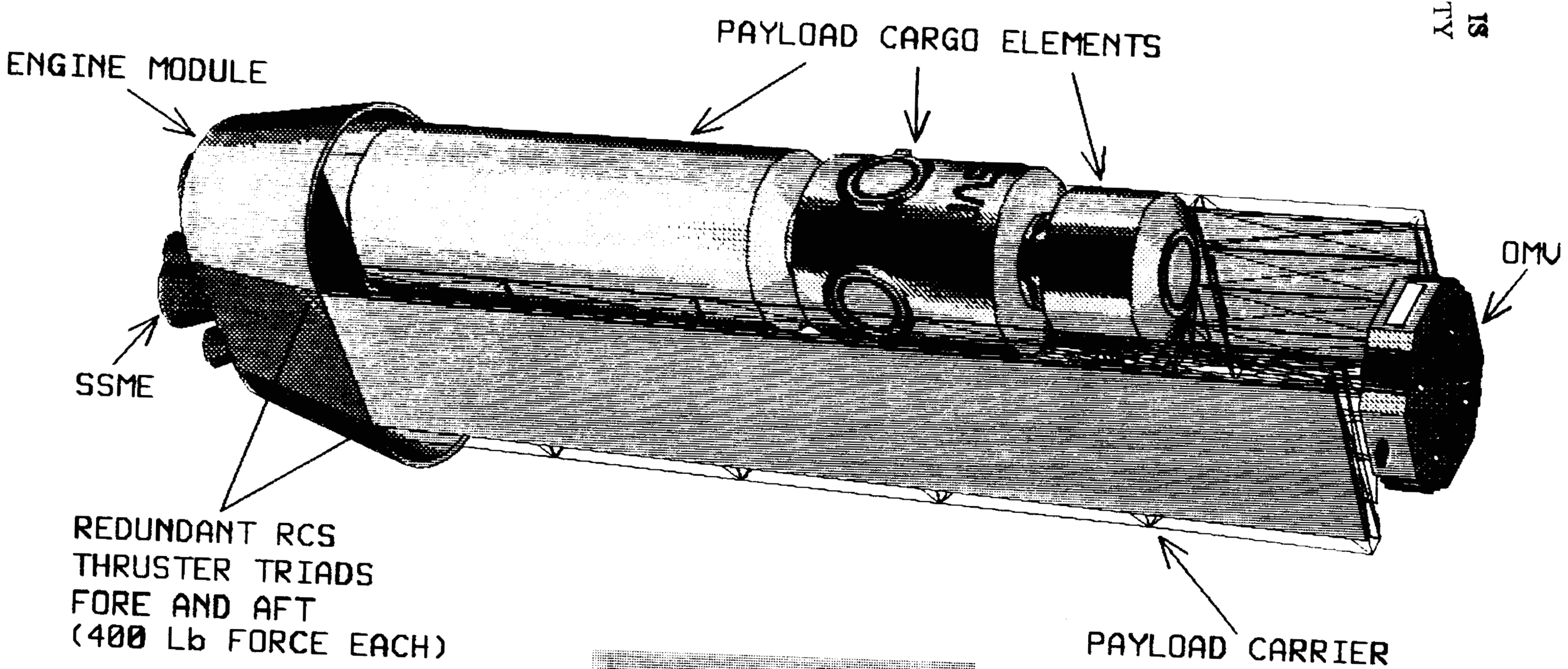
HLLV PAYLOAD CARRIER ASSEMBLY

The concept for a SDV/HLLV cargo carrier that provides a dual compatibility with the utilization of the Space Shuttle requires a major design definition effort. The key components of such a SDV P/L carrier assembly for Space Station utilization would consist of the SSME engine assembly with a separation plane to permit the engine module to be jettisoned prior to Station or Orbiter rendezvous. Electrical and avionics subsystems utilized during the powered flight would be focused on the engine module assembly and considered expendable along with the SSMEs. The P/L carrier structure can be considered either to be expendable or could be utilized as an element of the Station structure.

The OMV would be interfaced with the P/L carrier to provide guidance, navigation, and control as well as other avionics functions after engine module separation. The OMV would, in concept, be retrieved by the Space Shuttle and returned to earth for refurbishment and reuse.

Heavy Lift Launch Vehicle Study

HLLV PAYLOAD CARRIER ASSEMBLY



- * ELECTRICAL POWER (FUEL CELLS)
- * COMM & DATA SYSTEM

PAYLOAD CARRIER GUIDANCE, NAVIGATION, AND CONTROL CONCEPT

An integrated systems concept for an unmanned launch, orbital rendezvous and docking capability for delivering Space Station components to assembly altitudes utilizing a HLLV/SDV must be developed and flight tested. A flight demonstration program must be initiated to validate the hardware and operational procedures from launch to final Station berthing. Four major subsystems will require integration: the SDV, the OMV, the P/L carrier, and the Station itself.

SDV systems will be required to provide power, guidance, and control from liftoff through orbit insertion. After orbit insertion, a SDV P/L carrier RCS system will be required to function in response to OMV command and control. The OMV will be required to take over guidance and communications after post-orbit insertion to provide approach guidance for the Space Station. It will again be required to provide commands to the SDV P/L carrier thrusters and to provide the interface for overall system command/control and data feedback. The P/L carrier/OMV will be required to stationkeep with respect to the SS. Separation of the SDV main engine module should be performed before proximity operations begin for berthing to the Station. During this period, translation and orientation control will be provided by the P/L carrier reaction control system (RCS) and control moment gyros (CMGs). The final berthing operation will require the Station's RMS to grapple the OMV/Payload Carrier. The P/L carrier attitude control will need to be inhibited during this grapple/berthing operation.

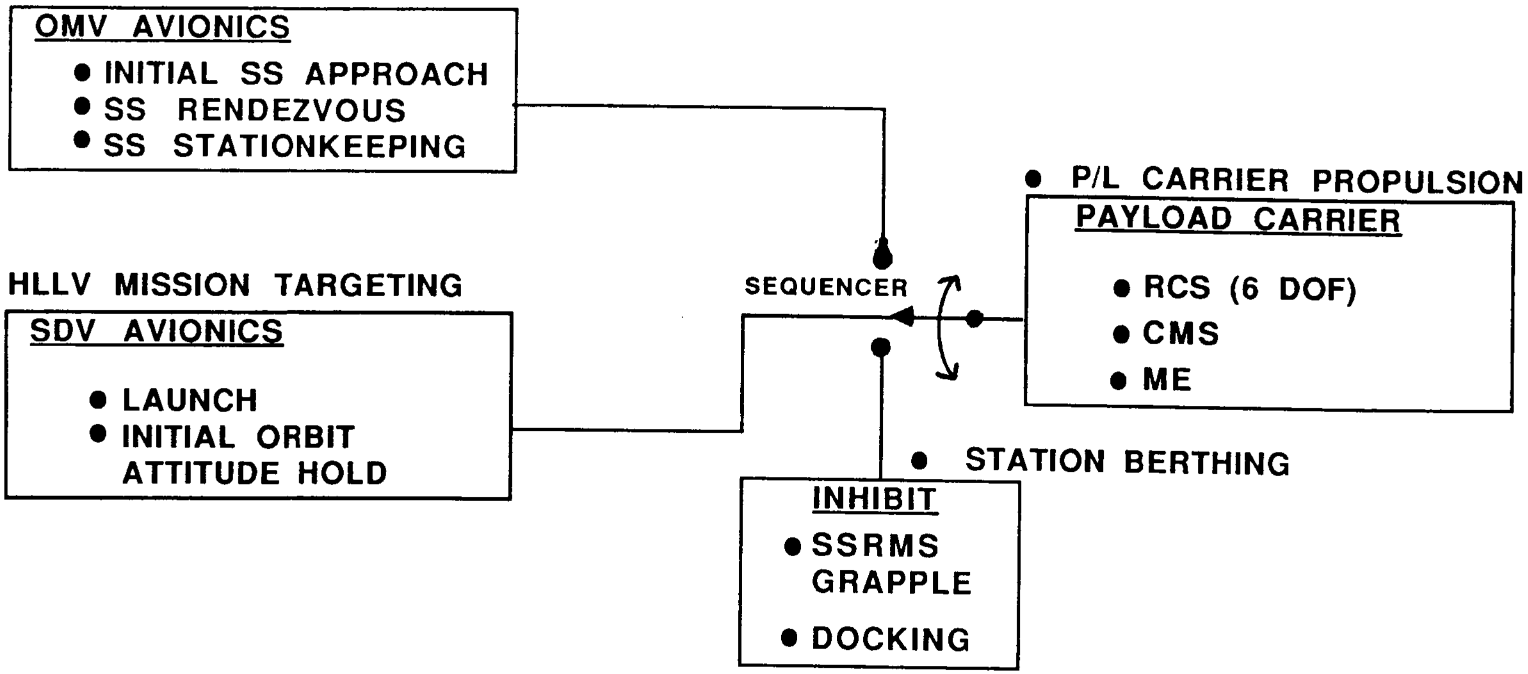
Key issues that need to be addressed in the design definition of these systems and their integrated operations are approach velocity and docking load constraints, manual monitoring/teleoperation (post PMC), GN&C performance, and effects of mission abort.

Heavy Lift Launch Vehicle Study

PAYLOAD CARRIER GUIDANCE, NAVIGATION AND CONTROL CONCEPT

UNMANNED RENDEZVOUS & DOCKING CAPABILITY

- OMV REQUIRED FOR EACH HLLV P/L CARRIER LAUNCH



- STATION APPROACH GUIDANCE

  OMV AVIONICS
  - INITIAL SS APPROACH
  - SS RENDEZVOUS
  - SS STATIONKEEPING

- HLLV MISSION TARGETING

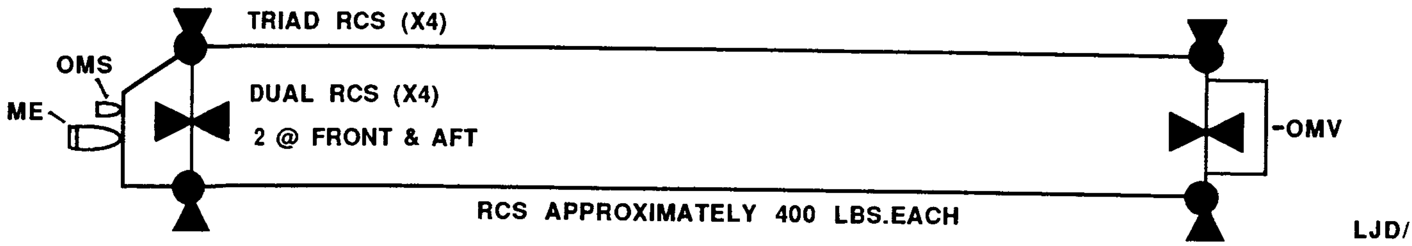
  SDV AVIONICS
  - LAUNCH
  - INITIAL ORBIT ATTITUDE HOLD

- P/L CARRIER PROPULSION

  PAYLOAD CARRIER
  - RCS (6 DOF)
  - CMS
  - ME

- STATION BERTHING

  INHIBIT
  - SSRMS GRAPPLE
  - DOCKING



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3.0 ASSEMBLY: CETF BASELINE SEQUENCE

CETF ASSEMBLY SEQUENCE HIGHLIGHTS

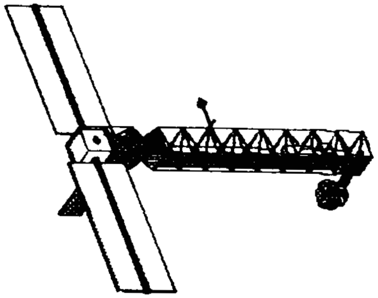
The baseline assembly sequence for the Space Station Program was determined by the NASA Critical Evaluation Task Force (CETF) and is based on exclusive, dedicated use of the Space Shuttle. This sequence will be described and then modified to reflect the accommodation impacts of HLLV utilization to assemble and operationally maintain the Station.

Key highlights of the CETF assembly procedure are:

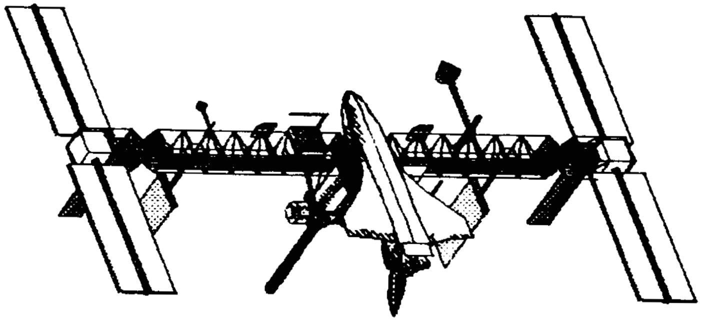
- Assembly Flight 1 - the first assembly flight which establishes a fully functional free flying spacecraft in earth orbit
- Assembly Flight 2 - launch of the U.S. LAB module and commencement of a man-tended capability
- Assembly Flight 8 - completion of construction of the pressurized structural volume and beginning of Permanently Manned Capability (PMC)
- Assembly Flight 11 - commencement of full participation with all international partners
- Assembly Flight 17 - completion of Space Station Assembly - Initial Operational Capability (IOC)

These assembly flights represent key function capability build-up levels for which significant science and commercial utilization of Space Station resources can be accommodated.

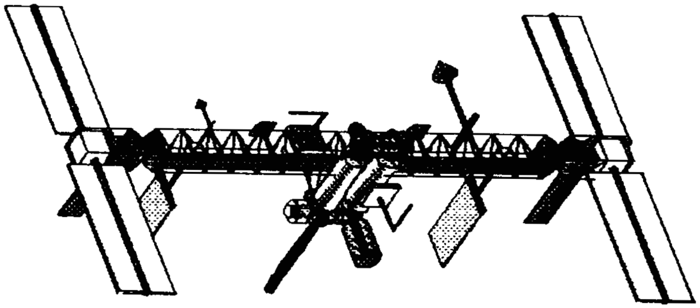
ASSEMBLY SEQUENCE HIGHLIGHTS



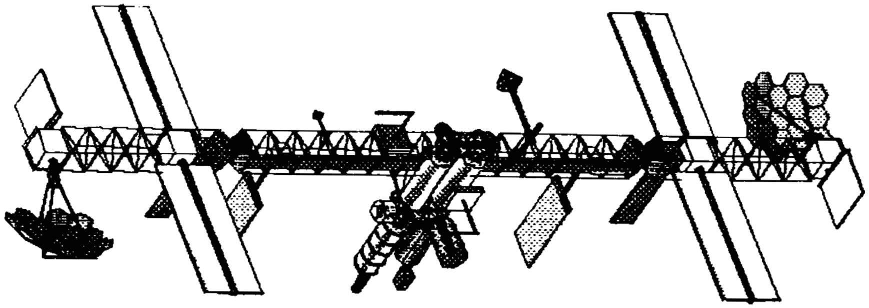
ASSEMBLY FLIGHT 1



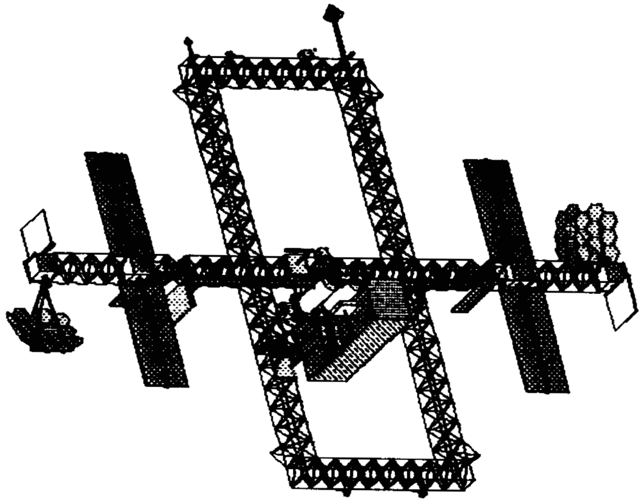
ASSEMBLY FLIGHT 5
(MAN TENDED CAPABILITY)



ASSEMBLY FLIGHT 8
(PERMANENTLY MANNED CAPABILITY)



ASSEMBLY FLIGHT 11
(INTERNATIONAL PARTICIPATION)



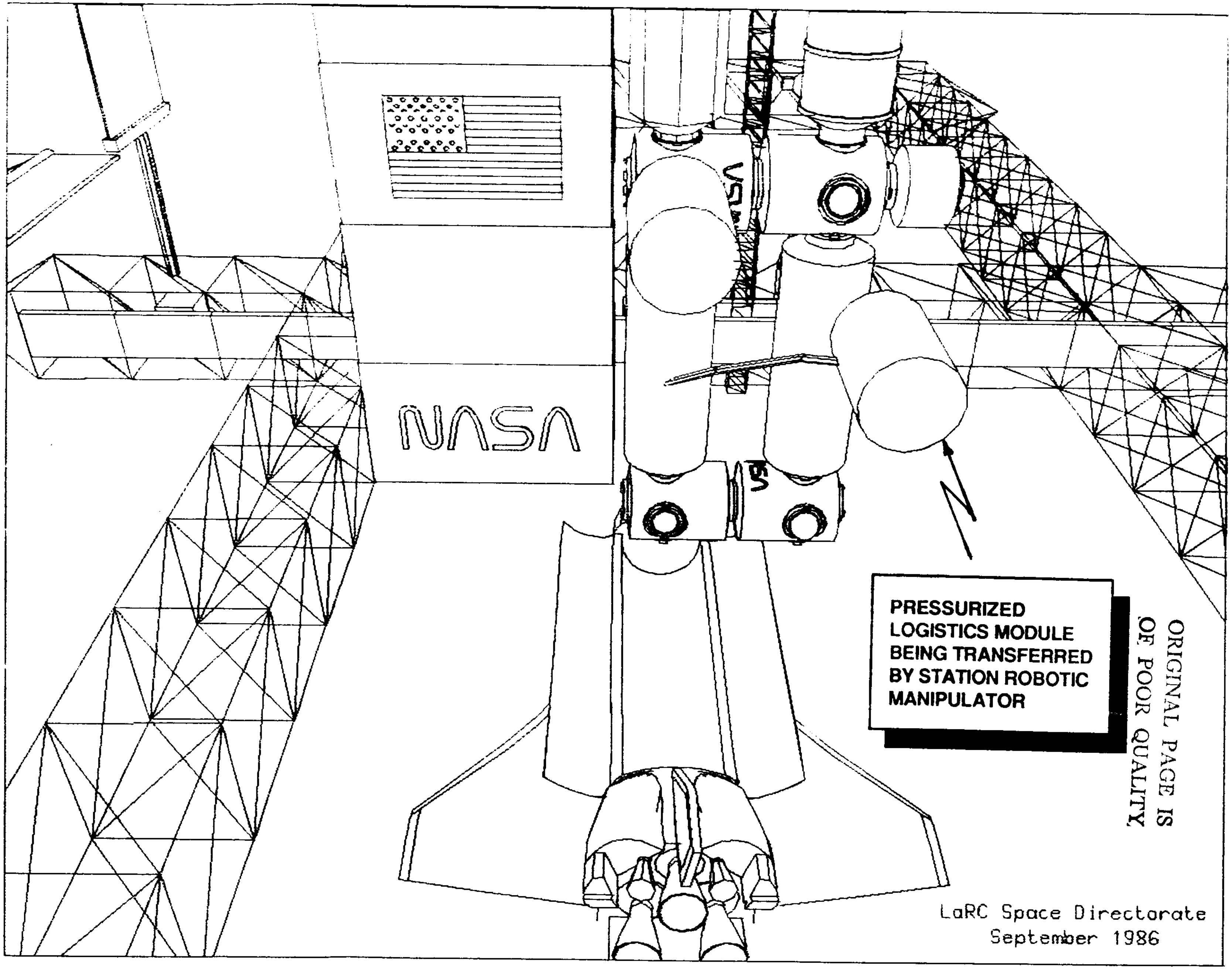
ASSEMBLY COMPLETE-FLIGHT 17

CETF BERTHED ORBITER CONFIGURATION

The Space Shuttle berthing location is at either of the two pressurized forward nodes that connect the hab and lab modules. Astronauts may translate between the Station and the berthed Orbiter via a pressurized docking adapter without the need for Extra Vehicular Activity (EVA) which requires space suits.

The Space Station Remote Manipulator System (SSRMS) is utilized to extract a pressurized cargo container from the Orbiter cargo bay which contains logistics for the crew as well as equipment and science instruments for use on the pressurized modules. These pressurized "Logistics Modules" are berthed on the aft nodes which connect the hab and lab modules.

CETF BERTHED ORBITER CONFIGURATION



CETF FLIGHT SEQUENCE OVERVIEW

This is a detailed break-down of STS flights supporting Station assembly and operations beginning with the first of 32 flights and ending with launch of the co-orbiting platform element. The second column designates the type and number of each flight, whether an assembly flight for the Manned Base (MB), platform (P), outfitting (OF), logistics (L), or platform refurbishment (PR). Outfitting refers to equipment to be installed inside a pressurized module, whereas logistics refers to resupply of spares and consumables. The first 4 flights (MB-1,2,3,4) all carry components of the manned base, including parts of the photovoltaic (PV) power system, thermal control system (TCS), the Space Station remote manipulator system (SSRMS), and the first user payloads (P/Ls). After the first platform launch (P-1) from the western test range (WTR), build-up of the Manned Base continues with the laboratory module (MB-5) and habitability module (MB-6). The lab module outfitting flight (OF-1) is needed because the fully equipped laboratory module is too heavy for a single STS launch, so part of its accommodations and user equipment must be offloaded before launch. These offloads are combined with follow-on assembly and installation flights for later installation in the pressurized modules.

Once the Station achieves permanently manned capability (PMC) on MB-8, the logistics flights occur at regular intervals (L-1, L-2, etc.). Additional power, 50 kw, is provided by launch and installation of the solar dynamic (SD) power subsystems on MB-9. International modules are added to the basic configuration on MB-10 (Japanese Experiment Module (JEM) and Exposed Facility (EF)) and on MB-11 (European (ESA) module). Augmentation of the JEM is provided separately on MB-14 by the Experimental Logistics Module (ELM). Important components of the Station servicing equipment are sent up on a series of flights (MB-12, 13, 15, and 17), with completion of this build-up and over-all Station initial operational capability (IOC) occurring on MB-17.

Critical Evaluation Task Force

FLIGHT SEQUENCE OVERVIEW

FLIGHT			
1	(MB-1)	1/2 PV, NODE, TRUSS	
2	(MB-2)	1/2 PV, NODE, TRUSS	
3	(MB-3)	TCS, AIRLOCK, P/L, SSRMS	
4	(MB-4)	AIRLOCK	
5	(PI)	U.S. POLAR PLATFORM (WTR)	
6	(MB-5)	U.S. LAB MODULE	← MAN-TENDED
7	(OF-1)	LAB MODULE OUTFITTING	
8	(MB-6)	U.S. HAB MODULE	
9	(P-2)	ESA POLAR PLATFORM (WTR)	
10	(MB-7)	NODES, CUPOLAS	
11	(MB-8)	CREW (4), LOGISTICS	← PMC
12	(MB-9)	SD POWER	← SD
13	(L-1)	LOGISTICS	
14	(MB-10)	JEM, EF #1	
15	(L-2)	LOGISTICS	
16	(MB-11)	ESA MODULE	

FLIGHT			
17	(L-3)	LOGISTICS	
18	(MB-12)	SERV. FAC., PAYLOADS	PHASE 1 ← SERVICE
19	(L-4)	LOGISTICS	
20	(MB-13)	SERV. FAC., OUTFITT.	PHASE 2 ← SERVICE
21	(L-5)	LOGISTICS	
22	(MB-14)	JEM EF #2, ELM	
23	(L-6)	LOGISTICS	
24	(MB-15)	MSC/TRANSPORTER	
25	(L-7)	LOGISTICS	
26	(PR-1)	PLATFORM SERV. (WTR)	
27	(L-8)	LOGISTICS	
28	(MB-16)	UPPER & LOWER BOOMS	
29	(L-9)	LOGISTICS	
30	(MB-17)	FAC. PAYLOADS	PHASE 3 ← SERVICE IOC
31	(L-10)	LOGISTICS	
32	(P-3)	CO-ORBITING PLATFORM (ETR)	

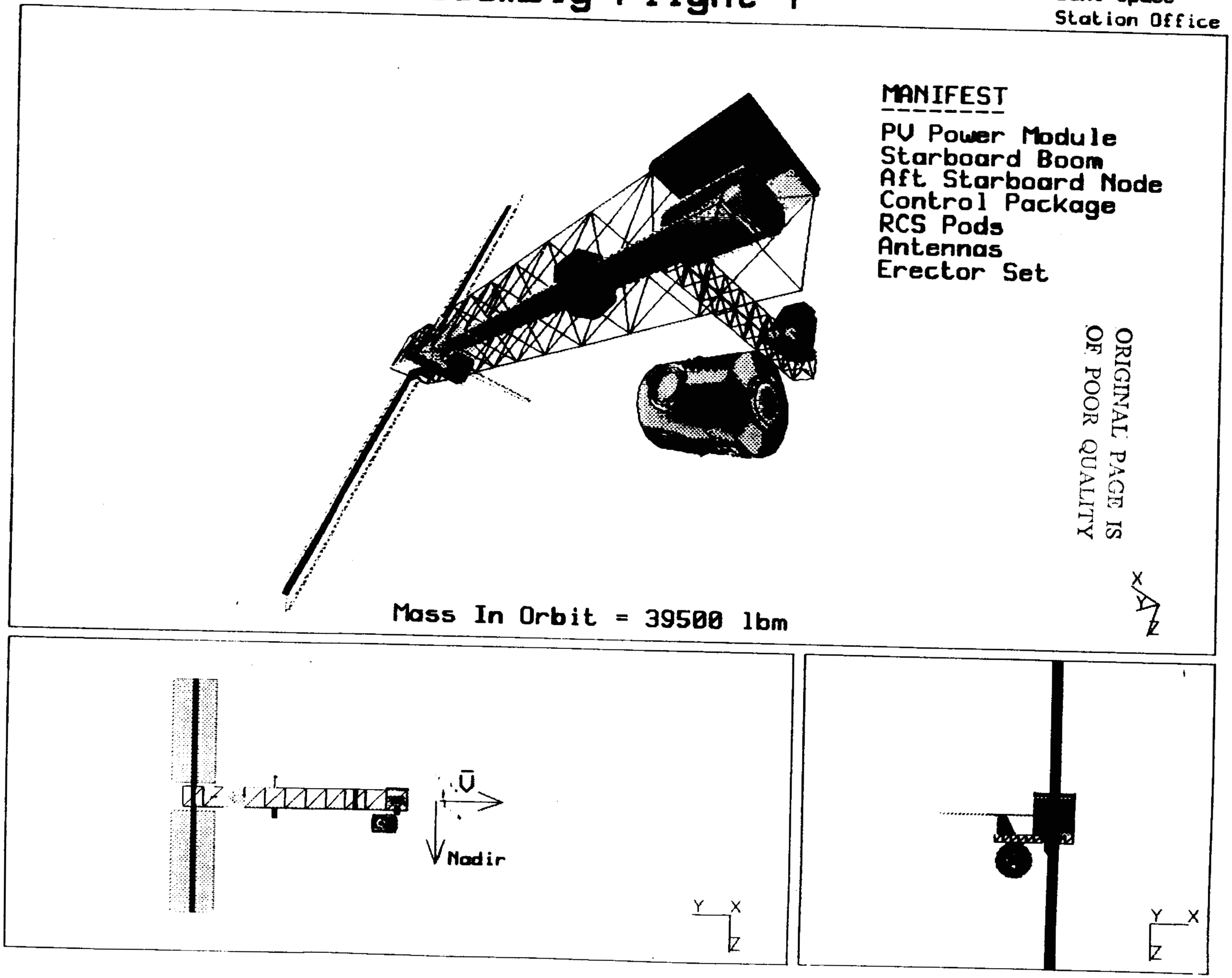
ASSEMBLY FLIGHT 1

The first Manned Base assembly flight includes the elements needed to construct a powered, dynamically stable subset of the ultimate Station configuration. These elements include power generation and distribution, attitude sensing and control, communications, and structural components.

At the completion of Flight 1 EVA, the partial Station is already capable of reboost and attitude control, and has available an initial 18.75 kw. of peak power. It flies in an arrow mode; that is, because of the location of the vehicle center of gravity and the aerodynamic effect of the large PV panels, the direction of motion is along the long truss axis with the panels in a minimum drag orientation.

Assembly Flight 1

LaRC Space
Station Office



MANIFEST

PV Power Module
Starboard Boom
Aft Starboard Node
Control Package
RCS Pods
Antennas
Erector Set

Mass In Orbit = 39500 lbm

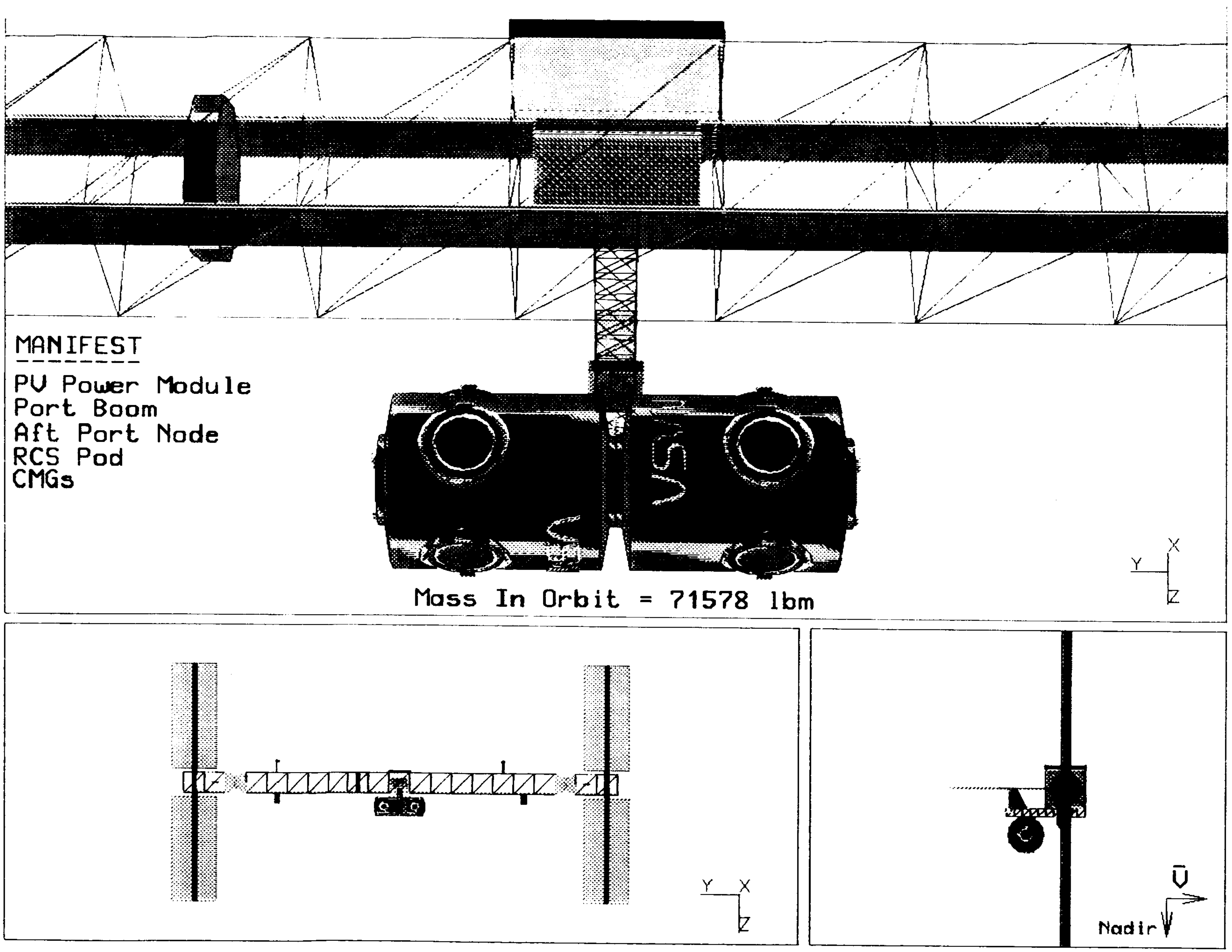
ASSEMBLY FLIGHT 2

The second flight manifests the opposite half of the basic truss structure which includes the aft node and PV module. After EVA completion, the structure is basically symmetrical, with the second set of PV panels deployed at the opposite end of the truss. An Orbiter docking adapter is installed on the second aft node for future use as a docking location.

Both solar arrays are operational at the end of Flight 2 delivering a peak 37.5 kw. of power. The umbilical cabling and thermal plumbing running along the utility tray is connected in orbit. Although the whole structure is now aerodynamically symmetrical, the "Arrow" flight mode orientation is still utilized to keep the large area solar arrays feathered to minimize aerodynamic drag which systematically causes orbital altitude decay. The vehicle is rotated for reboost delta V to be applied along the + X axis direction.

Assembly Flight 2

LaRC Space
Station Office



MANIFEST

PV Power Module
Port Boom
Aft Port Node
RCS Pod
CMGs

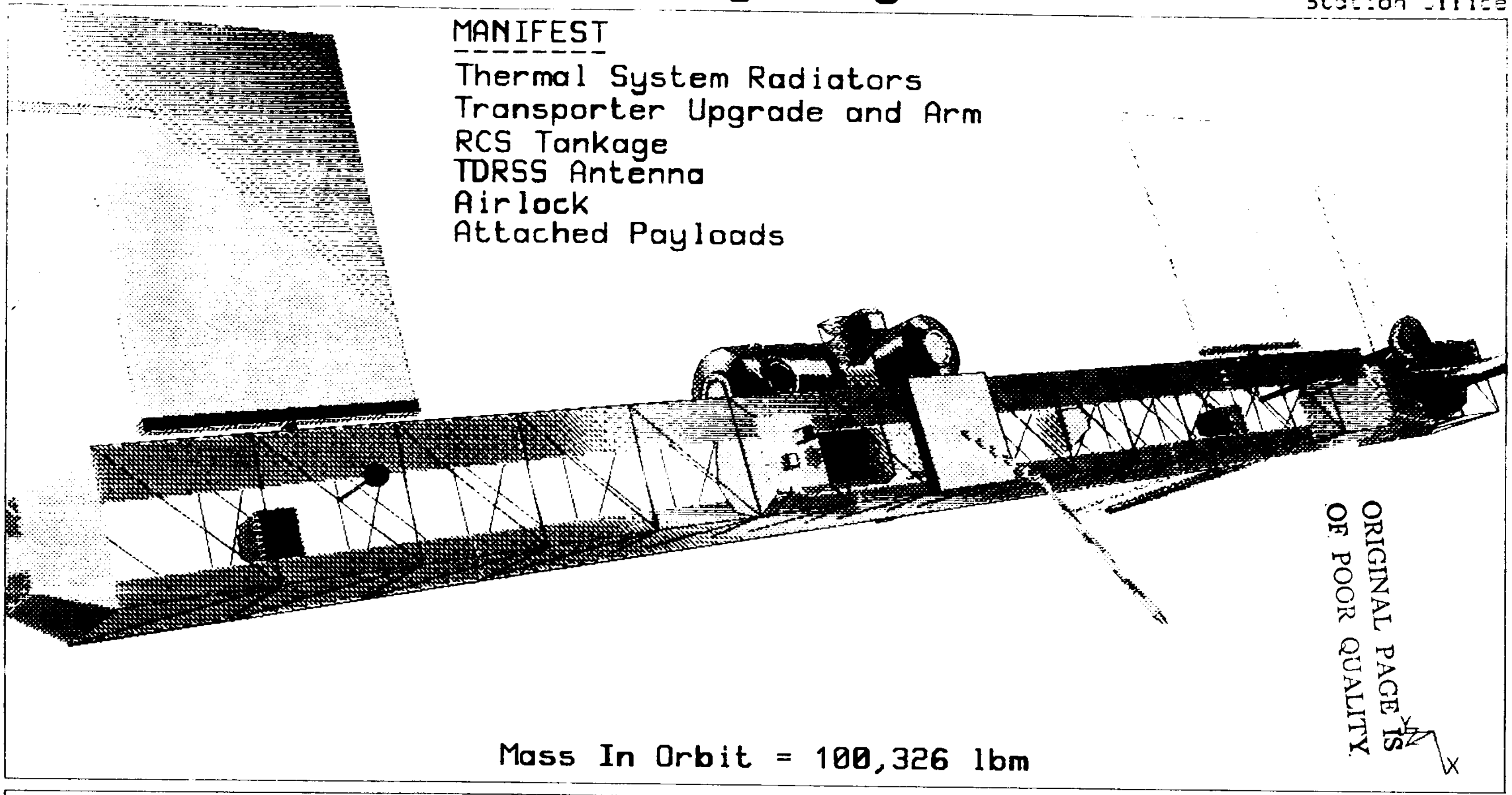
Mass In Orbit = 71578 lbm

ASSEMBLY FLIGHT 3

Four main packages are launched and assembled on this flight. Thermal radiators for the TCS are manifested, although only the port radiator is actually installed on flight 3. The Space Station Remote Manipulator System (SSRMS) is installed for later use assisting in assembly tasks. Its arm can be seen in the isometric view protruding from the foreside of the truss. The erector installed on Flight 2 will later be converted to a transporter unit for the SSRMS, making it a mobile system, and equipment to effect this conversion is brought up on Flight 3. RCS propellant tankage is brought up and installed, fully charged with an initial load of hydrogen and oxygen fuel. Also, the first complement of user payloads, to be attached to the truss, is carried up for installation.

This flight involves complicated Orbiter maneuvering, including multiple berthing/unberthing operations to accomplish the assembly sequence objectives. The EVA crew is also required to perform complex operations to assemble the varying types of payloads manifested on Flight 3.

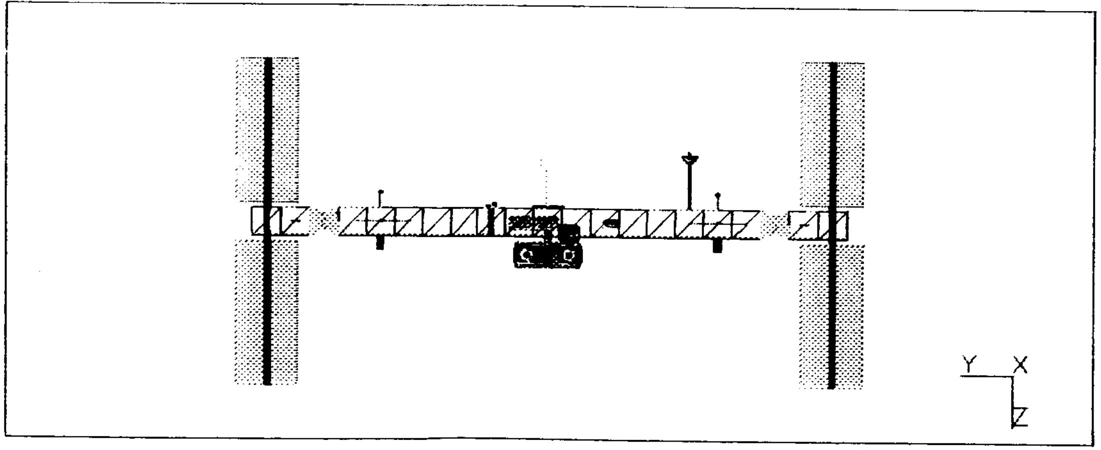
Assembly Flight 3

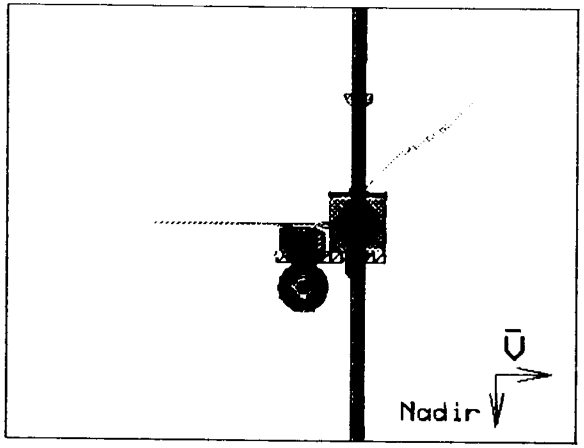


MANIFEST

- Thermal System Radiators
- Transporter Upgrade and Arm
- RCS Tankage
- TDRSS Antenna
- Airlock
- Attached Payloads

Mass In Orbit = 100,326 lbm



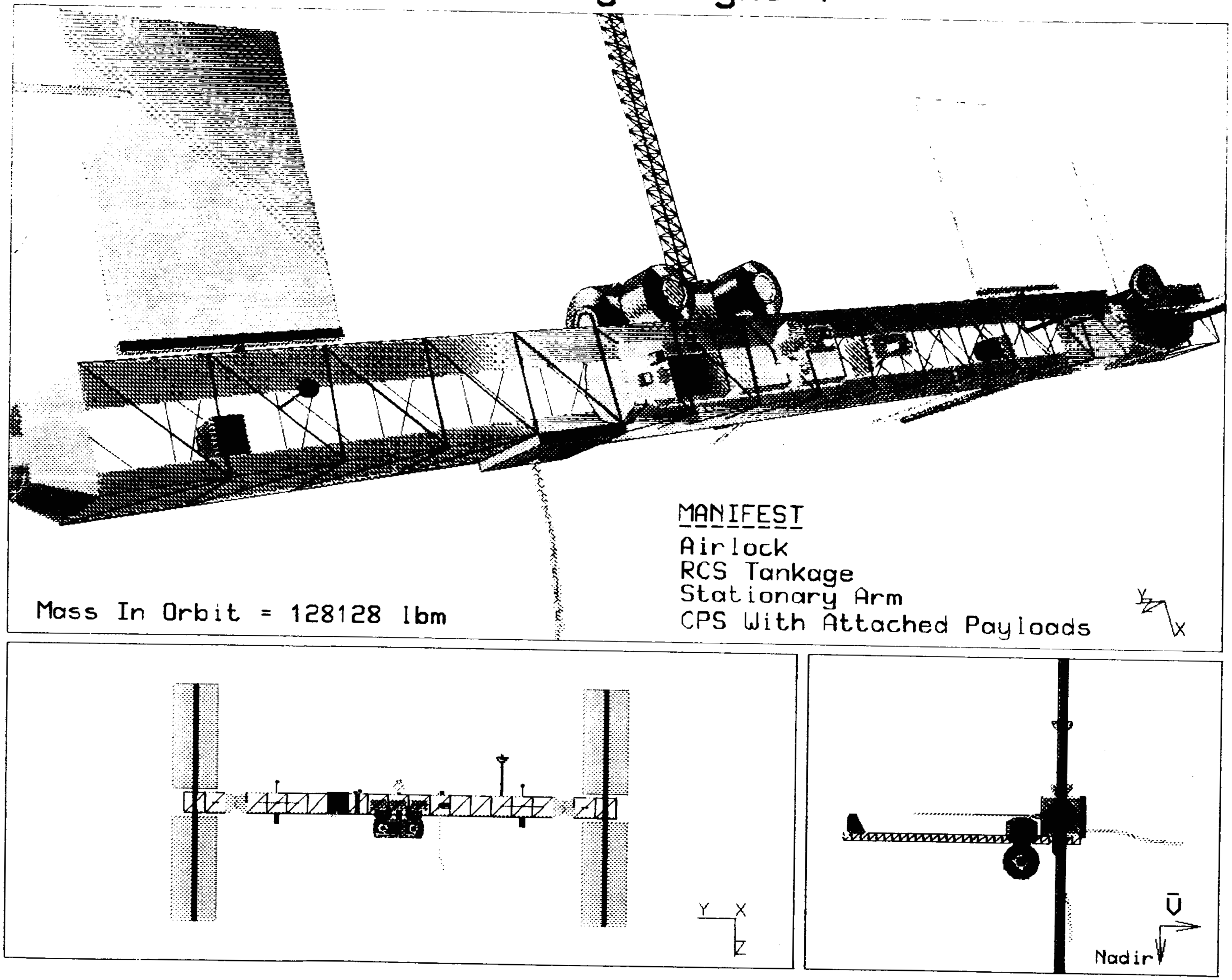


ASSEMBLY FLIGHT 4

Additional RCS tankage is manifested on this flight, in addition to the hyperbaric airlock, the stationary RMS (SRMS), and structure to support the SRMS. More user payloads are also carried up on this flight and includes a payload course pointing system (CPS).

After the Orbiter berths to the adapter on the aft port node, the (still fixed) SSRMS moves the existing airlock to the starboard side of the aft starboard node. The second (hyperbaric) airlock is then installed on the top of the aft port node, and the new RCS tankage is installed. The SRMS and its support structure are lashed to the truss for installation in a later flight. The SRMS is to be mounted on a structure attached to the Hab Module. The conversion equipment brought up on Flight 3 is now used to convert the erector into a transporter for the original SSRMS to provide a mobile arm capability. Note that the SRMS can also be plugged into the transporter later if desired. Finally, the starboard radiator assembly manifested on Flight 3 is installed.

Assembly Flight 4



Mass In Orbit = 128128 lbm

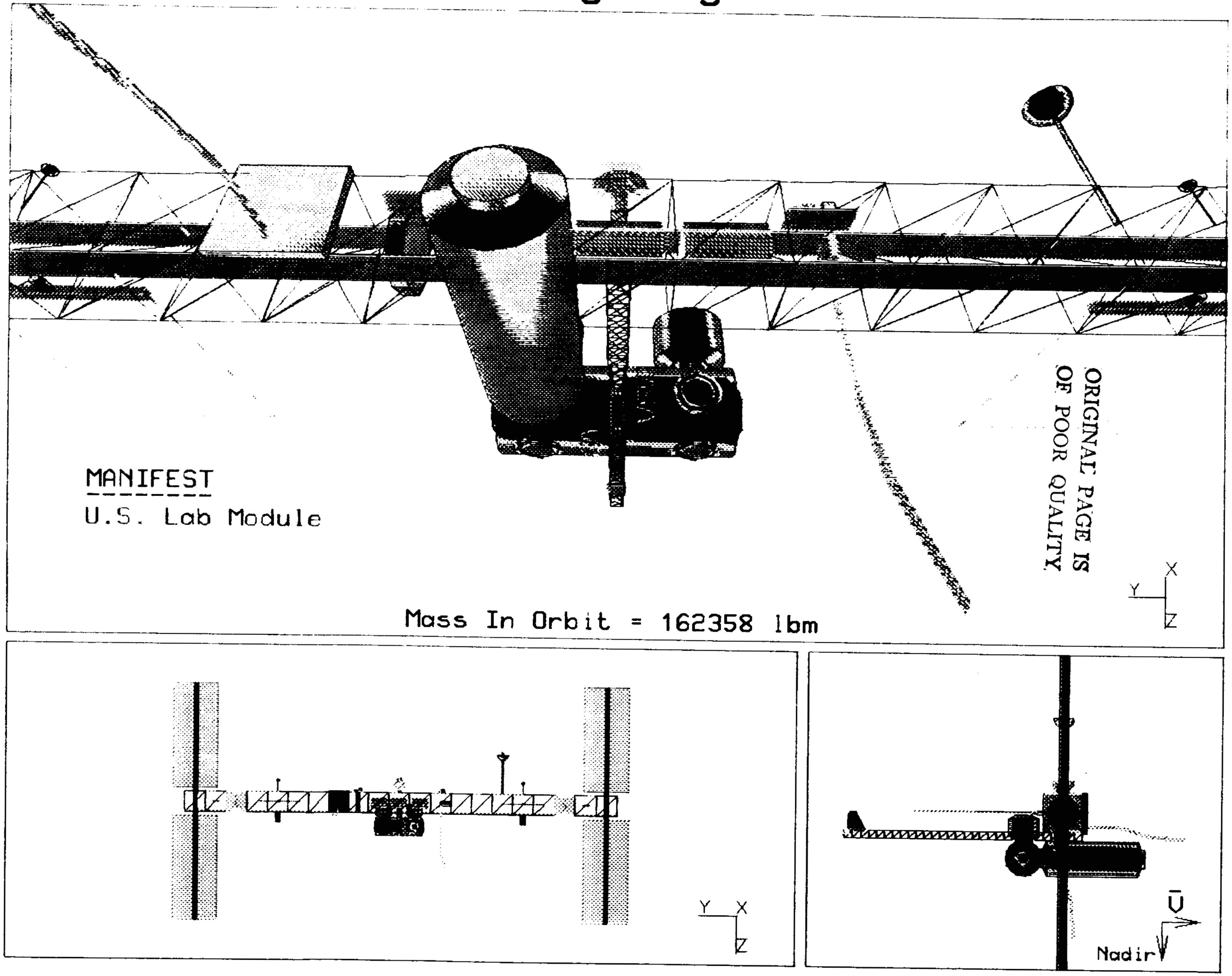
MANIFEST
Airlock
RCS Tankage
Stationary Arm
CPS With Attached Payloads

ASSEMBLY FLIGHT 5 (MTC)

On this flight, the Station achieves man-tended capability (MTC). The STS' entire lift capability is devoted to bringing up the lab module, which has had a portion of its internal accommodations and payloads removed prior to launch so as not exceed the STS lift capability. Pressurized egress from the Orbiter to the lab module is provided via the installation of a pressurized docking adapter. Crew staytime, however, is limited to Shuttle Orbiter logistics available.

At the completion of this mission, the lab module is fully functional, including 4 double racks of user equipment. Astronauts enter the lab for the first time on orbit and activate and verify correct functioning of the Station space suit called the Space Station Extravehicular Maneuvering Unit (SSEMU). A series of EVA flight tests are performed to qualify both the suit and backpack which will eventually be stored for exclusive use for station-based EVA.

Assembly Flight 5



MANIFEST

U.S. Lab Module

Mass In Orbit = 162358 lbm

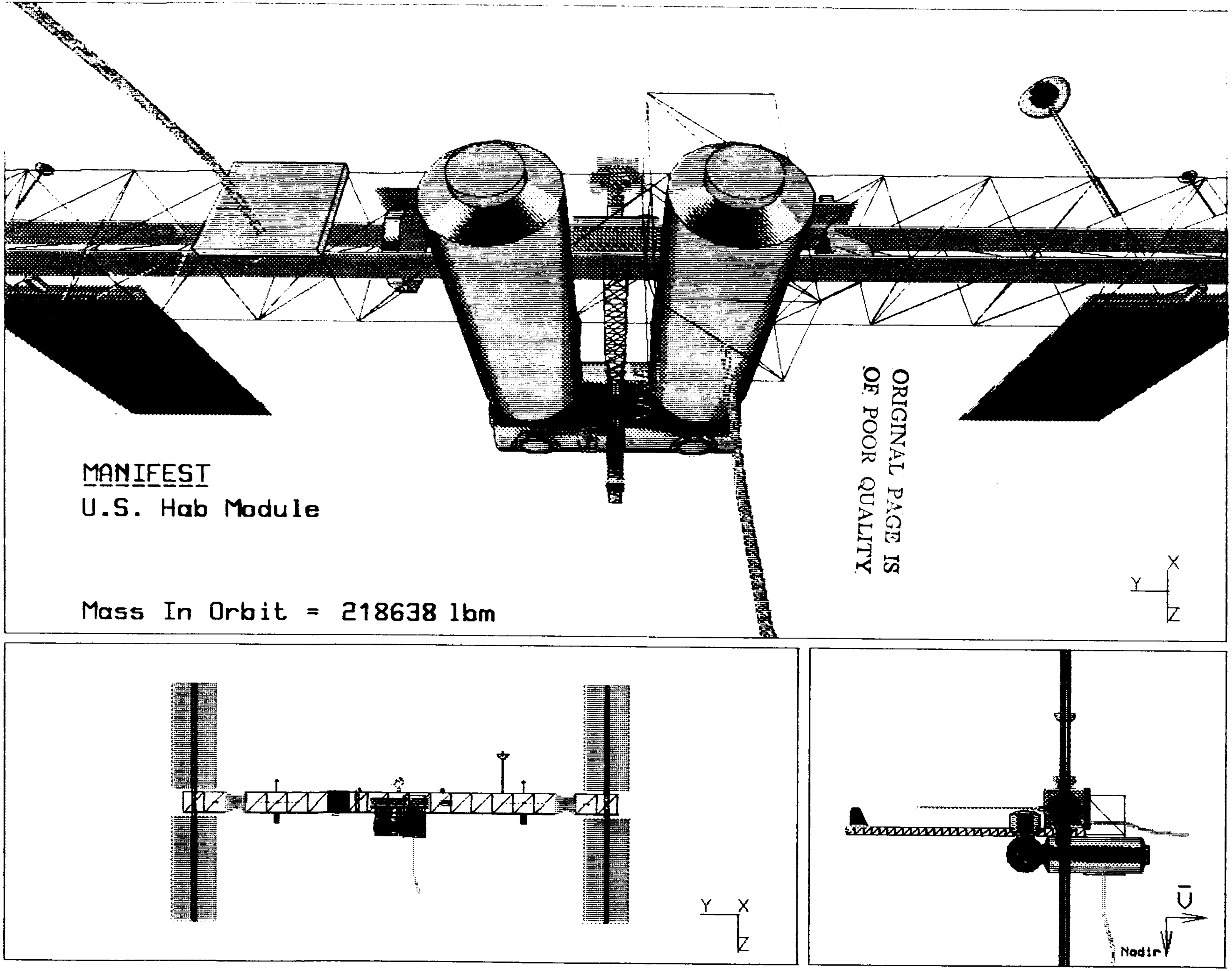
ASSEMBLY FLIGHT 6

This flight is devoted to carrying up the habitability module, which, together with the pressurized docking adapter, occupies the entire Orbiter bay.

First, the Orbiter berths to the truss docking adapter where it was left by the previous flight. The hab module is berthed to the aft node, and a long EVA is devoted to reinstalling the lab docking adapter to the hab module. Then, the Orbiter leaves the truss docking adapter and berths to this newly installed hab module docking adapter. The truss bay to support the stationary SRMS is installed on the hab module, and the SRMS is installed on it.

Astronauts enter the hab module via the pressurized docking adapter and confirm that all systems are functional.

Assembly Flight 6



MANIFEST
U.S. Hab Module

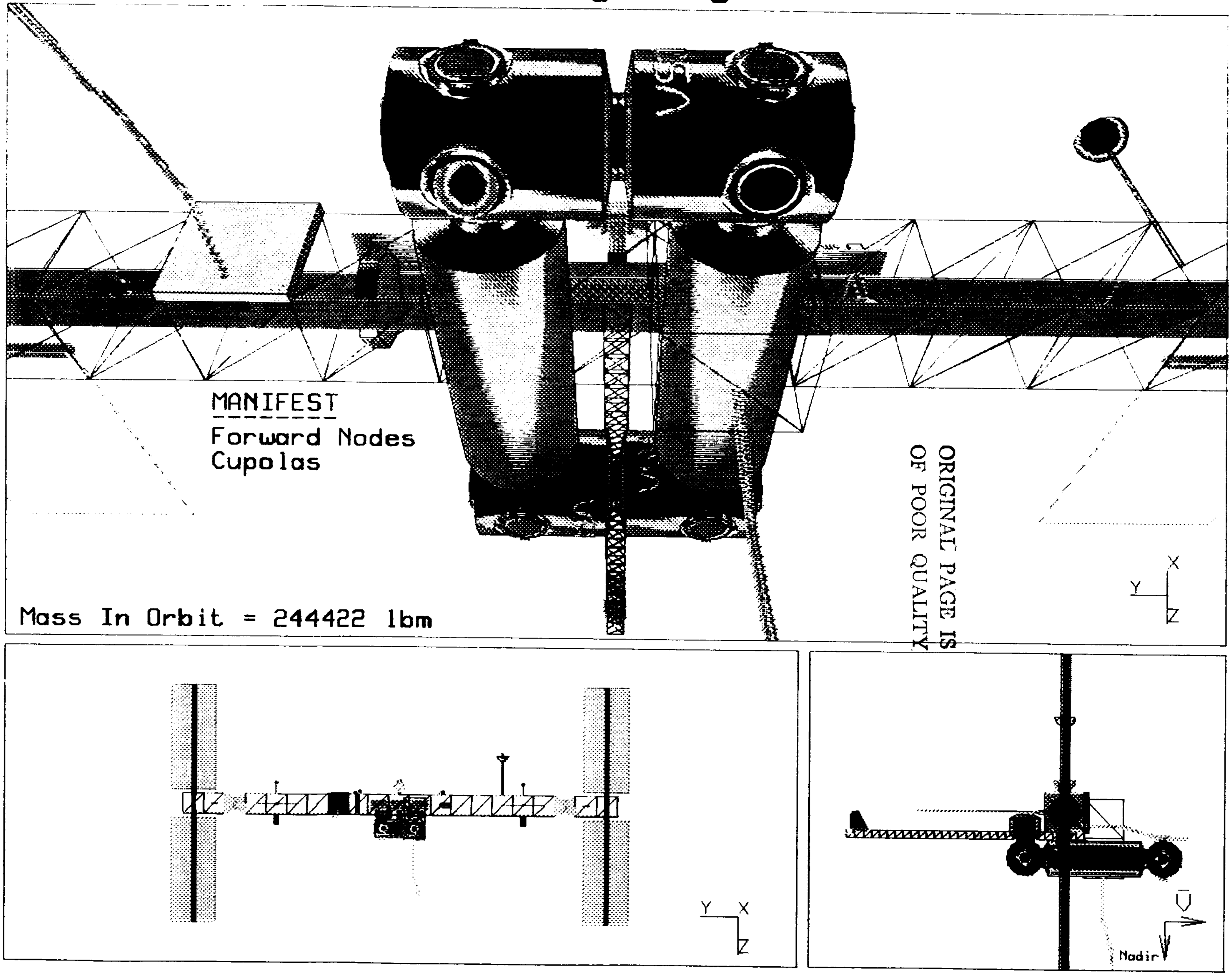
Mass In Orbit = 218638 lbm

ASSEMBLY FLIGHT 7

The pressurized volume configuration for PMC resembles an oval, where the longer lab and hab modules are joined at each end by a pair of shorter, connected nodes. This flight delivers the two forward nodes to complete this configuration. Also on Flight 7 are two cupolas, which are enlarged node viewports used for proximity operation viewing. As substantial amount of subsystem and user equipment earlier offloaded preflight from the modules for weight reasons is manifested for installation. SSEMUs to support Station crew EVA are also manifested and will be based on the Station for future use.

After the Orbiter berths to the truss docking adapter where it was left near the hab module, the hab docking adapter is removed in preparation for installing the forward nodes. Now, however, the SRMS is available to assist. The SRMS receives the starboard node from the STS RMS and berths it to the lab module, and the procedure is repeated to berth the second node to the hab module. The cupolas are then installed on the forward nodes. After the pressurized docking adapters are reinstalled in the forward nodes, the Orbiter berths to one of the nodes and an IVA to complete internal connections is carried out.

Assembly Flight 7



MANIFEST

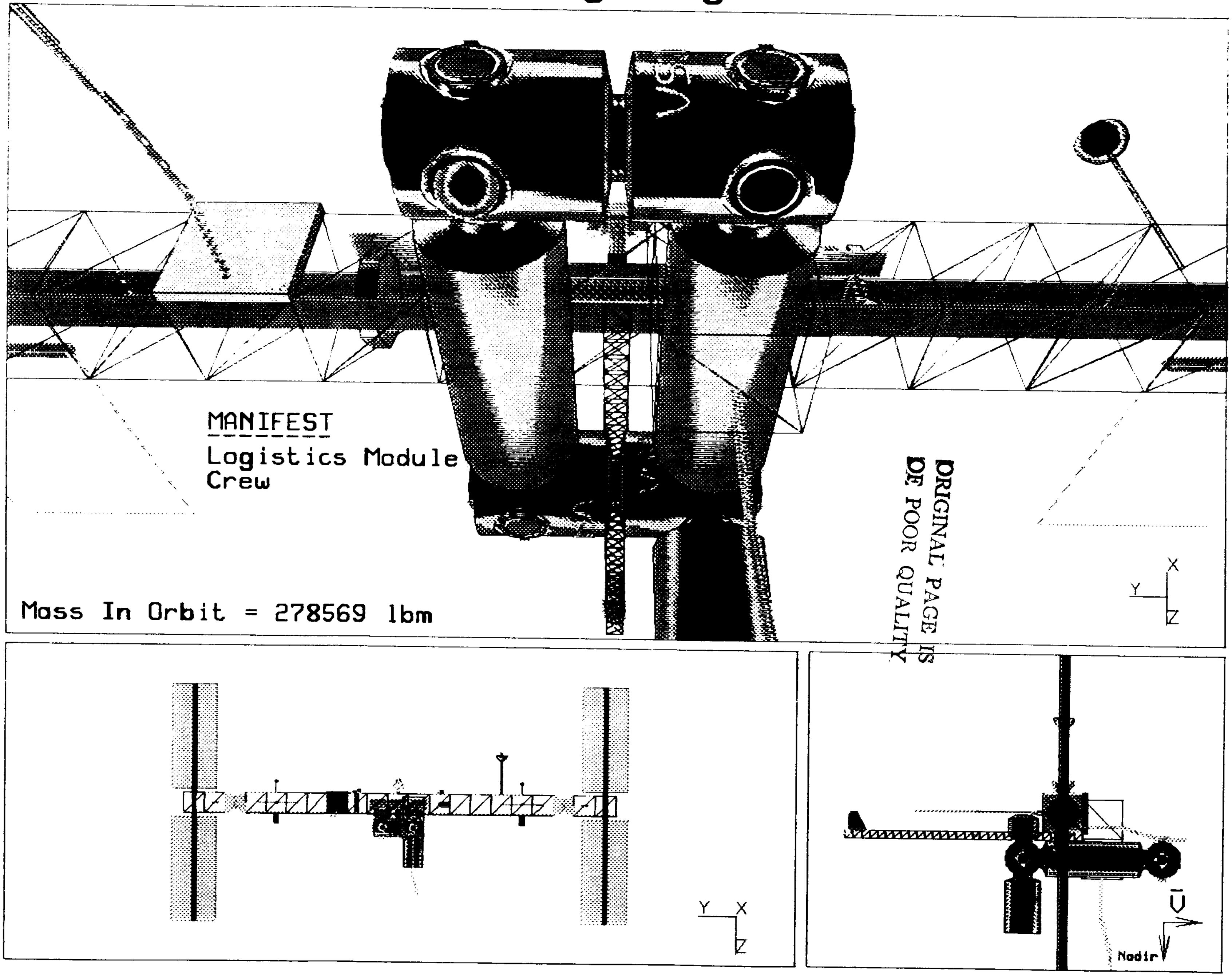
Forward Nodes
Cupolas

Mass In Orbit = 244422 lbm

ASSEMBLY FLIGHT 8 (PMC)

Flight 8 manifests crew and a pressurized logistics module. With this flight, the Station receives logistics for 180 days and its first crew of 4 to establish a permanently manned capability (PMC).

Assembly Flight 8



MANIFEST

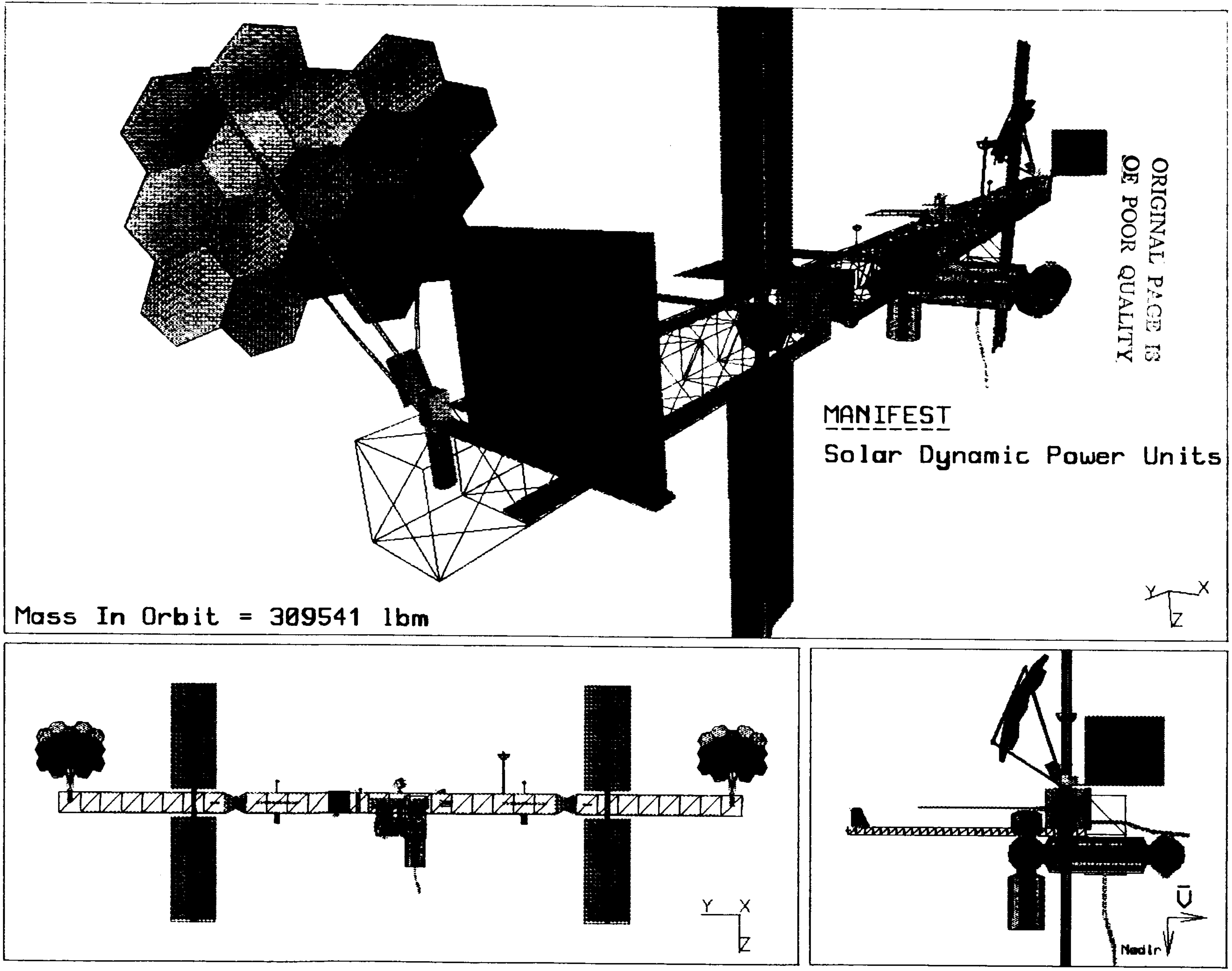
Logistics Module
Crew

Mass In Orbit = 278569 lbm

ASSEMBLY FLIGHT 9 - (SOLAR DYNAMIC)

One major focus for Station user accommodation is the availability of adequate electrical power to support all desired operations, particularly some of the more demanding science and commercial payloads. On this flight, a pair of solar dynamic power generation systems are installed, increasing total available power by 50 kw to 87.5 kw.

Assembly Flight 9



MANIFEST

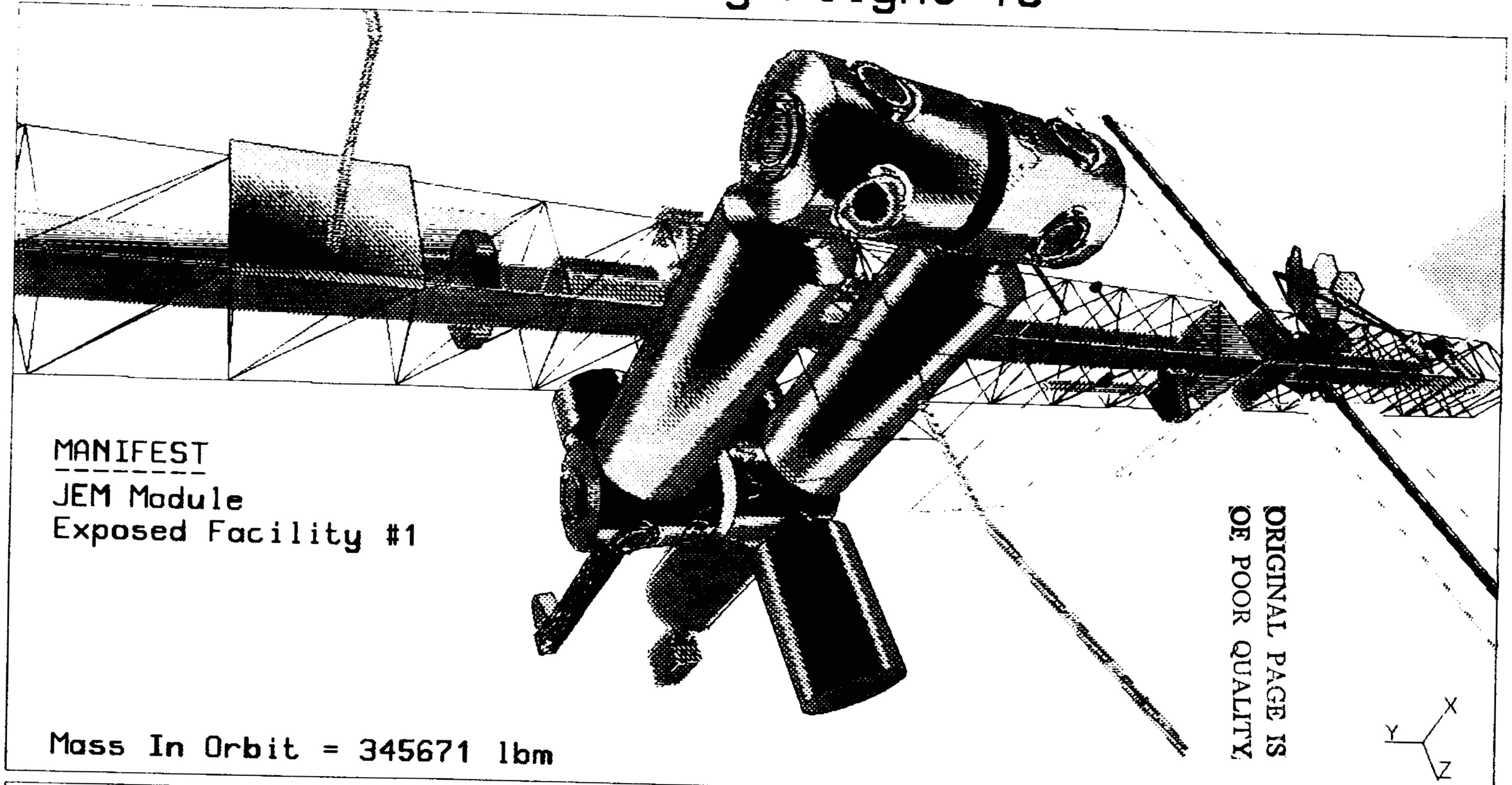
Solar Dynamic Power Units

Mass In Orbit = 309541 lbm

ASSEMBLY FLIGHT 10 (INTERNATIONAL)

On this flight, international participation commences with the installation of the Japanese Experiment Module (JEM).

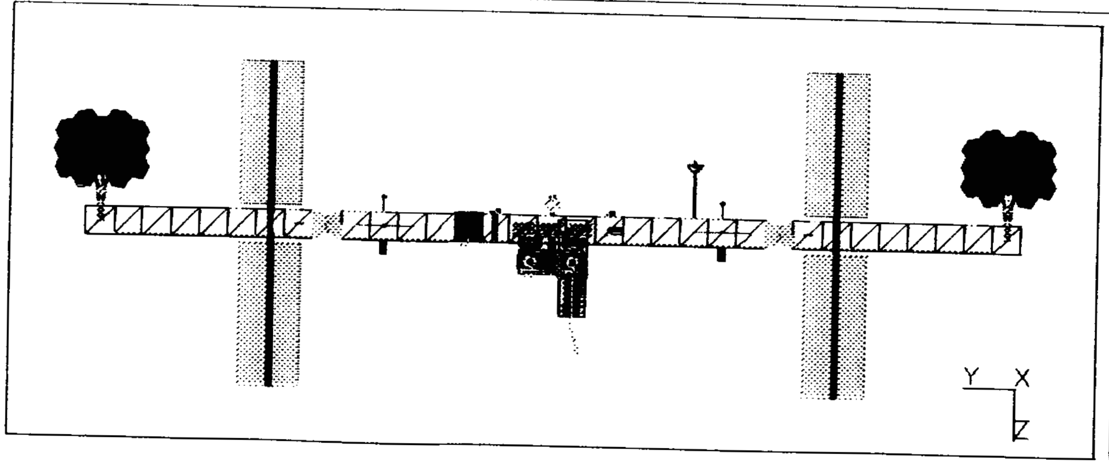
Assembly Flight 10

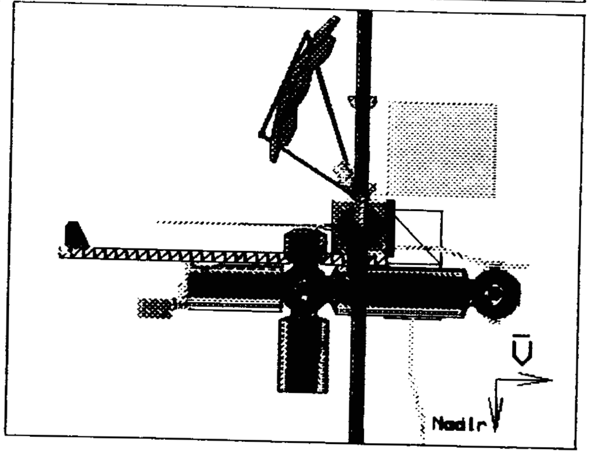


MANIFEST

JEM Module
Exposed Facility #1

Mass In Orbit = 345671 lbm

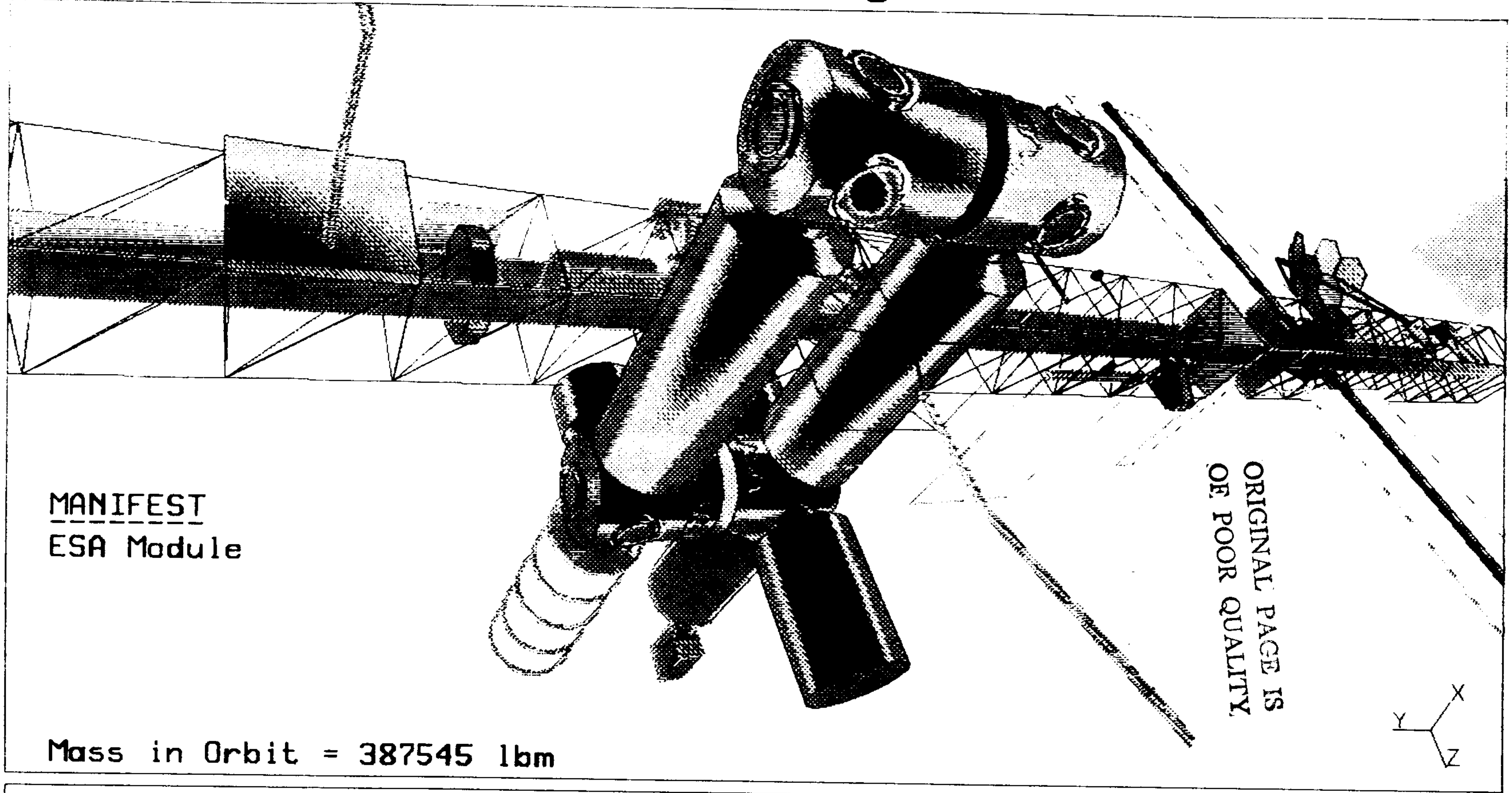




ASSEMBLY FLIGHT 11 - (INTERNATIONAL)

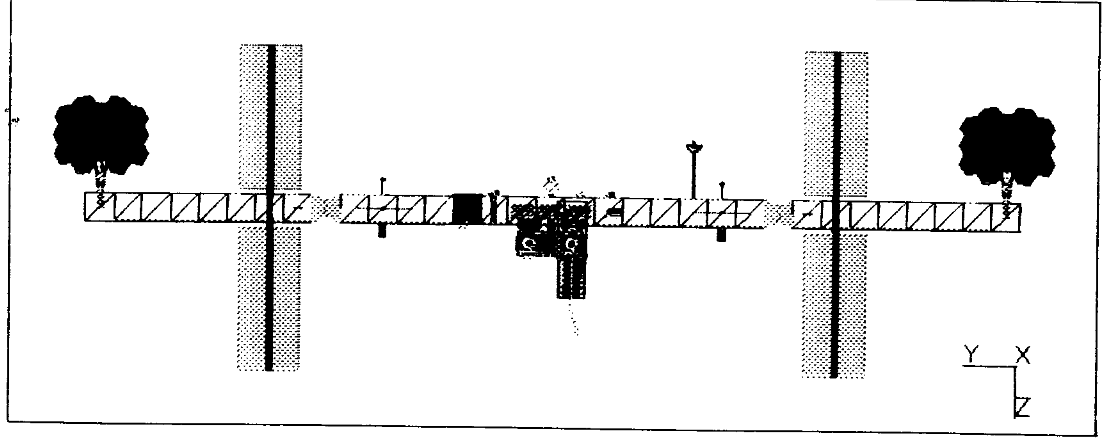
The European Space Agency (ESA) module is installed on this flight. This completes the planned IOC configuration of pressurized laboratory volume, including facilities required for life sciences research.

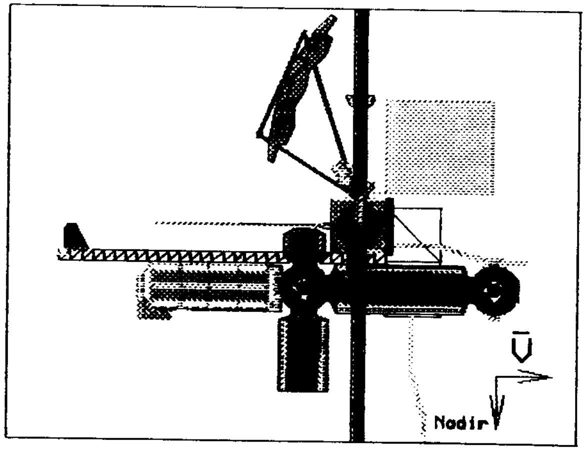
Assembly Flight 11



MANIFEST
ESA Module

Mass in Orbit = 387545 lbm

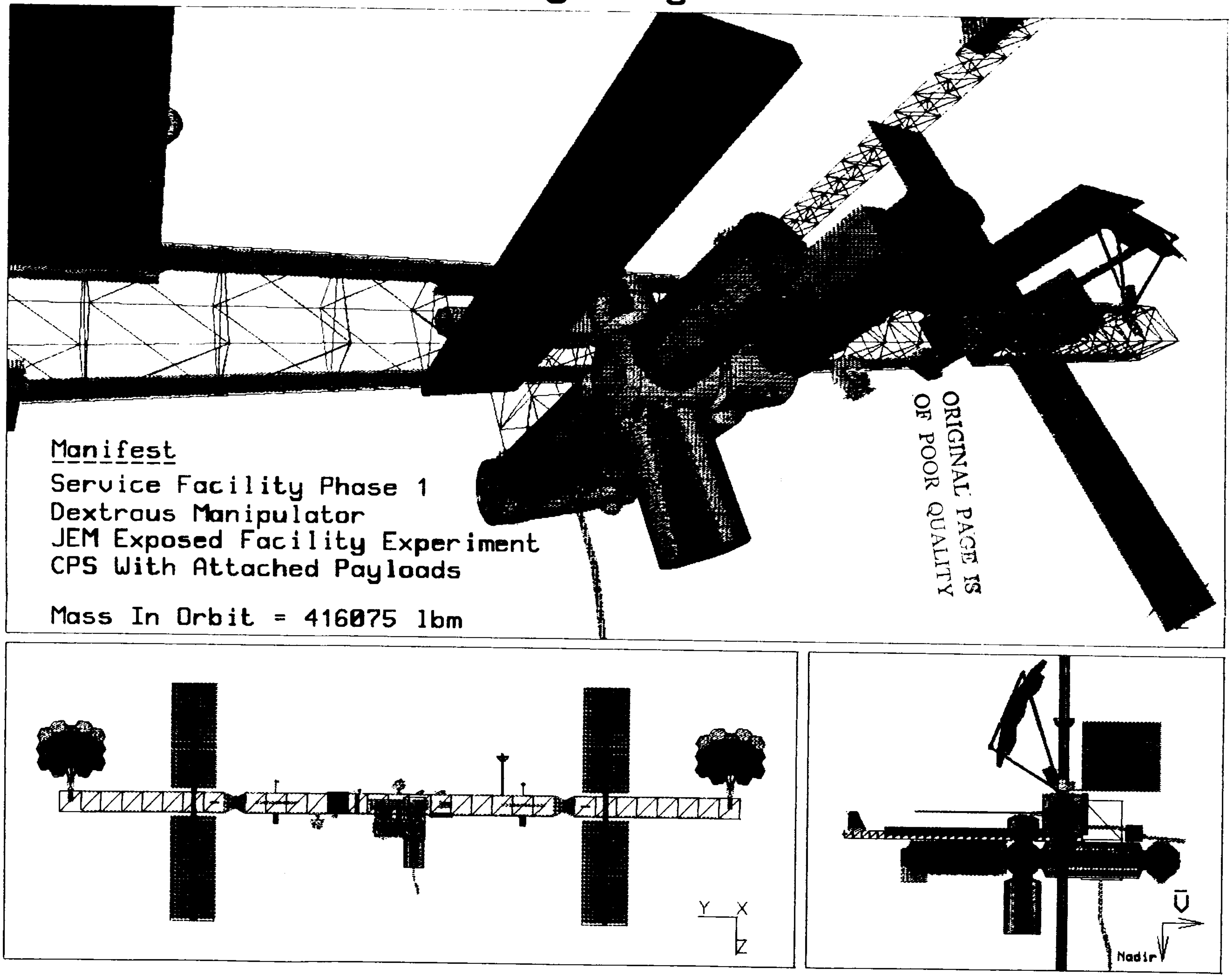




ASSEMBLY FLIGHT 12 (SERVICING)

The phased build-up of Station servicing capability spans several flights. In Fslight 12, the first phase of this capability is manifested and installed. Additional user payloads are also manifested and installed.

Assembly Flight 12



<u>Manifest</u>

Service Facility Phase 1
Dextrous Manipulator
JEM Exposed Facility Experiment
CPS With Attached Payloads

Mass In Orbit = 416075 lbm

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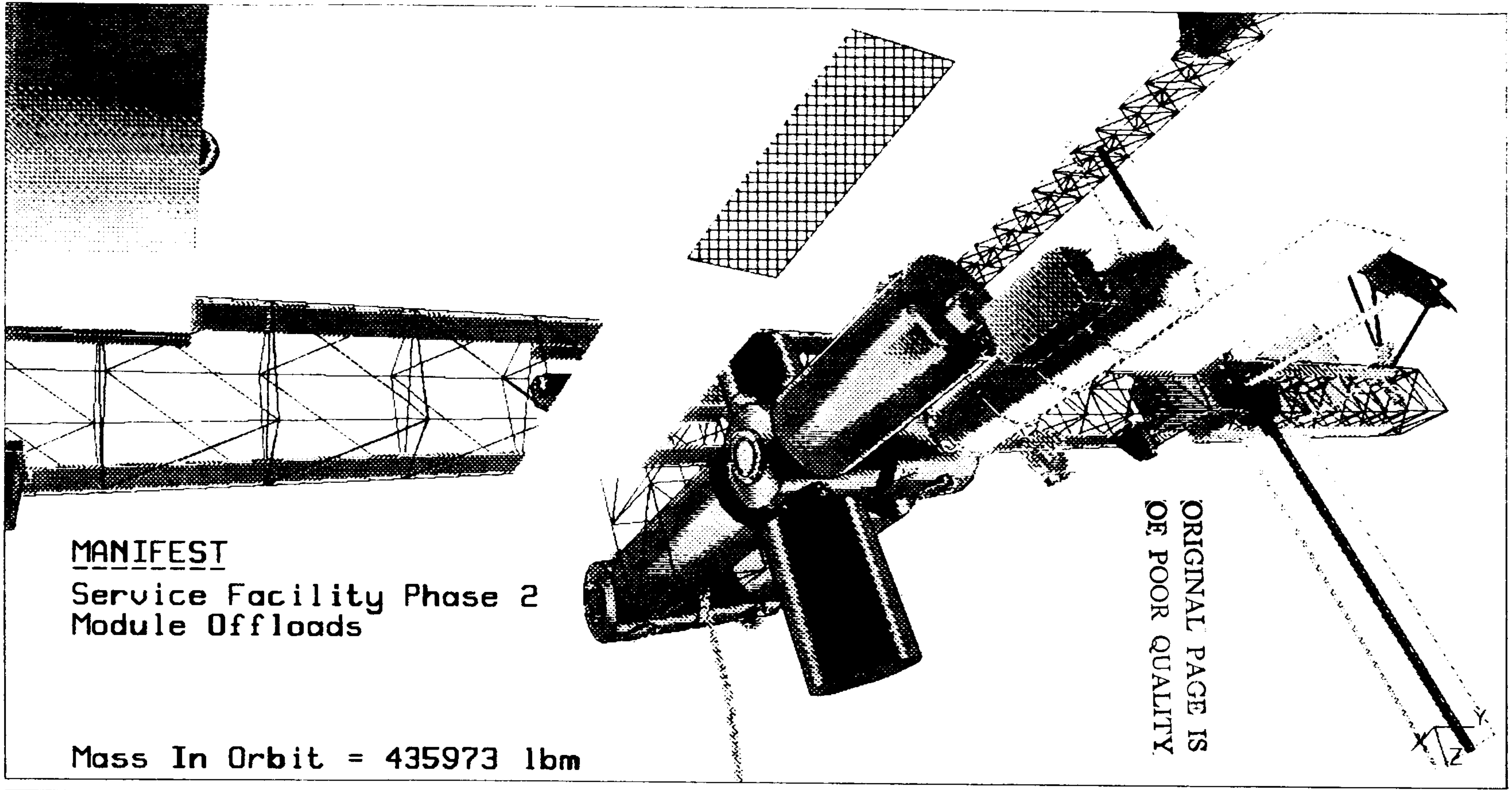
ASSEMBLY FLIGHT 13 - (SIGNIFICANT SERVICING)

With Flight 13, the Station servicing bay is in place and available for servicing the OMV, free flyer platforms, and payloads attached to the Station truss. This completes Phase 2 of the service facility.

Assembly Flight 13



MANIFEST

Service Facility Phase 2
Module Offloads

Mass In Orbit = 435973 lbm

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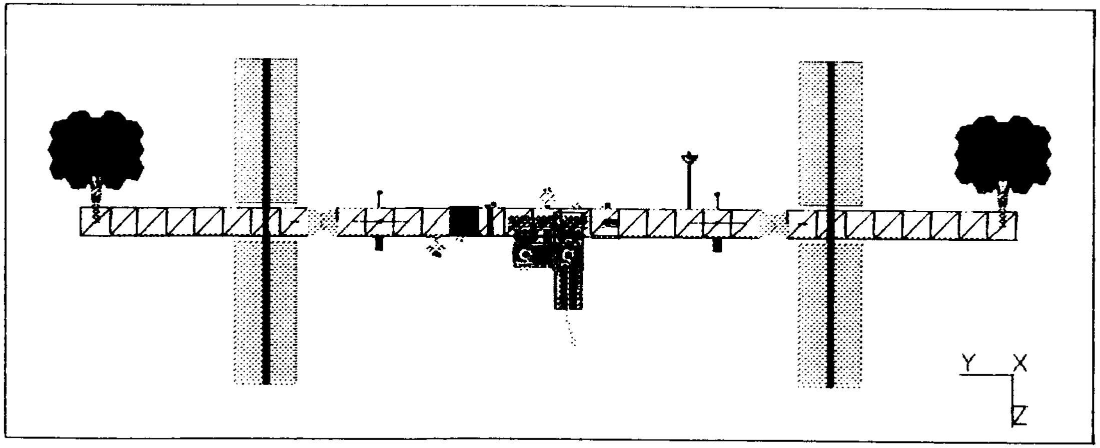
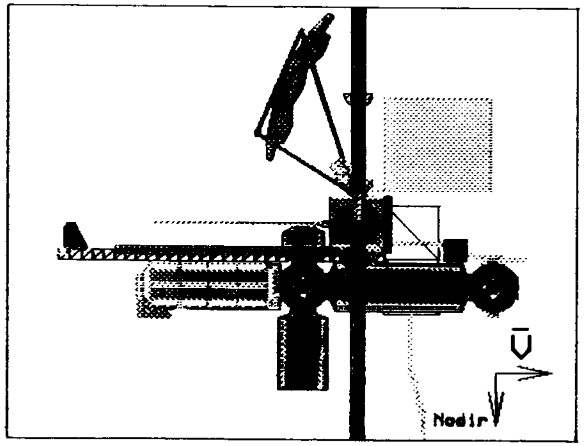
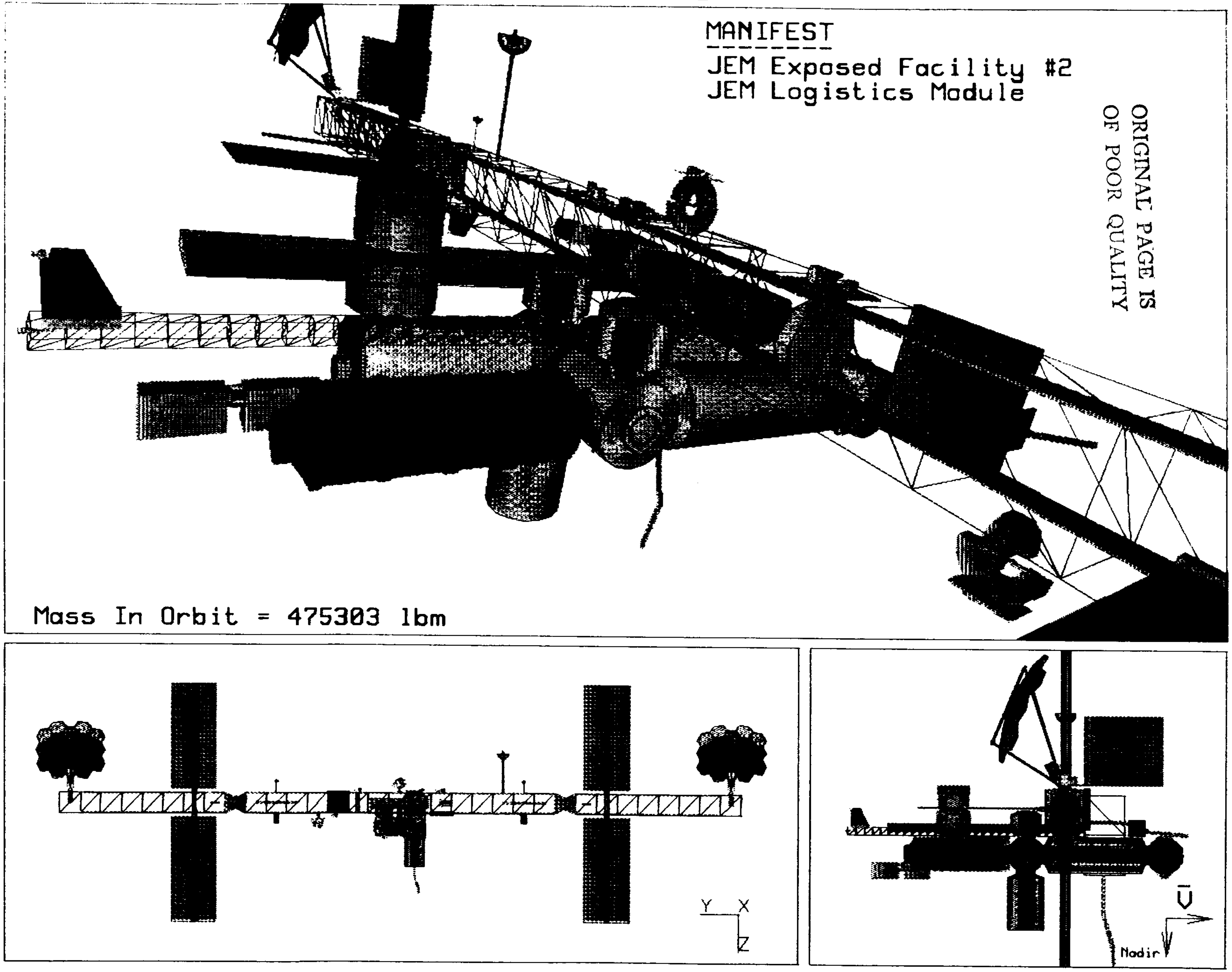




ASSEMBLY FLIGHT 14 (INTERNATIONAL)

On this flight, the second JEM Exposed Facility and Experiment Logistics Module (ELM) is manifested and installed.

Assembly Flight 14



MANIFEST

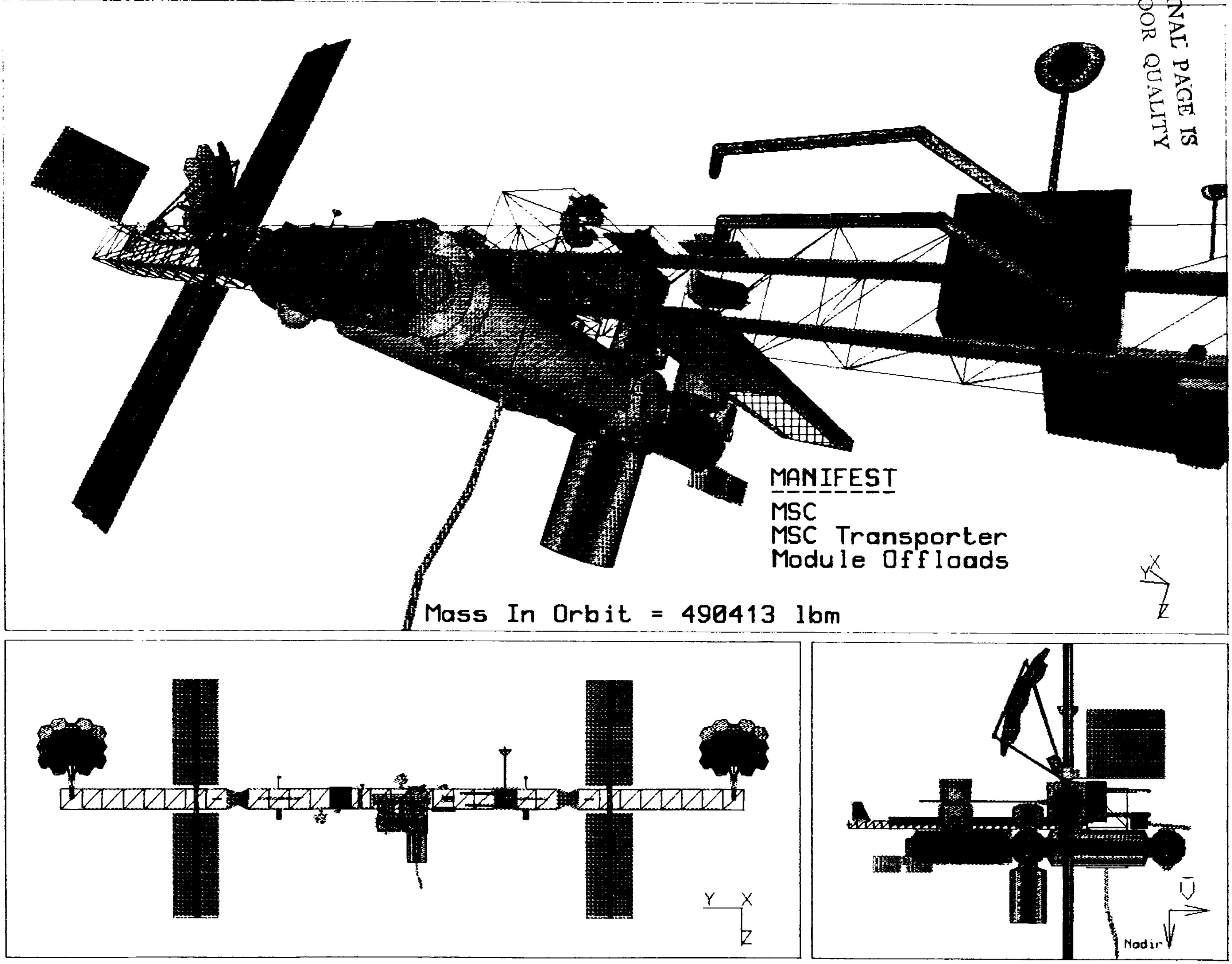
JEM Exposed Facility #2
JEM Logistics Module

Mass In Orbit = 475303 lbm

ASSEMBLY FLIGHT 15

The Canadian Mobile Servicing Centre (MSC) is brought up and installed on this flight.

Assembly Flight 15



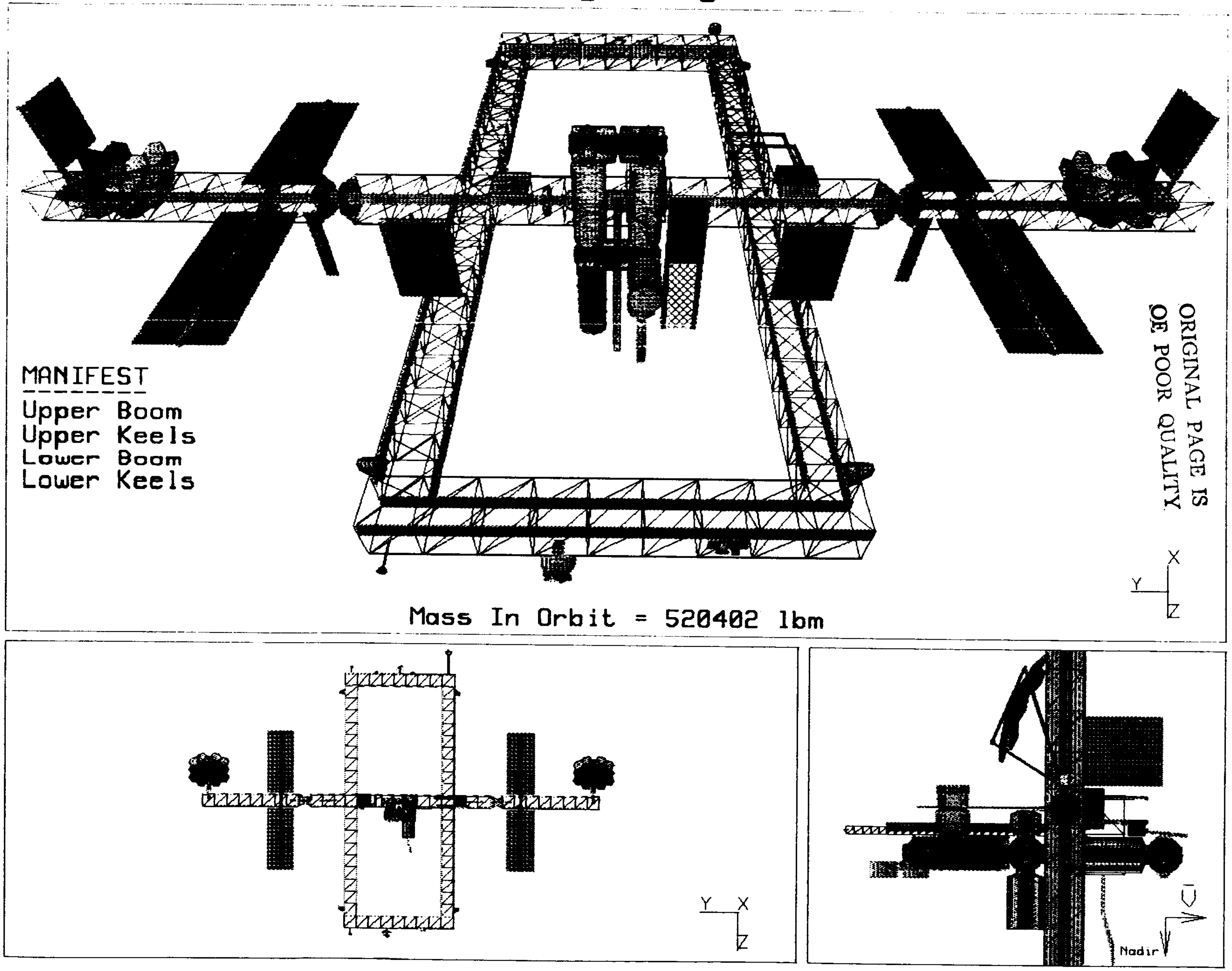
MANIFEST
MSC
MSC Transporter
Module Offloads

Mass In Orbit = 490413 lbm

ASSEMBLY FLIGHT 16

The upper and lower booms of the full rectangular configuration are manifested on Flight 16. Station based EVA is utilized to complete the structural assembly and installation of utilities.

Assembly Flight 16



MANIFEST

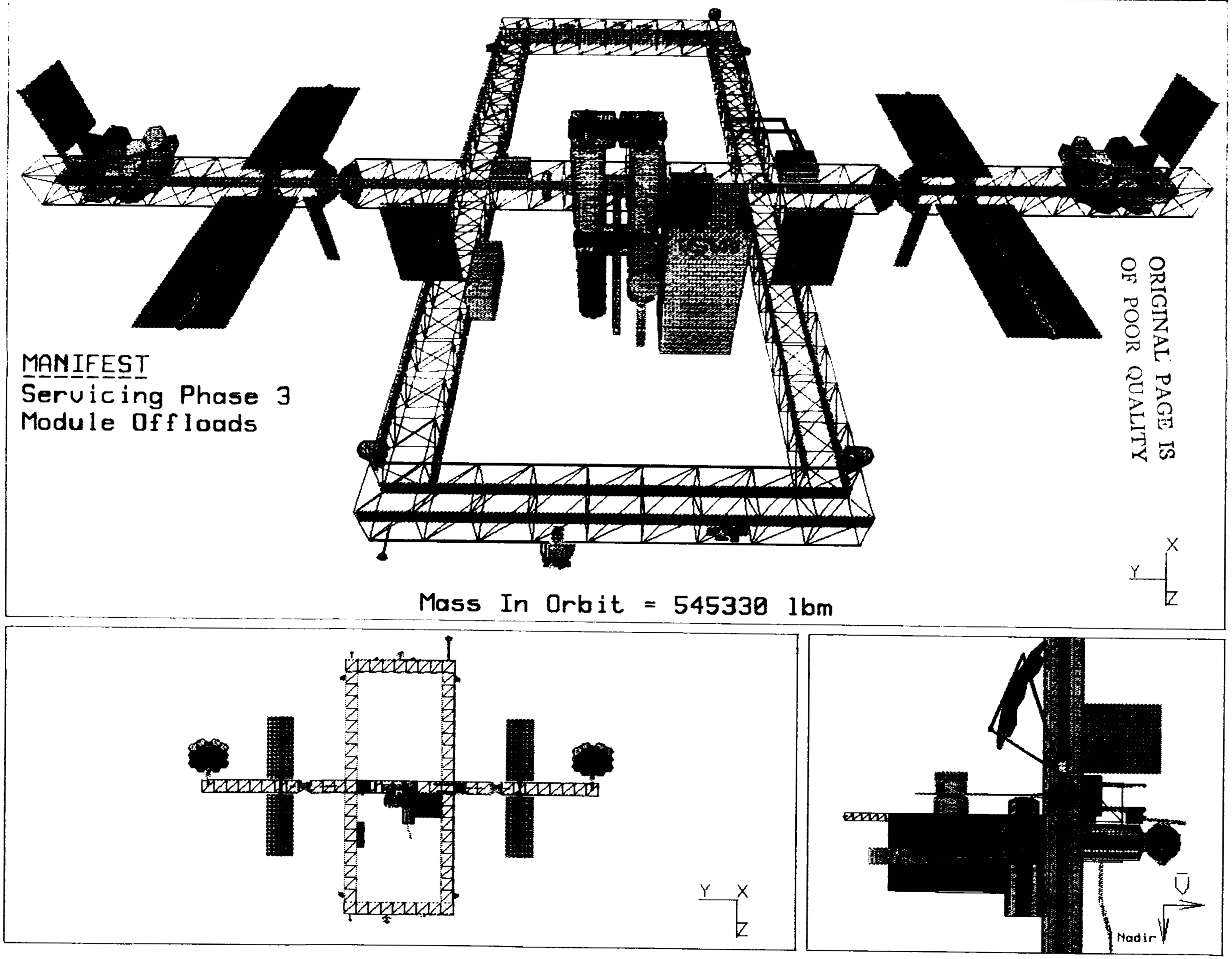
- Upper Boom
- Upper Keels
- Lower Boom
- Lower Keels

Mass In Orbit = 520402 lbm

ASSEMBLY FLIGHT 17 - (IOC)

Flight 17 marks the achievement of initial operational capability (IOC). The upper and lower trusses of the full rectangular configuration are in place, utilities are installed, and the entire structure is available for placement of user equipment or other uses. The Mobile Servicing System Maintenance Depot (MMD) is installed to complete the MSC.

Assembly Flight 17



MANIFEST
Servicing Phase 3
Module Offloads

Mass In Orbit = 545330 lbm

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4.0 ASSEMBLY: HLLV UTILIZATION OPTIONS

HLLV UTILIZATION OPTIONS

Concepts for utilization of HLLV for Space Station assembly are seen to fall into two categories: those which are compatible with the Shuttle and, therefore, current SS design, and those which require configuration redesign. The Shuttle compatible options impact the SSP the least, while the redesign options minimize on-orbit assembly and verification.

Utilization of HLLVs later on in the assembly sequence, after PMC, is seen to have the minimum impact on the Space Station Program because resources for dual launch vehicle compatibility do not have to be considered early in the program as up front costs. However, early commitment to HLLV utilization permits a flight assembly sequence to be derived that optimizes the mass needed to be delivered to orbit which can greatly reduce the total number of Shuttle flights required.

Given a HLLV early in the Space Station design definition phase, alternative configuration options could address two current program issues to (1) reduce Shuttle based EVA and (2) maximize ground based verification of key Space Station elements. These alternatives and options for early and late Space Station program utilization of HLLVs will be assessed and evaluated in this report.

HLLV UTILIZATION OPTIONS

SHUTTLE COMPATIBILITY

- LATE ASSEMBLY UTILIZATION
  - POST PMC ASSEMBLY & GROWTH
  - MINIMUM PROGRAM IMPACT
- EARLY ASSEMBLY UTILIZATION (PRE PMC)
  - PRE PMC MASS TO ORBIT OPTIMIZATION
  - MINIMIZES NUMBER OF SHUTTLE FLIGHTS

CONFIGURATION REDESIGN

- MODIFIED TRANSVERSE BOOM
  - FULLY DEPLOYABLE UTILITIES MINIMIZES EVA
- INTEGRATED RACE TRACK
  - FULLY GROUND VERIFIED PMC MODULE PATTERN

POST PMC HLLV UTILIZATION OPTION

In this option, HLLVs are used for SS assembly after Permanently Manned Capability (PMC) has been achieved. Prior to PMC ELVs of sufficient performance capability are utilized to launch the polar platforms. The flight sequence described permits the manned base Station assembly flights to remain solely Shuttle compatible which has a minimal impact on the current program definition.

If single engine SDVs are utilized for platform launches, shuttle bay compatibility can be maintained, thereby further minimizing program impacts and permitting a dual launch compatibility for all polar platform flights.

POST PMC HLLV UTILIZATION OPTION (#1)

- **PRE PMC MIXED FLEET CONSIDERATIONS FOR PLATFORMS**
  - SINGLE ENGINE SDV PROVIDES SHUTTLE CARGO BAY COMPATIBILITY

PRE PMC LAUNCH SEQUENCE

- **MIXED FLEET EXPENDABLE EMPHASIS**

	FLIGHT	LV	
1	MB-1	STS-1	1/2 PV, TRUSS, NODE: TANKAGE, 2 RCS
2	MB-2	STS-2	1/2 PV, TRUSS, NODE, ACA, DOCKING ADAPTER, 1 RCS
3	MB-3	STS-3	RADIATORS, TANKAGE ATTACH PAYLOADS, AIRLOCK
4	MB-4	STS-4	AIRLOCK, TANKAGE, SS RMS, SSEMU, ATTACH PAYLOADS
5	P-1	ELV-1	US POLAR PLATFORM
6	MB-5	STS-5	LAB MODULE
7	MB-6	STS-6	HAB MODULE
8	P-2	ELV-2	ESA POLAR PLATFORM
9*	MB-7	STS-7	NODES, OMV, CUPOLAS
10	OF-1	STS-8	MODULE OFFLOADS
11	MB-8	STS-9	LOGISTICS, EMU'S, CREW

*POTENTIAL ELV-3 CONCURRENT WITH FLIGHT # 10

POST PMC UTILIZATION OPTION
(cont.)

Once PMC is achieved, two-engine HLLVs can be used to launch assembly payloads. Shuttle flights from PMC to IOC can be reduced from 9 (CETF) to 6. A combination of ELV, SDV, and STS flights can complete SS assembly in 22 launches instead of 32 (CETF baseline). Post PMC assembly by Station crew members can follow the same flight sequence of events per the CETF baseline definition with no program impact.

Another advantage of Post PMC HLLV utilization is that Station based crew can provide man-in-the-loop rendezvous and docking control from the Station. This alleviates the need for unmanned automatic rendezvous and docking systems early on.

POST PMC HLLV UTILIZATION OPTION

DUAL SSME SDV PERFORMANCE

- 3 HLLV LAUNCHES REPLACE 6 STS LAUNCHES

- POST PMC ASSEMBLY SEQUENCE
  - MIXED FLEET EMPHASIS

FLT	TYPE	LV-	FLIGHT MANIFEST DESCRIPTION
12	L-1	STS-10	LOGISTICS
13	MB-9	SDV-1	SD POWER, ESA, ATTACH. P/L
14	L-2	STS-11	LOGISTICS
15	MB-10	SDV-2	● JEM + EF1 + P/L ● MSC + X PORTER + MAINT. DEPOT ● UPPER/LOWER KEELS & BOOMS
16	L-3	STS-12	LOGISTICS
17	MB-11	SDV-3	● SERVICING FACILITY ● JEM EF2 + ELM + ELM P/L ● MODULE OUTFIT & OFFLOAD MAKEUP
18	L-4	STS-13	LOGISTICS
19	L-5	STS-14	LOGISTICS
20	P-3	ELV-3	CO-ORBITING PLATFORM (ETR)
21	L-6	STS-15	LOGISTICS
22	PR	STS-16	POLAR PLATFORM SERVICING (WTR)

ASSEMBLY SCENARIO COMPARISON

Post PMC HLLV Utilization Option

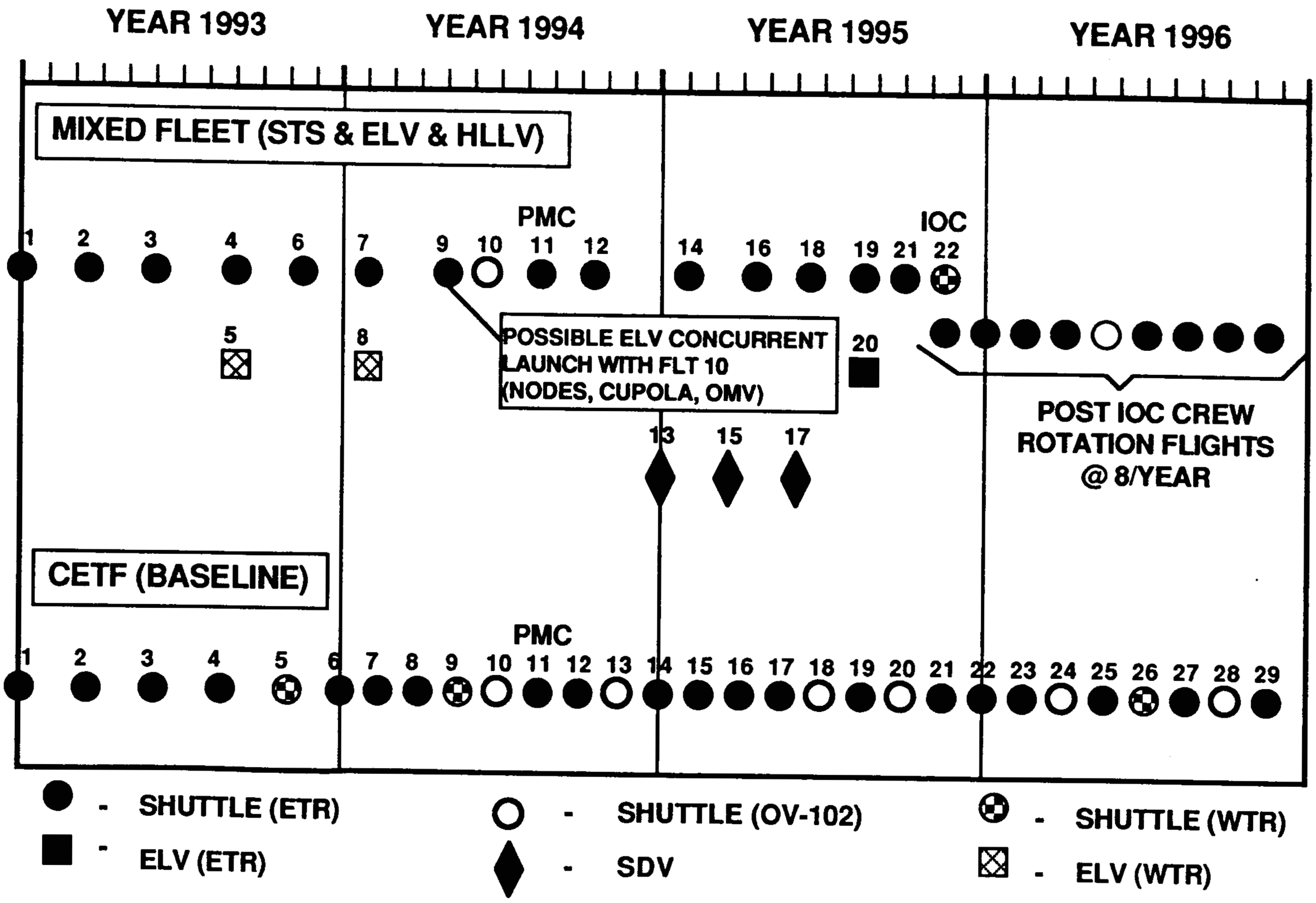
A comparison of the CETF flight sequence and the Post PMC HLLV utilization scenario clearly shows the impact of the three SDV launches. This comparison is made holding the PMC point in time the same for both scenarios, 8/94 for this case, and shows that IOC can be achieved in late 1995 which is over a year earlier than the CETF baseline completion in the first quarter of 1997. It can also be seen that the Shuttle flight rate of 5 per year can be accommodated for almost three years until Flight 22. Flight 22 is a Polar Platform Refurbishment mission which can only be accomplished via a STS mission. However, after IOC, 8 flights per year are required to accommodate a crew of 8 with a maximum 90 day orbital staytime for each.

Heavy Lift Launch Vehicle Study

SPACE STATION ASSEMBLY SCENARIO COMPARISON

SHUTTLE DERIVED VEHICLE (SDV) AUGMENTATION

POST PMC HLLV UTILIZATION OPTION



PRE-PMC UTILIZATION OPTION

This scenario would incorporate HLLVs into the SS assembly sequence from the beginning. This option was constrained to maintaining the Space Station element definitions as currently specified, and an assembly sequence profile that takes advantage of HLLV mass and volume performance in an optimum manner was developed.

The first HLLV flight would consist of four equivalent Shuttle payloads, and the Shuttle would transport crew for assembly of the HLLV cargo. Use of a telerobotic P/L cargo carrier would reduce the amount of EVA time required. The SS design and payload carriers would be completely Shuttle compatible, so that reversion to CETF would be possible, if necessary.

The major advantages are minimal risk via Shuttle compatibility, reduction in EVA time, and increased ground-based integration and verification of Station flight elements. As per CETF, the assembly flight sequence can still lead to program success without being dependent on any single STS flight.

PRE-PMC UTILIZATION OPTION

SHUTTLE PERFORMANCE CONSTRAINS SPACE STATION ASSEMBLY MANIFESTING

- FIRST HLLV FLIGHT MANIFEST EQUIVALENT TO CETF FLIGHTS 1-4
- EVA USED TO ASSEMBLE ALL ELEMENTS OUT OF CARRIER
- AFT NODES (2) AND AIRLOCK INTEGRATED AND VERIFIED PRE-LAUNCH
- PROGRAM SUCCESS NOT DEPENDENT ON ANY SINGLE STS FLIGHT
- CAN REVERT BACK TO CETF BASELINE AT ANY POINT

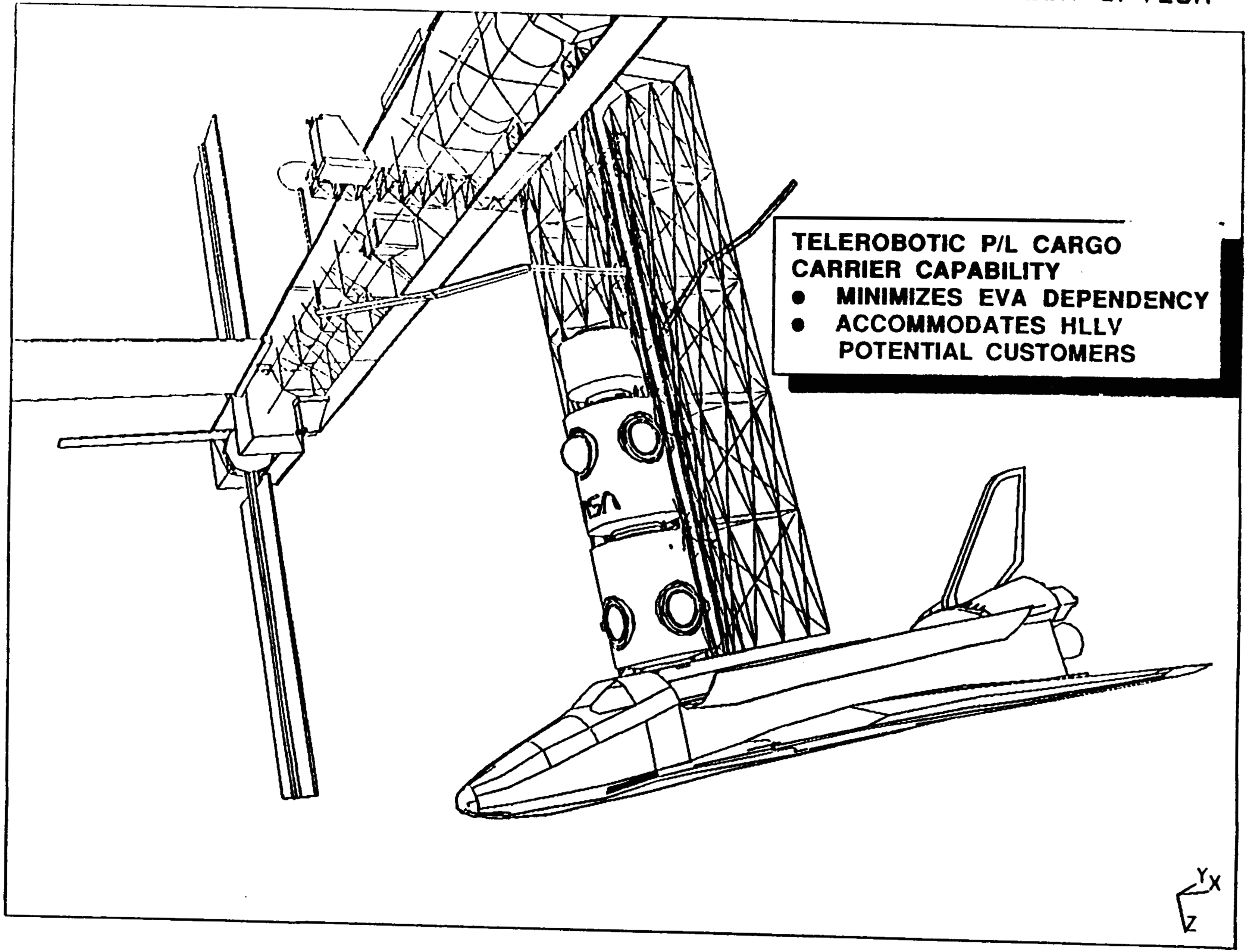
OPTIMIZES MASS TO ORBIT WHILE MAINTAINING SHUTTLE COMPATIBILITY

PRE-PMC UTILIZATION OPTION

(cont.)

This scenario envisions that a Shuttle would dock to a previously launched HLLV P/L carrier and that construction would take place out of the carrier cargo bay. It can be seen that a P/L carrier telerobotic arm could enhance HLLV customer payload delivery and reduce EVA time.

HEAVY LIFT LAUNCH VEHICLE STUDY - PRE PMC UTILIZATION OPTION



TELEROBOTIC P/L CARGO CARRIER CAPABILITY

- **MINIMIZES EVA DEPENDENCY**
- **ACCOMMODATES HLLV POTENTIAL CUSTOMERS**

PRE-PMC UTILIZATION OPTION
(cont.)

Utilization of HLLVs prior to PMC requires that a STS launch accompany the launch of the unmanned SDV to provide the EVA to assemble the manifested Station elements. In this scenario a single three engine SDV is capable of launching all of the transverse boom elements and subsystems including the two aft resource nodes. This is equivalent to the first 4 CETF STS assembly flights. Therefore, to accomplish all EVA assembly tasks, the STS-1 flight must be provisioned for an extended orbit staytime to provide approximately 40 hours of EVA. Extra STS/EVA flights would be needed if the 24 EVA hours per STS flight CETF baseline is maintained. Two flights of the three engine SDV configuration, each launched with a concurrent STS flight, could deliver to orbit all Station elements needed for PMC in a total of four flights. After PMC the first STS flight provides for crew and logistics to permanently man the Station. The remaining assembly flights may be time sequenced to satisfy program objectives. To meet CETF mission assembly profile guidelines, two engine SDV configurations can accomplish this goal in two launches. The fourth STS flight shown in the assembly sequence is utilized in this scenario to provide for crew rotation in addition to manifesting Station elements for Station based EVA assembly.

PRE PMC UTILIZATION OPTION

LAUNCH	ELEMENTS	WEIGHT (KLBS)
SDV-1 (3 SSME)	ALL COMPONENTS OF CETF FLIGHTS 1-4, CUPOLA	153
STS-1	CONSUMABLES TO EXTEND STAY TIME AND EVA TIME. MISC. CETF COMPONENTS	37
SDV-2 (3 SSME)	LAB MODULE, HAB MODULE, ECS, OMV, STRUCTURE, SOLAR DYNAMICS	153
STS-2	FORWARD NODES (2), CUPOLA, EVA SUPPORT EQUIPMENT	23
STS-3	LOGISTICS, CREW, EVA SUPPORT	37
SDV-3 (2 SSME)	JEM, EF & EXP., PAYLOADS, SERVICE 1 & 2, MANIPULATOR	96
SDV-4 (2 SSME)	ESA MODULE, KEEL & BOOMS, MSC & TRANSPORTER, SERVICE 3, MMD	109
STS-4	JEM E.F. 2 & PAYLOAD EXPERIMENT LOGISTICS MODULE	37

ASSEMBLY SCENARIO COMPARISON

Pre-PMC Utilization Option

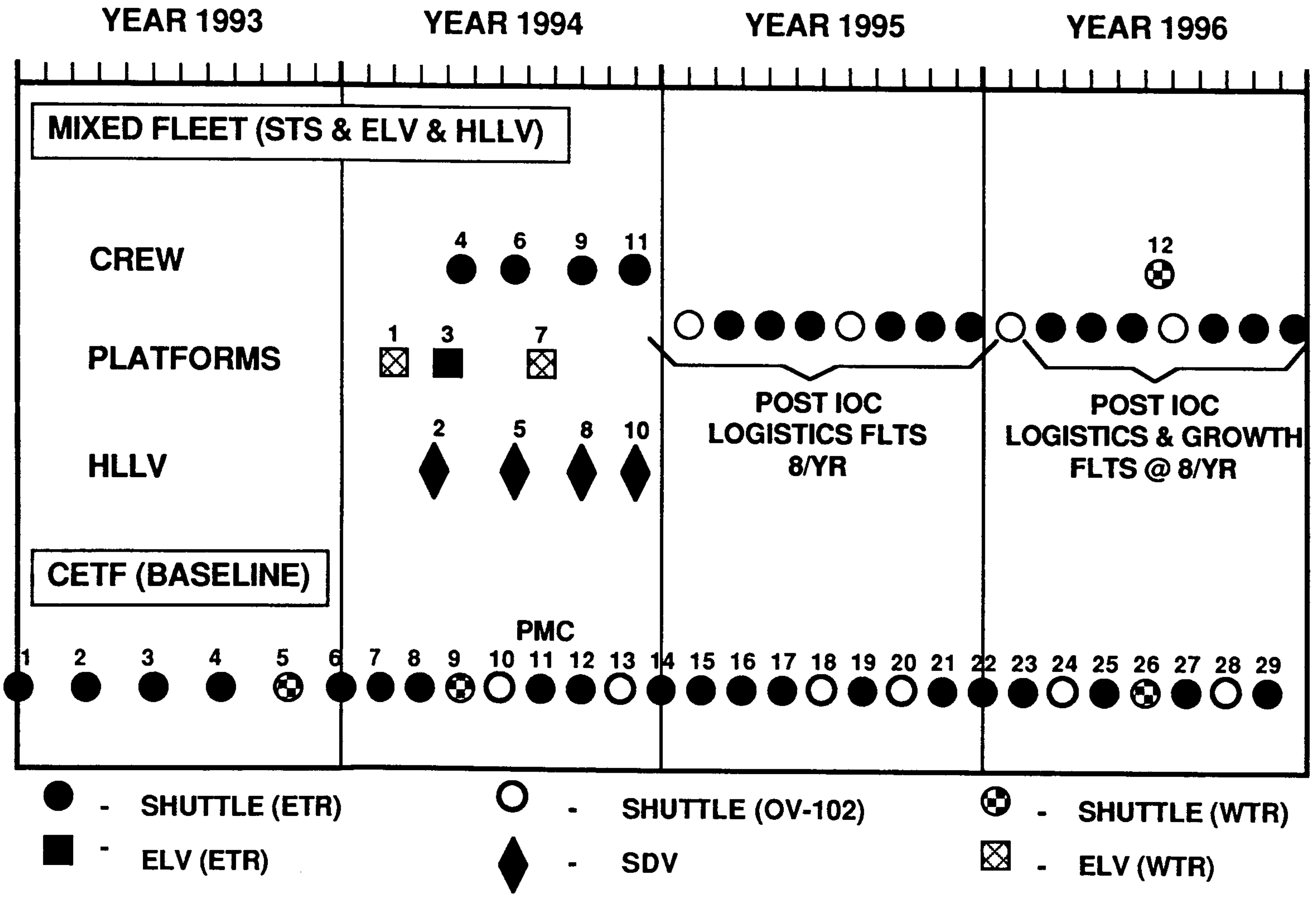
Utilization of HLLV capability has a significant impact on the Station assembly sequence profile if these vehicles can be made available for program use by the time of the first assembly flight. As can be seen, to accomplish PMC in the same time period as the CETF definition, assembly flights do not need to start until early 1994 to accomplish the same objective. This scenario, however, has the constraint that the first two HLLV flights (#2 & #5) must be launched concurrent with companion STS flights (#4 & #6). Flight #9 (STS) establishes PMC, and Flight #11 (STS) completes the IOC configuration assembly. PMC is accomplished with only three STS flights compared to 11 for the CETF baseline. The total number of program launches required for IOC is reduced by approximately a factor of three.

It should be also noted again, as rather dramatically shown, that 8 STS flights per year are required Post IOC to maintain the CETF 8 crew baseline of a 90 day maximum orbit staytime.

Heavy Lift Launch Vehicle Study

SPACE STATION ASSEMBLY SCENARIO COMPARISON

PRE PMC UTILIZATION OPTION



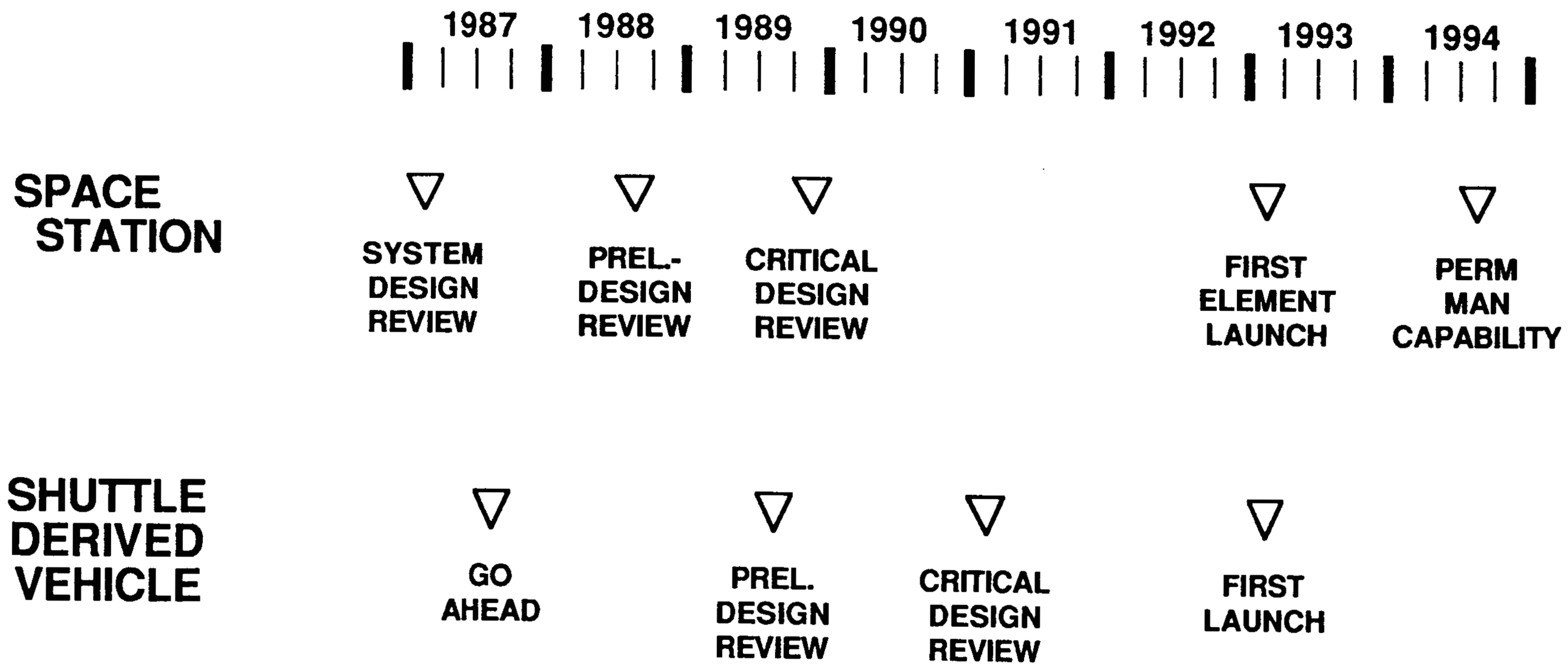
SS AND HLLV COMPARATIVE DEVELOPMENT SCHEDULES

One of the concerns with post PMC utilization of the SDV is that delaying its development will reduce commitment to the HLLV program. Pre-PMC utilization alleviates this concern by forcing concurrent HLLV and SS development. However, the complications arising from this parallel effort must be considered. The major concern of the Space Station program is developing and maintaining dual launch vehicle integration design and installation processes.

Heavy Lift Launch Vehicle Study

SPACE STATION AND HLLV COMPARATIVE DEVELOPMENT SCHEDULES

POST PMC UTILIZATION DELAYS PROGRAM COMMITTMENT



PARALLEL DEVELOPMENT IS SPACE STATION PROGRAM CONCERN

MODIFIED TRANSVERSE BOOM OPTION
(cont.)

The manifests of the SDV and STS for the modified transverse boom option show that four Shuttle flights and five SDV launches would be required to IOC. In contrast, the pre-PMC option would provide IOC in four STS flights and four SDV launches (some three engine and some two engine). This option would require early program commitment, more STS flights than pre-PMC, and SS redesign, and it would provide no substantial PMC or IOC schedule advantage. However, EVA time would be drastically reduced, and full ground-based integration and verification would be possible.

MODIFIED TRANSVERSE BOOM OPTION

DEPLOYABLE UTILITIES OBVIATES EARLY EVA DEPENDENCE

- FIRST HLLV LAUNCH FUNCTIONALLY EQUIVALENT TO CETF FLIGHTS 1 & 2
- TRANSVERSE BOOM DEPLOYED AS EXTENSION OF CARRIER
- 9 FT. TRUSS REQUIRED TO MEET CARRIER SIZE CONSTRAINTS

ABLE TO LAUNCH FULLY VERIFIED VIABLE S/C ON FIRST FLIGHT

SS FULLY DEPLOYABLE FIRST LAUNCH CONCEPT

Modified Transverse Boom (cont.)

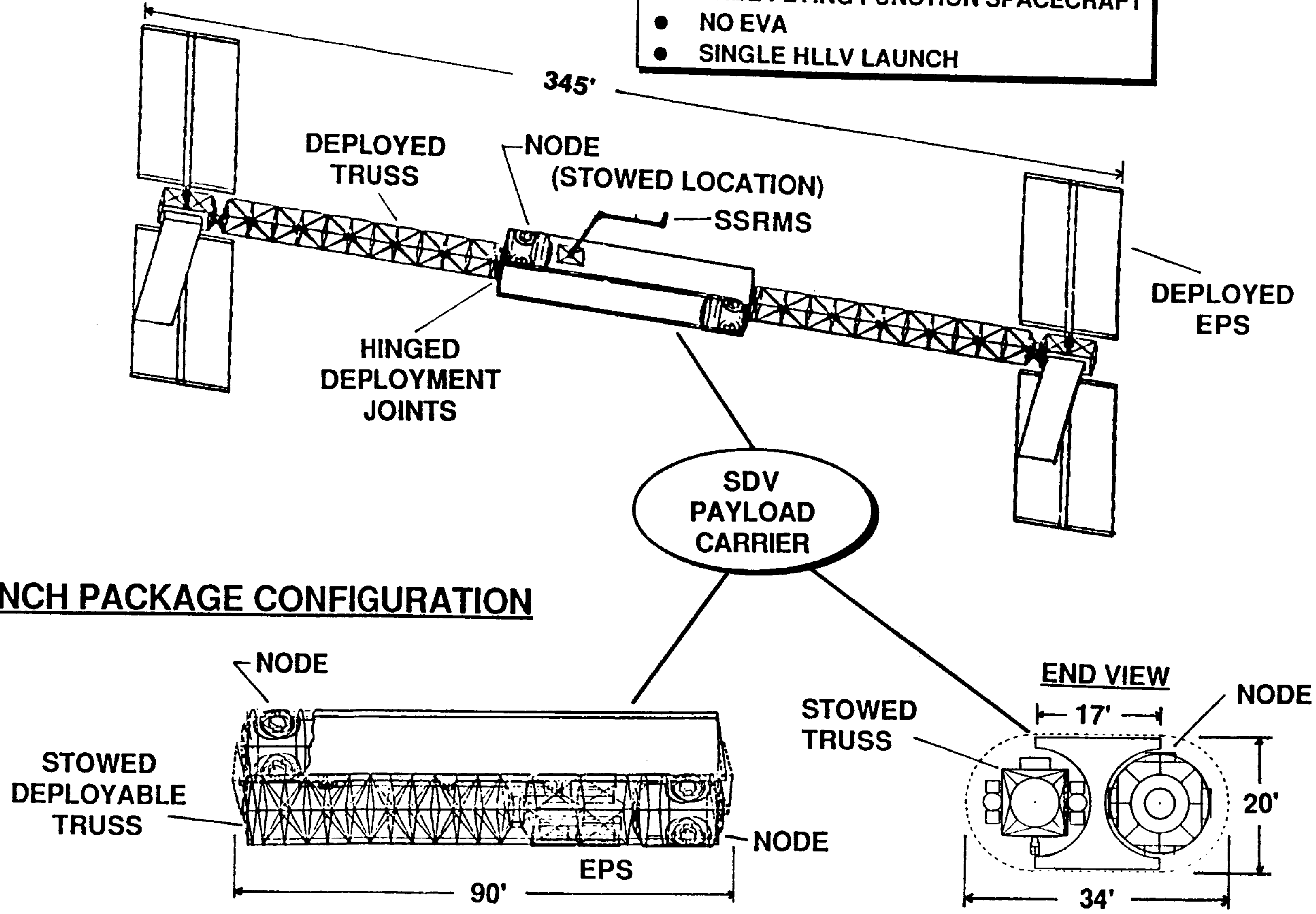
The SS nodes, SSRMS, the electrical power system (EPS), and the deployable truss are conceived to be integrated with the core truss that makes up the payload carrier. This drawing shows the stowed and deployed configurations of the components. A successful HLLV mission would provide a fully deployed, verified spacecraft without any attendant STS flight to provide EVA support.

SPACE STATION FULLY DEPLOYABLE FIRST LAUNCH CONCEPT

- FULLY GROUND VERIFIED
- FREE FLYING FUNCTION SPACECRAFT
- NO EVA
- SINGLE HLLV LAUNCH

DEPLOYED CONFIGURATION

LAUNCH PACKAGE CONFIGURATION



MODIFIED TRANSVERSE BOOM OPTION
(cont.)

The manifests of the SDV and STS for the modified transverse boom option show that four Shuttle flights and five SDV launches would be required to IOC. In contrast, the pre-PMC option would provide IOC in four STS flights and four SDV launches (some three engine and some two engine). This option would require early program commitment, more STS flights than pre-PMC, and SS redesign, and it would provide no substantial PMC or IOC schedule advantage. However, EVA time would be drastically reduced, and full ground-based integration and verification would be possible.

MODIFIED TRANSVERSE BOOM OPTION # 3

- EARLY PROGRAM HLLV UTILIZATION COMMITMENT (1994)
- ADDITIONAL SDV HLLV LAUNCH REPLACES 2 INITIAL STS FLIGHTS
- FULLY DEPLOYABLE FUNCTIONAL FREE FLYING SPACECRAFT ON 1ST LAUNCH
  - TRANSVERSE BOOM DEPLOYED AS EXTENSIONS TO SDV INTEGRAL CARRIER

ASSEMBLY FLIGHT SEQUENCE

	LAUNCH	ELEMENTS	WEIGHT
	SDV-1	37.5 KW SYS, TRANSVERSE BOOM, 2 NODES, SSRMS, TCS, RCS, CMG'S	87 K
CONCURRENT	STS-1	AIRLOCKS, PAYLOADS	25 K + ASE
	SDV-2	LAB MODULE, RCS, STRUCTURE, OMV	91 K
MANTENDED CONCURRENT	STS-2	NODES (2), CUPOLA (2), EMU, EVA SUPPORT EQUIP.	23 K + ASE
	SDV-3*	HAB MODULE, PAYLOADS, SOLAR DYNAMIC POWER, SERVICE 1	88 K
MODULE CHECKOUT **MANNED**	STS-3	LOGISTICS, EMU'S CREW	34 K
	SDV-4	JEM, E.F. & EXP, PAYLOADS, SERVICE 2, MANIPULATOR	91 K
	SDV-5	ESA MODULE, KEEL & BOOMS, MSC & XPORTER, SERVICE 3, PAYLOADS, EXP LOGISTICS	91 K
INTERNATIONALS **IOC**	STS-4	JEM E.F. 2 & PAYLOAD, SERVICE 3, MSC MAINT.	28 K + ASE

* OPTION TO DELAY INSTALLATION OF PAYLOADS & SOLAR DYNAMIC POWER DUE TO EVA TIME LIMITS

ASSEMBLY SCENARIO COMPARISON
Modified Transverse Boom Option

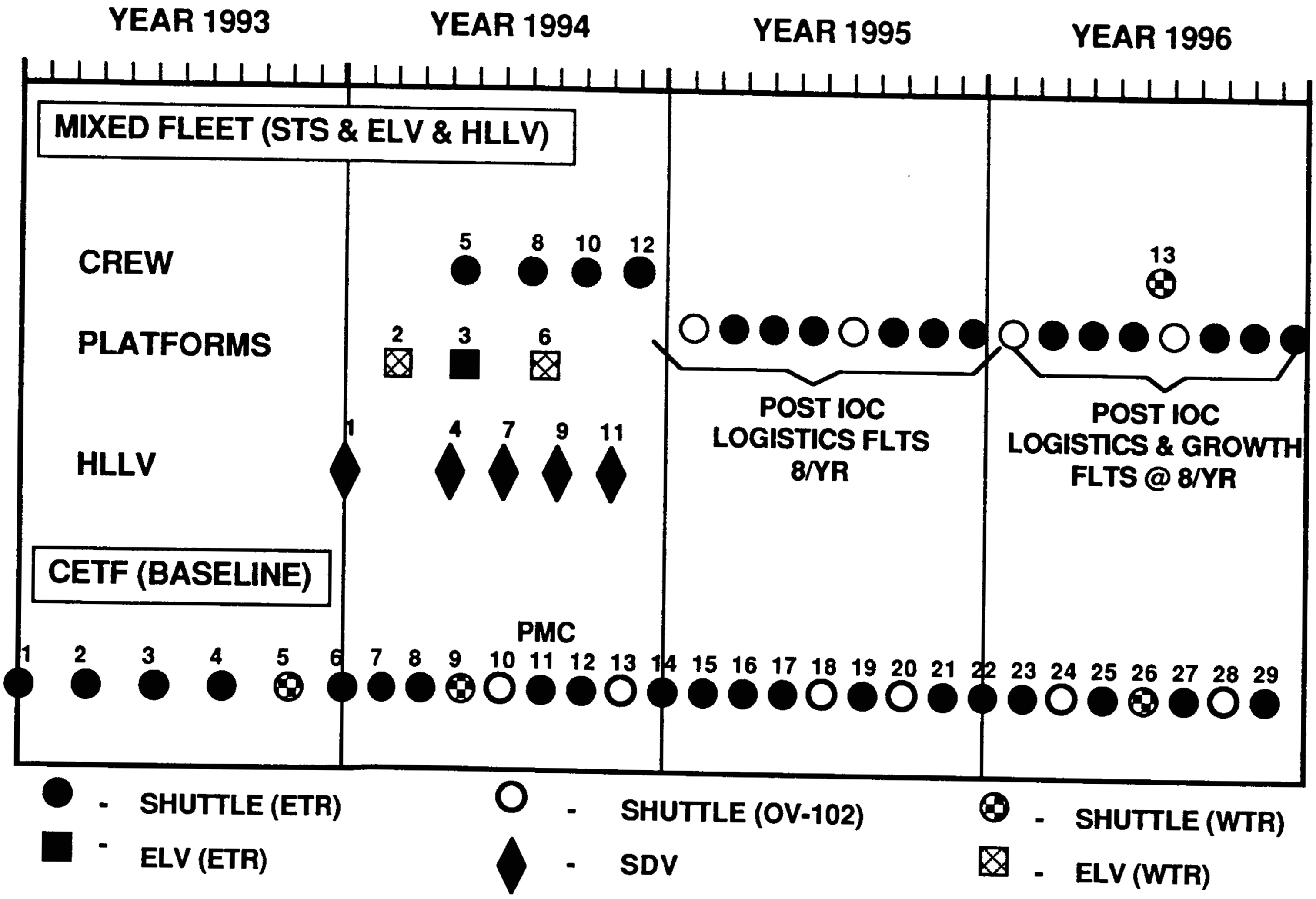
Comparing this scenario with the CETF baseline shows a significant advantage in both schedule and STS demands. PMC, constrained to occur at approximately the same time as the CETF baseline, requires only three Shuttle flights to be achieved, and the first launch (HLLV) would not need to occur until 1994. As with the other HLLV options, IOC would be realized by 1995 (late 1994).

It should be noted that this does <u>not</u> offer significant advantages in schedule or number of launches over the pre-PMC option which maintains the current Space Station design definition.

Heavy Lift Launch Vehicle Study

SPACE STATION ASSEMBLY SCENARIO COMPARISON

MODIFIED TRANSVERSE BOOM OPTION



INTEGRATED RACE TRACK OPTION

The Integrated Race Track option employs the concept of deployable structures to an even greater extent than the Modified Transverse Boom (MTB) option. The first launch would deploy a fully verified spacecraft (as with the MTB option), and the second launch would consist of a pre-integrated hab/lab/node module race track configuration. The race track modules would be integrated and verified prior to launch and then joined to the transverse boom by EVA crew on the first Shuttle mission launched concurrently with the HLLV flight that manifests the race track. PMC could be achieved in only three total launches.

This option is anticipated to require down sizing the pressurized volume of the Space Station race track configuration to fit within SDV P/L carrier aerodynamic shroud envelope guidelines as currently being conceived. However, the race track mass to orbit can be accommodated with a 3 engine SDV and could include fully outfitted and fully pre-launch integrated modules.

INTEGRATED RACE TRACK

C-2

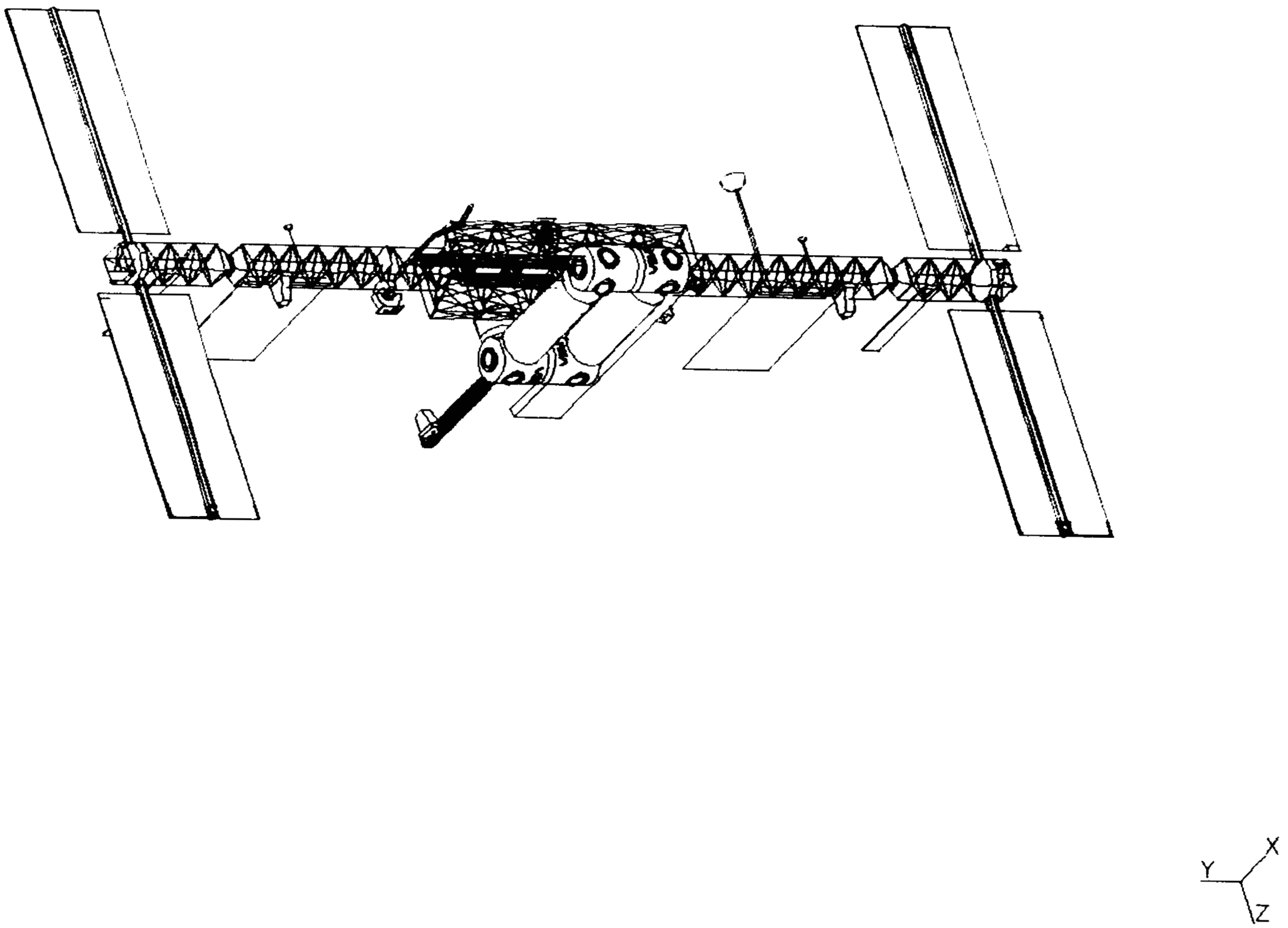
- FIRST HLLV LAUNCH SIMILAR TO INTEGRATED TRANSVERSE BOOM OPTION
  - CETF NODE FUNCTION BY REDUNDANT EXTERIOR AVIONICS
- ABLE TO LAUNCH FULLY VERIFIED VIABLE S/C ON FIRST FLIGHT
- SECOND HLLV LAUNCH INCLUDES PRE-INTEGRATED RACE TRACK HABITATION
- ABLE TO TOTALLY INTEGRATE AND VERIFY HABITABLE VOLUME
- ON-ORBIT ASSEMBLY TO PMC LIMITED TO MATING TWO MAJOR ELEMENTS
- REQUIRES 3-SSME HLLV CAPABILITY TO ORBIT EACH PACKAGE

INTEGRATED RACE TRACK

Launch Configuration

This illustrates the Station configuration after three launches, two HLLV and one Shuttle. The transverse boom, solar panels, SSRMS, antenna, lab module, and hab module are all in place. Air locks could be externally added on later flight manifests, or they could be integrated into the nodes.

HEAVY LIFT LAUNCH VEHICLE STUDY
INTEGRATED RACE TRACK
HLLV-2/STS-1 Launch Configuration



INTEGRATED RACE TRACK

(cont.)

The manifests and sequence of the assembly launches for the integrated race track (IRT) option show that only three STS missions would be required, along with four SDV launches, to achieve IOC. This will reduce EVA time and Shuttle demands to an absolute minimum for SS assembly. On-orbit assembly and verification will be virtually eliminated. However, there are risks associated with reliance on pre-launch integrated, pre-launch verified deployable space structures, such as the risk of failure to deploy properly or at all. This option also requires SS redesign, and is HLLV launch vehicle dependent and not STS compatible.

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INTEGRATED RACE TRACK

LAUNCH	ELEMENTS
SDV-1	37.5 KW POWER SYSTEM, TRANSVERSE BOOM, TCS, RCS, CMG & MANIPULATORS
SDV-2	LAB MODULE, HAB MODULE, NODES - INTEGRATED
STS-1	LOGISTICS, CREW
SDV-3	JEM, EF & EXP, PAYLOADS, SERVICE 1 & 2, MANIPULATOR
STS-2	LOGISTICS, CREW
SDV-4	ESA MODULE, KEEL & BOOMS, MSC & TRANSPORTER, SERVICE 3, MMD
STS-3	JEM EF 2 & PAYLOADS, EXPERIMENT LOGISTICS MODULE

ASSEMBLY SCENARIO COMPARISON

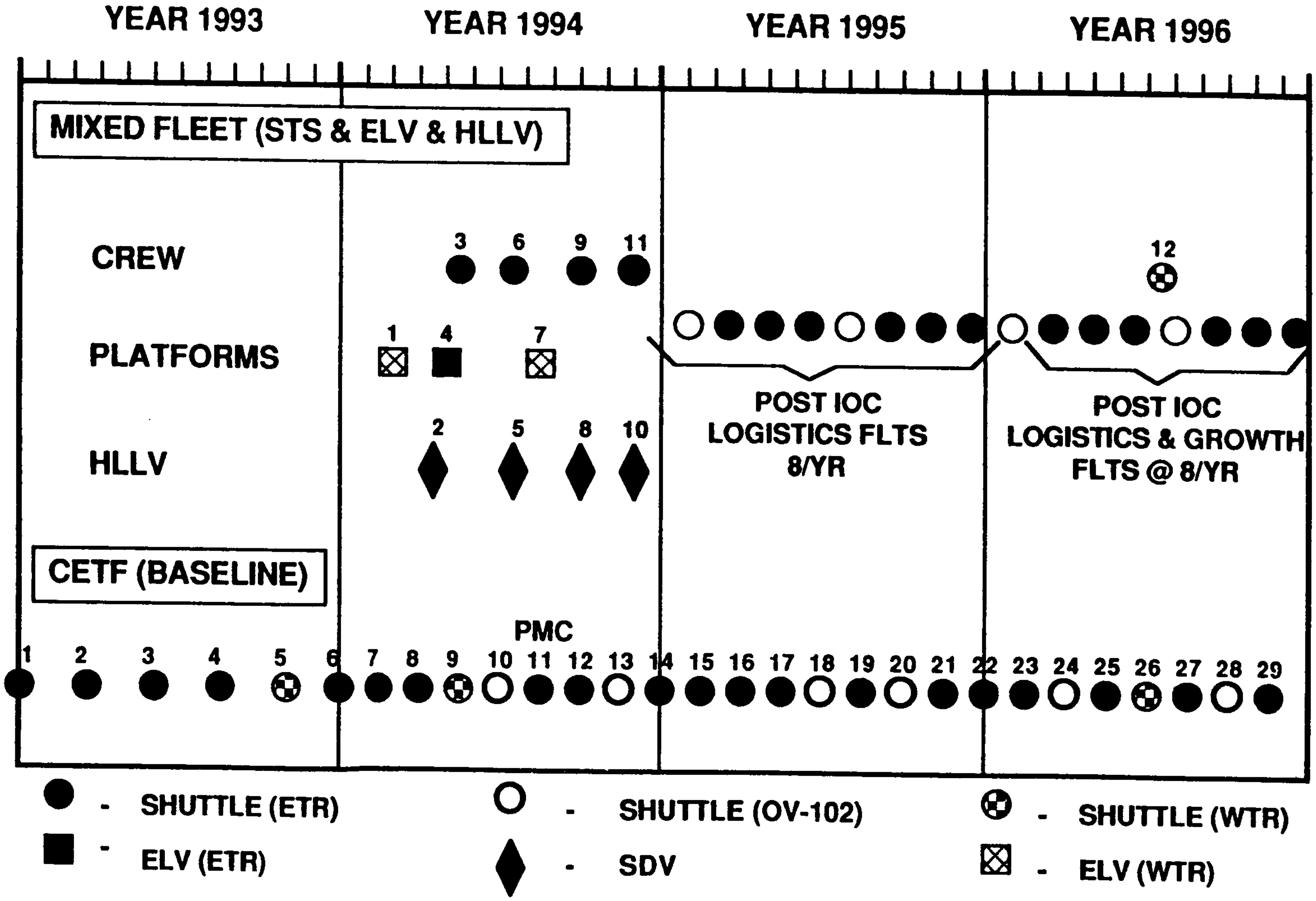
Integrated Race Track

The comparison of the IRT option with CETF baseline shows that IOC can be achieved in much less time and with many fewer launches using the HLLV. Only one STS mission would be required for PMC, and only four would be necessary to achieve IOC. CETF requires eleven and thirty-two for PMC and IOC, respecsively. Also, a total of only eleven launches would be needed to complete SS assembly (three for PMC).

Heavy Lift Launch Vehicle Study

SPACE STATION ASSEMBLY SCENARIO COMPARISON

INTEGRATED RACE TRACK



OPTION 4A - SINGLE HAB/LAB LAUNCH

In this scenario, the U.S. laboratory and habitability modules would be redesigned and combined into one, large module, deployable only via the use of a HLLV. In the CETF baseline sequence, the modules must be dismantled before launch on the STS due to weight limitations, and the risk of failure can be viewed by some to be substantial. The single HAB/LAB module would significantly reduce that risk by permitting on-ground integration and verification prior to launch. This option would also provide increased HAB/LAB volume. However, design of a single HAB/LAB module would force dependence on a specific launch vehicle and obviate STS/HLLV compatibility for the Space Station pressurized module volume.

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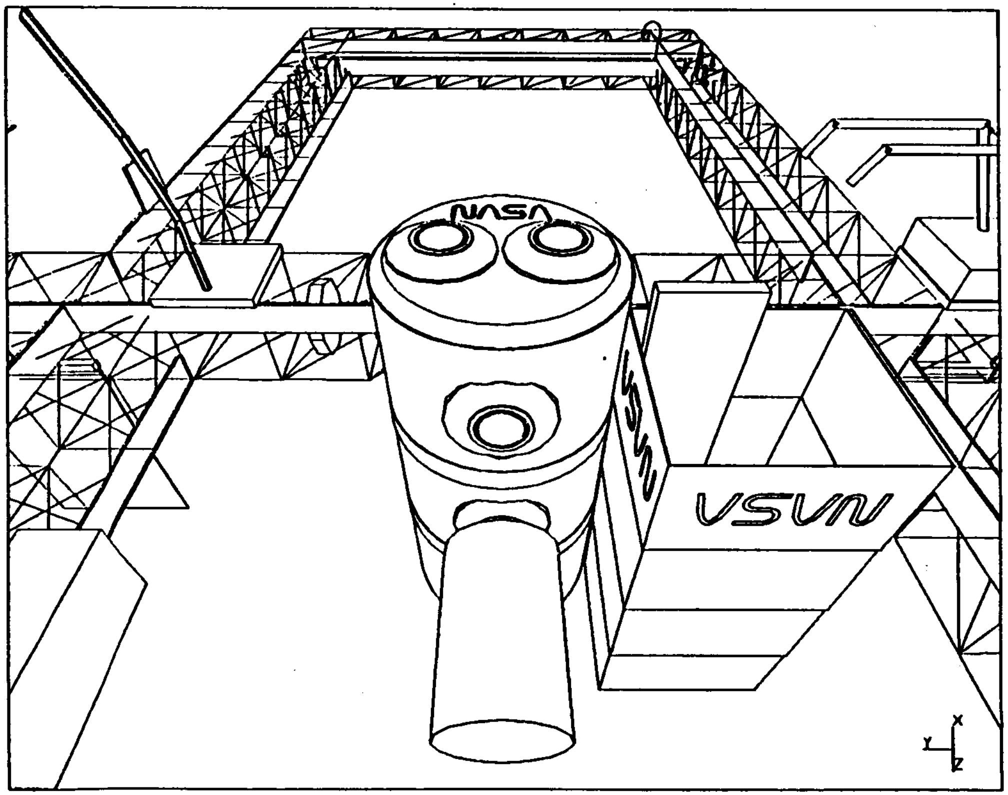
OPTION 4A - SINGLE HAB/LAB MODULE LAUNCH

- **SINGLE LARGE (30' X 65') HAB/LAB MODULE**
- **600% MORE VOLUME THAN SEPARATE HAB/LAB MODULES**
- **FULLY GROUND VERIFIED PMC**



SINGLE HAB/LAB LAUNCH

(cont.)

The single Hab/Lab module would require dual Orbiter +X axis berthing ports and dual -X axis ESA and JEM berthing ports. It would require multiple logistics module berthing ports on the +Z axis

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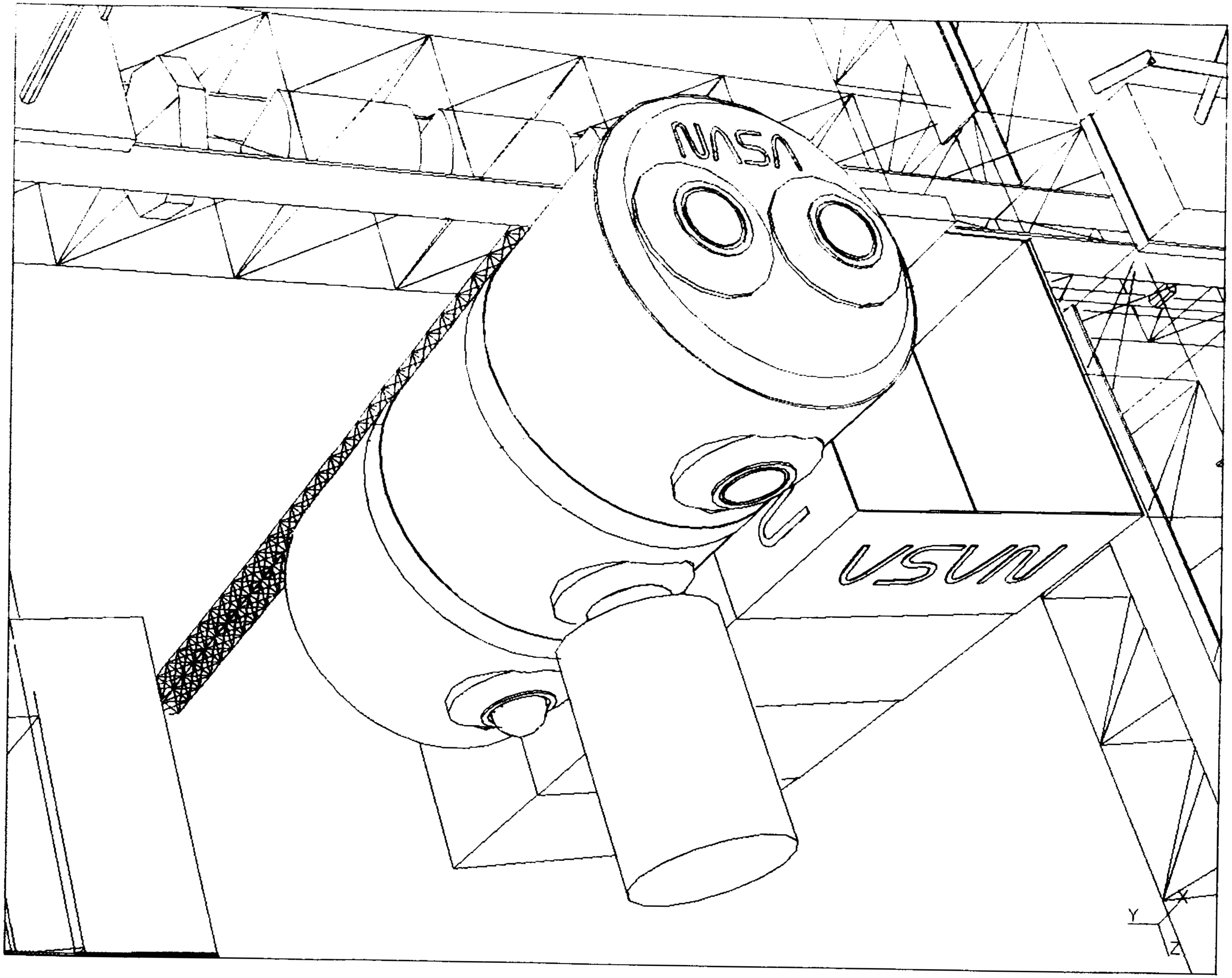
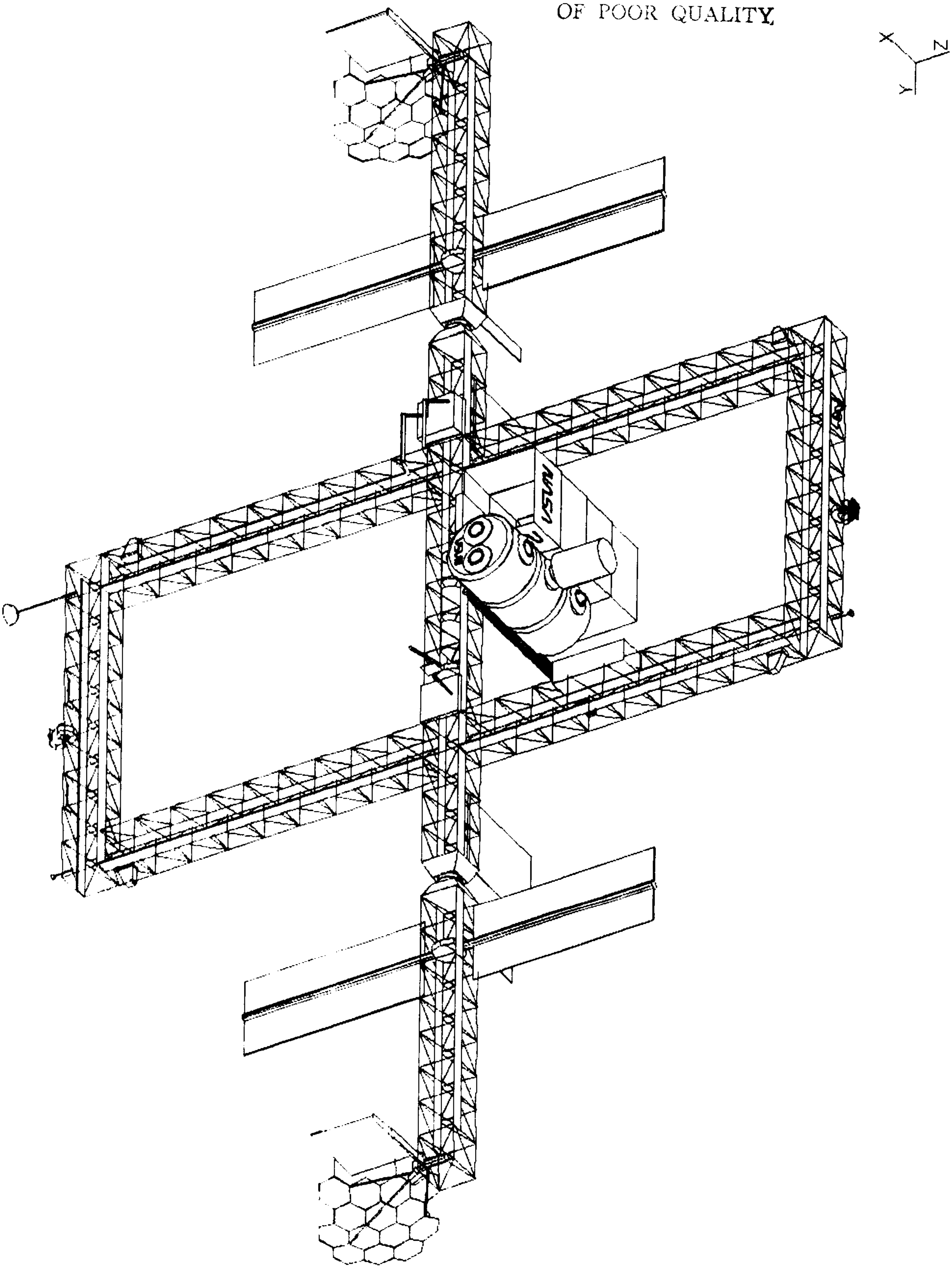


SINGLE HAB/LAB LAUNCH
(cont.)

Of major concern about the single hab/lab configuration is the evolutionary growth options that could be considered compatible with the dual keel configuration. Initial considerations indicate a very limited set of growth options. However, most important is the concern that a HLLV compatible space station evolutionary definition would focus on different station configurations with different mission objectives that utilized heavier and more voluminous station system elements.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SS ERECTABLE VS. DEPLOYABLE ASSEMBLY CONSIDERATIONS

The last three HLLV utilization options discussed all raised the issue of erectable vs. deployable SS components. The use of deployable structures as depicted in these options would reduce STS demands and EVA time and would provide PMC and IOC rapidly.

The disadvantages include increased weight, increased cost of structure design, fabrication, and ground testing, and the additional level of effort required for the re-definition of segments of the SS design. Deployable structures also limit SS growth.

Other, previously mentioned disadvantages are the loss of STS/HLLV compatibility and the risk of failure to deploy the structure. Failure of one such mission would be catastrophic; whereas, with smaller STS compatible payloads, program success is not wholly dependent on the success of one or two launches.

Areas in which deployable structures are anticipated to have marginal performance are redundancy, reparability, maintenance and predictability.

SPACE STATION ERECTABLE VERSUS DEPLOYABLE ASSEMBLY CONSIDERATIONS

- HLLV UTILIZATION DEPLOYABLE APPROACHES NOT EFFICIENT FOR STS SPACE STATION LAUNCH AND ERECTABLE ASSEMBLY [1]
  - DOUBLE THE STRUCTURE WEIGHT
  - STRUCTURE REQUIRES 5 TIMES MORE VOLUME
  - TRIPLE THE STRUCTURE COST
  - RAISES GROUND CHECK-OUT CONCERNS

DUAL KEEL STS/HLLV DUAL LAUNCH VEHICLE COMPATIBLE DEPLOYABLE APPROACHES REQUIRE RE-DEFINITION STUDIES

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[1] "DEPLOYABLE/ERECTABLE TRADE STUDY FOR SPACE STATION TRUSS STRUCTURES," NASA TM 8757, JULY 1985, MIKULAS, M. M. ET AL

STS/HLLV DUAL COMPATIBILITY
ASSESSMENT OF OPTIONS

The retention of the capability to launch payloads using either the HLLV or the STS is an important criterion for the selection of a HLLV utilization option. This compatibility allows for a back-up vehicle in case of a STS or HLLV launch failure. Of major Space Station Program concern is that the two options which take advantage of a HLLV's ability to launch deployable structures are also options which forfeit STS/HLLV

STS/HLLV DUAL COMPATIBILITY ASSESSMENT OF OPTIONS

OPTION	COMPATIBILITY SHUTTLE	COMPATIBILITY HLLV
1. POST PMC UTILIZATION	YES	YES
2. EARLY ASSEMBLY UTILIZATION (PRE PMC)	YES	YES
3. MODIFIED TRANSVERSE BOOM	NO*	YES
4. INTEGRATED RACE TRACK	NO*	YES

* DEPLOYABLE APPROACHES ARE LAUNCH VEHICLE UNIQUE
-- IMPLIES LAUNCH VEHICLE DEPENDENCE

STS/HLLV DUAL COMPATIBLE REVERSIBILITY REQUIRES FURTHER STUDY

SSP SHUTTLE COMPATIBLE PROGRAM NEED

Based on STS compatibility issues, Option 2, pre-PMC utilization, is preferable to the others. Not only does this option minimize the number of Shuttle flights and optimize the use of HLLVs, it also minimizes the changes to SS design. Therefore, it would be possible to revert back to the CETF baseline at any point if the need arose.

The selection of this option would require the development of a STS compatible P/L carrier.

SPACE STATION PROGRAM SHUTTLE COMPATIBLE PROGRAM NEED

OPTION 2 IS BEST SCENARIO FOR STS/HLLV DUAL COMPATIBILITY

- PROVIDES OPPORTUNITY FOR EARLY HLLV UTILIZATION BENEFITS
  - MINIMIZES NUMBER OF REQUIRED STS FLIGHTS
- MAINTAINS SPACE STATION PROGRAM CONFIGURATION DESIGN DEFINITION
  - EVA ASSEMBLY IS CURRENT PROGRAM BASELINE
- OPTIMIZES MASS TO ORBIT WHILE MAINTAINING STS/HLLV COMPATIBILITY
  - REQUIRES DUAL LAUNCH VEHICLE INTEGRATION AND MANIFESTING PROGRAM DEFINITION
- REVERTABLE BACK TO SHUTTLE DEPENDENT BASELINE AT ANY POINT
  - BASELINE HARDWARE ELEMENT DEFINITION AND INTEGRATION IS PRESERVED

REQUIRES HLLV PROGRAM TO DEVELOP A SHUTTLE SURROGATE P/L CARRIER

ADVANTAGES OF HLLVs COMMON TO ALL OPTIONS

All four options have several key advantages which result from the increased lift capacity of the HLLV which result in the reduction of the total amount of required Shuttle flights. However, utilization of the HLLV should also address some key shortcomings and concerns that are inherent in the current assembly sequence. For example, both the pre-PMC option and the Modified Transverse Boom option launch a large mass to orbit on the first SDV flight to achieve the same functional spacecraft objective. However, the MTB option provides for much greater ground-based integration and verification than the pre-PMC scenario which requires an attendant EVA bearing STS flight. Further detailed study is required to determine the real value to the Space Station Program of such a key advantage to determine its worth, or liability in terms of additional redefinition resources required, versus the savings of additional STS flights dedicated for Station assembly use.

ADVANTAGES OF HLLV COMMON TO ALL OPTIONS

- LARGE MASS TO ORBIT
- REDUCE NUMBER OF ASSEMBLY FLIGHTS TO PMC, IOC
- ELIMINATE INITIAL MODULE OUTFITTINGS
- LARGER PIECES INTEGRATED AND VERIFIED PRE-LAUNCH
- POTENTIAL EARLIER USER OPTIONS, SERVICING
- CARRIER MAY HAVE CONTINUING ON-ORBIT USE
  - UPPER, LOWER BOOMS
  - SERVICE CENTER CORE
- ALL FLIGHTS ASSEMBLED AT 220 NMI

ASSEMBLY SEQUENCE OPTION ASSESSMENT SUMMARY

Another important consideration in evaluating HLLVs is the additional new hardware development required compared to the degree of Shuttle flight relief provided. HLLV utilization will require near-term development of some very sophisticated equipment, particularly rendezvous and docking hardware and the payload carrier.

While HLLVs greatly reduce the number of STS assembly flights to a desired 4 or 5 flights per year, the number of STS logistics flights remain at the same 8 flights per year level which must continue for the operational life of the station. HLLV utilization cannot address this situation.

ASSEMBLY SEQUENCE OPTION ASSESSMENT SUMMARY

- HLLV UTILIZATION REQUIRES NEAR-TERM DEVELOPMENT OF ADDITIONAL HARDWARE ELEMENTS
    - -- UNMANNED FREE FLYING CARGO CARRIER
    - -- EARLY FLIGHT DEMONSTRATION OF LARGE MASS 3-BODY AUTOMATED RENDEZVOUS AND DOCKING
- IOC ASSEMBLY HLLV UTILIZATION PROVIDES NO SUBSTANTIAL SHUTTLE DEPENDENCY RELIEF

TOTAL FLIGHTS FOR 8 CREW STATION OPERATION SCENARIO

VEHICLES	CETF	POST PMC	PRE PMC
SHUTTLE ASSEMBLY	17	8	3
SHUTTLE LOGISTICS	9	15	17
HLLV	0	3	4
TOTAL	28	26	24

CETF SCENARIO ADEQUATE FOR 8 CREW PRODUCTIVE PHASED BUILD-UP/CUSTOMER UTILIZATION AGENCY PROGRAM

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5.0 EVALUATION OF HLLV FOR LOGISTICS/RESUPPLY

SSP MAJOR LAUNCH VEHICLE NEEDS

Although the ability to meet SS assembly requirements is enhanced by the use of HLLVs, there are other needs that cannot be addressed by HLLV use. These are primarily logistics and crew rotation issues that arise post-IOC. The most significant of these is the inadequacy of the STS for SS growth. Given the limit of Shuttle flights per year and Shuttle passenger capacity, SS crew is currently limited to 8 members.

SPACE STATION PROGRAM MAJOR LAUNCH VEHICLE PERFORMANCE NEEDS

POST IOC OPERATIONS & GROWTH IS MAJOR LAUNCH VEHICLE PERFORMANCE IMPROVEMENT NEED FOR SPACE STATION PROGRAM

- HLLV ASSEMBLY BUILD-UP UTILIZATION GETS TO IOC SOONER WITH FEWER SHUTTLE FLIGHTS

BUT

- PROVIDES NO CREW CARRYING RELIEF TO :
  1. REDUCE LARGE NUMBER OF SHUTTLE CREW ROTATION LOGISTICS FLIGHTS
  2. PROVIDE STATION GROWTH

SHUTTLE CAPABILITY LIMITS CREW GROWTH BEYOND 8 PEOPLE

- A PROBLEM HLLV UTILIZATION CANNOT ADDRESS

LJD/MEY4

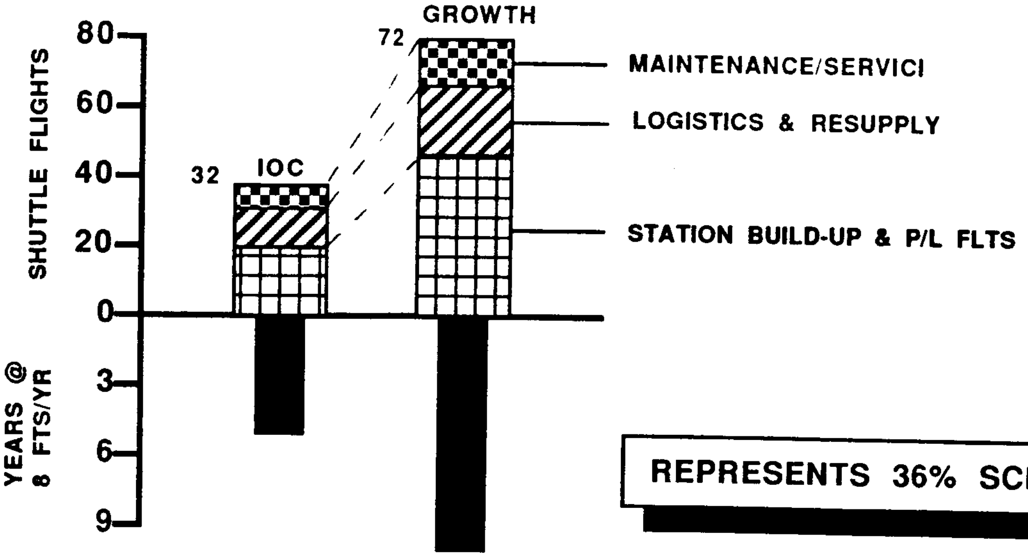
EVOLUTIONARY DEFINITION GROWTH REQUIREMENTS STUDIES SUMMARY

In order to adequately perform the science missions assigned for the Space Station, considerable crew/Station growth will be required. It can be demonstrated that forty flights would be needed just to provide 36% of the intended scientific mission support required for a period of five years after IOC. If all of the scientific work were to be completed, 22 additional shuttle flights would be needed for Station, crew, and payload growth. The Shuttle passenger capacity would also need to be increased.

Heavy Lift Launch Vehicle Study

EVOLUTIONARY DEFINITION GROWTH REQUIREMENTS STUDIES SUMMARY

- 5 YEAR EVOLUTIONARY GROWTH PERIOD FROM IOC[1]
  - -- 300 KW USER POWER
  - -- 18 PERSON CREW
  - -- 40 GROWTH SHUTTLE FLIGHTS



REPRESENTS 36% SCIENCE MISSION CAPTURE[2]

- 22 ADDITIONAL SHUTTLE FLIGHTS/YR NEEDED FOR 100% MRDB CAPTURE
- GROWTH CREW ROTATION REQUIREMENT INCREASES TO 9 PER SHUTTLE FLIGHT

1. LaRC EDO, "LIMITS TO GROWTH STUDY," JANUARY 1986; CETF CONSTRAINED 9/86
2. "SPACE STATION EVOLUTIONARY DEFINITION STUDY," MARCH 1987, MACDAC REPORT, NAS1-18227

LJD/MEY3

BALANCED EVOLUTION PLAN

A balanced Evolutionary Definition plan has been developed for SS growth for ten years post-IOC. From 1997 to 2006, growth from 87.5 kw, 8 crew members, 1 habitability module, and 3 labs to a maximum of 237.5 kw, 18 crew, 3 habitability modules, and 5 labs is anticipated. The difference between the available power and crew provided and what is required by the user is the resources (Power & Crew) required to operate the Station. The growth needs of the Station are seen, therefore, to challenge a corresponding growth plan for the Space Transportation System.

BALANCED EVOLUTION PLAN

POWER	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
AVAILABLE	87.5	87.5	137.5	137.5	137.5	137.5	187.5	187.5	187.5	237.5
USER	50	50	82.5	82.5	82.5	82.5	120	120	120	163
CREW										
AVAILABLE	8	8	12	12	12	12	14	14	14	18
USER	6	6	9	9	9	9	11	11	11	14
HAB MODULES	1	1	2	2	2	2	2	2	2	3
LAB MODULES	3	3	3	3	4	4	4	5	5	5
POCKET LABS				1	2	3	3	3	3	3
OMV		1	1	1	1	1	1	1	1	1
OTV										1

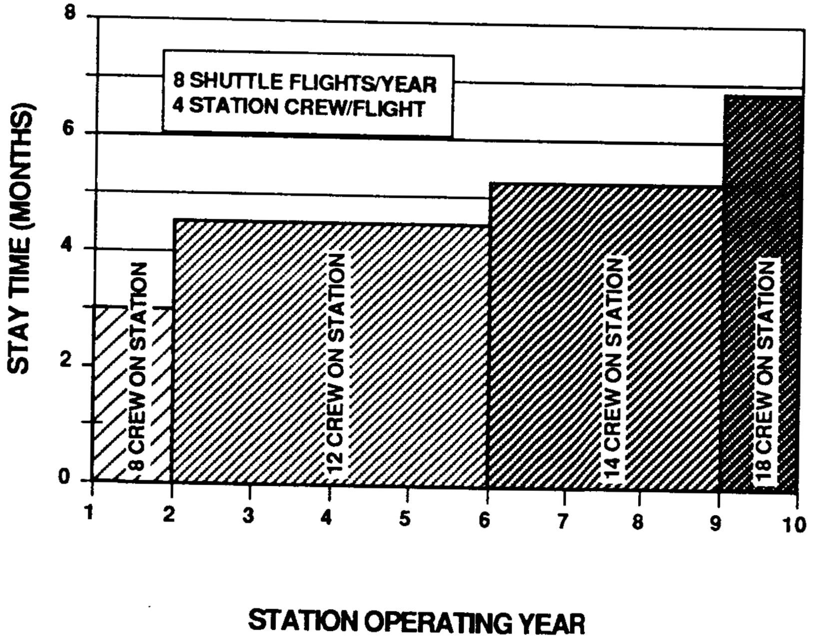
CREW ROTATION ISSUE

If the number of Shuttle flights is constrained to 8 per year, then new options are needed as potential solutions to the problem of crew rotation/station growth. Basically, there are two options given the current Shuttle System: to increase the on-orbit staytime per crew member beyond 90 days or to increase the crew carrying capacity to allow more crew to be rotated per Shuttle flight.

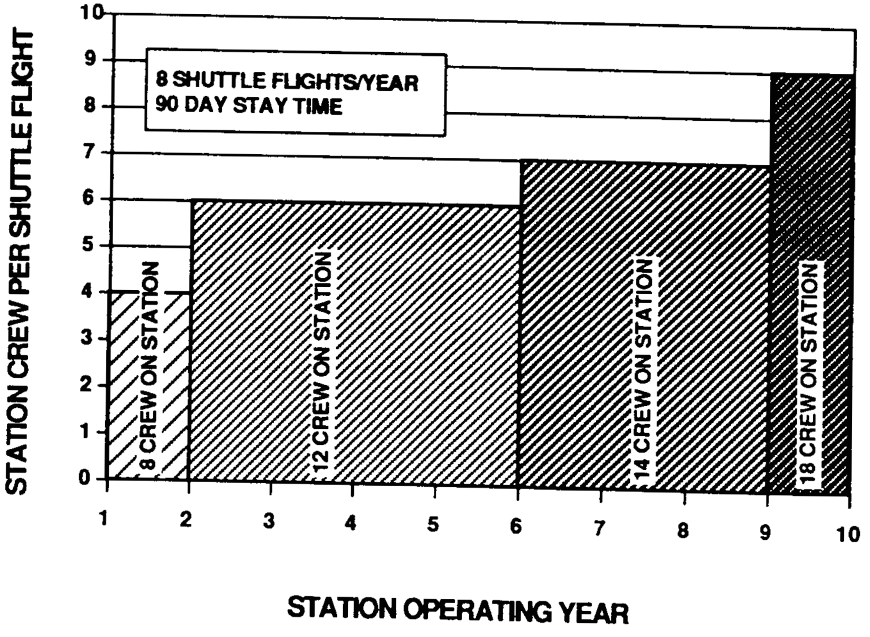
CREW ROTATION ISSUE

THE GRAPHS BELOW SHOW TWO OPTIONS FOR PROVIDING CREW ROTATION ASSUMING 8 STATION DEDICATED SHUTTLE FLIGHTS PER YEAR AND A MODERATELY AGGRESIVE GROWTH PLAN

INCREASING ONORBIT STAY TIME



INCREASING NUMBER OF STATION CREW ROTATED PER SHUTTLE FLIGHT



LOGISTICS CARRIERS
TARE WEIGHT/CARGO CAPABILITY

The logistics and resupply of the station crew and hardware is accomplished via the utilization of cargo carriers. There are two types of logistics cargo carriers currently defined in the Space Station program for Station operations: (1) a pressurized logistics carrier (PLC) and (2) an unpressurized logistics carrier (ULC). The pressurized carrier permits crewmen to retrieve stores, hardware and science hardware from the PLC in a shirt-sleeve environment. The ULC carriers hardware and fluids which are installed outside the pressurized volume and require either the use of EVA or the use of the MSC for cargo handling. The total weight of all cargo elements loaded to full capacity would require a launch weight capacity of 40,000 lbs. Therefore, all fully loaded logistics elements are not manifested together on single shuttle flights, but are sequenced between logistics at various cargo capacity levels. The total tare weight of these cargo carrier elements exceeds 21,000 lbs which is over 50% of the total logistics manifest per shuttle flight.

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LOGISTICS CARRIERS
TARE WEIGHT/CARGO CAPABILITY

		CARGO CAPABILITY	
	TARE WEIGHT (LBS.)	VOLUME (CU. FT.)	WEIGHT (LBS.)
PRESSURIZED LOG CARRIER (PL)			
● PRESSURIZED MODULE	11,452	1,100	22,050 (1)
UNPRESSURIZED LOG CARRERS (ULC)			
● UNPRESSURIZED DRY CARGO CARRIER	3,300	632	6,320 (2)
● FLUIDS CARRIER	3,746	(3)	3,200
● PROPELLANT CARRIER	2,940	(4)	7,414

NOTES:

(1) BASED ON AVERAGE CARGO DENSITY OF 20 LBS/ CU. FT.

(2) BASED ON AVERAGE CARGO DENSITY OF 10 LBS/ CU. FT.

(3) 60.28 CU. FT. LN_2, 3.5. CU. FT. He, 2.2 CU. FT. O_2 , 4.9 CU. FT. AR.

(4) 37.2 CU. FT. N_2H_4, 36.2 CU. FT. MMH, 36.4 CU. FT. N_2O_4 .

RETURN LOGISTICS REQUIREMENTS

In order to prioritize return cargo, it is broken into three categories. In the Required category are crucial experiment results and perishables. The Desired category consists of crew clothing and some failed spares. The remainder of the failed spares and waste products comprise Optional return payloads.

Heavy Lift Launch Vehicle Study

RETURN LOGISTICS REQUIREMENTS

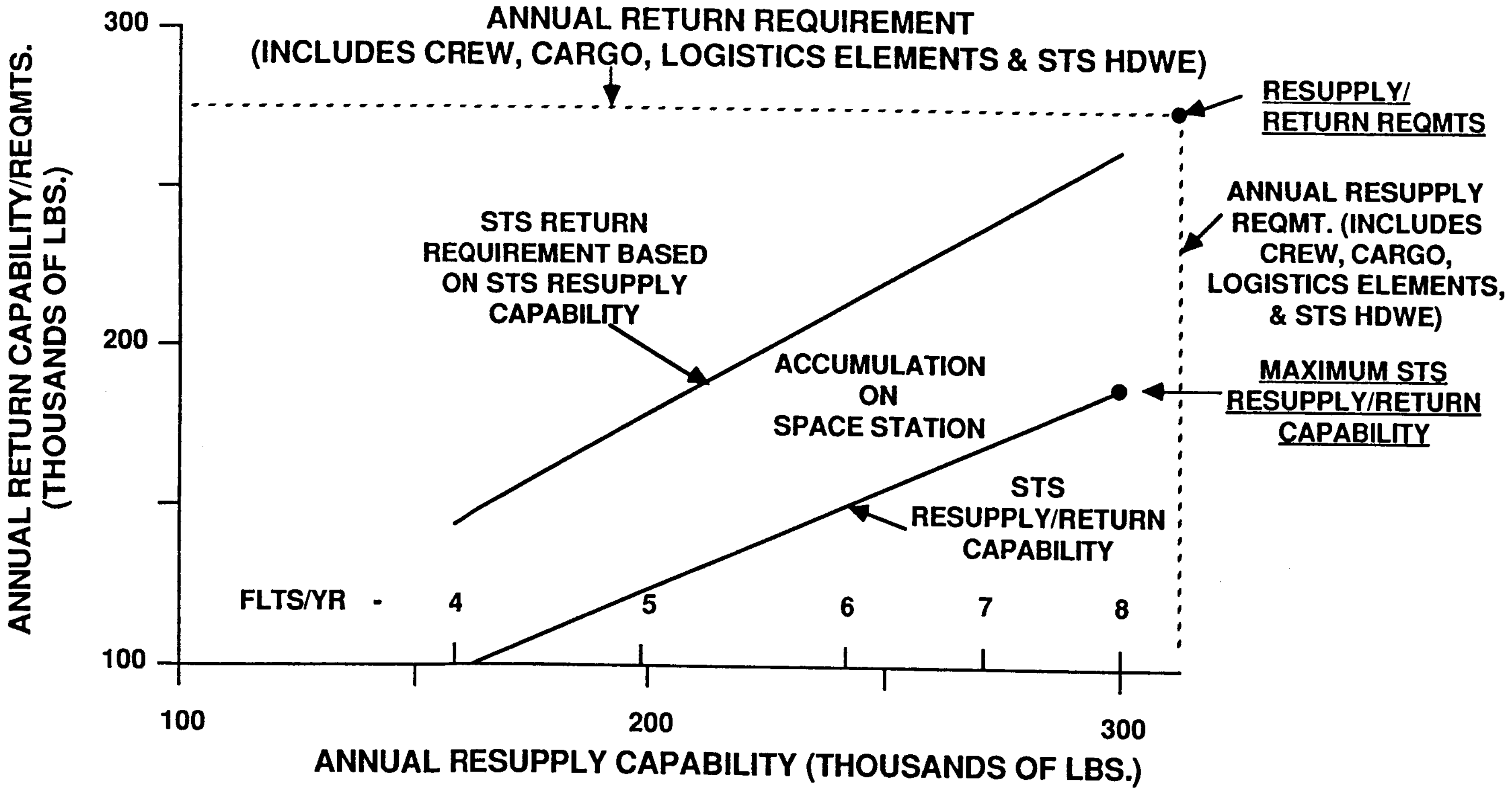
	CATEGORY 1	**CATEGORY 2**	**CATEGORY 3**
	EXPERIMENTS PRODUCTS	**CLOTHING & SELECTED FAILED PARTS**	**WASTE & BALANCE OF FAILED SPARES**
	● MTL PAYLOAD CHANGEOUT ● MTL PRODUCTS ● SLM LIVE WEIGHT ● SLM FROZEN WEIGHT ● JEM PLANT/ANIMAL ● COP PAYLOAD RETURN	● CLOTHING ● CREW SUPPORT/STATION SPARES ● SLM DRY WEIGHT ● ESA PAYLOAD RETURN ● JEM PLANT/ANIMAL ● COP ORU'S ● OMV SPARES	● HEALTH MAINTENANCE ● HOUSEKEEPING ● WASTE ● TRASH ● TRACE CONTAM. CONTROL ● WASTE WATER ● EVA CONSUMABLES ● EVA LIMITED LIFE ● LAB DISPOSABLES ● SLM WASTE ● ESA SPARES ● JEM PLANT/ANIMAL
ANNUAL REQMT (LBS)	50 K	40 K	30 K
RETURN DISPOSITION	REQUIRED	DESIRED	OPTIONAL

COMPARISON OF STS CAPABILITY TO SS LOGISTICS REQUIREMENTS

Using the previously described logistics carrier weights, cargo carrying capacities and return weight needs of the Station and its users, an annual station up/down logistics weight performance capacity can be established.

A comparison of the derived SS return/resupply requirements can then be made against the available STS capacities given a varying number of flights per year. The current maximum Shuttle capabilities (8 flights/year) do not meet SS requirements. Moreover, because the Shuttle's resupply capacity is significantly greater than its return capacity, there is seen to be a resulting accumulation of debris and equipment on the Space Station.

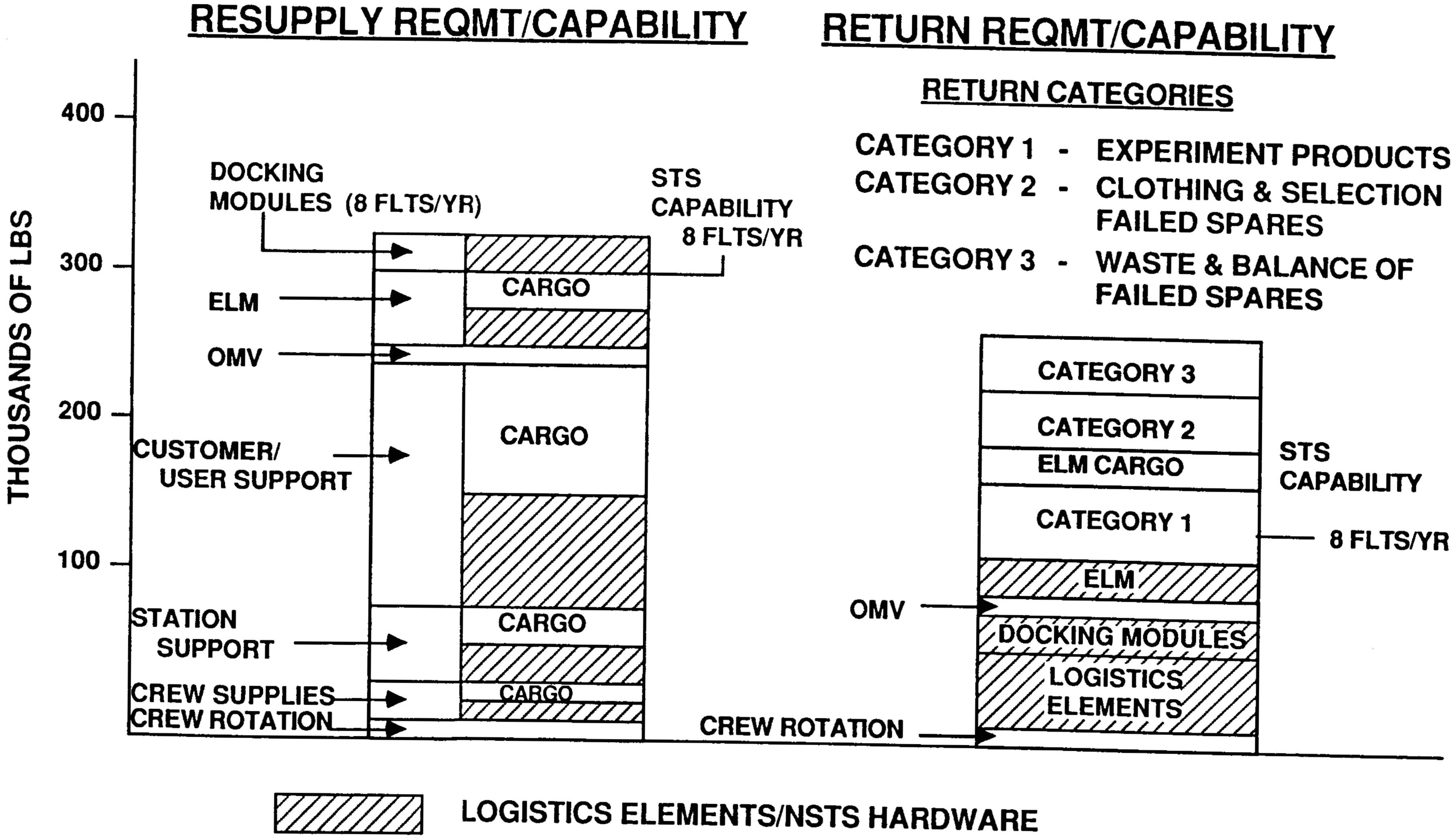
COMPARISON OF STS CAPABILITY TO SPACE STATION LOGISTICS REQUIREMENTS



COMPARISON OF ANNUAL RESUPPLY/RETURN REQUIREMENTS TO STS CAPABILITY

These graphs show the breakdown of resupply requirements and return-to-ground requirements on an annual basis. The STS capability, given 8 flights per year, is superimposed on both charts. While there is a small deficit of resupply capability (approx. 10-20,000 lbs), the shortfall of return capacity is quite large (approx. 100,000 lbs). The major impact is the inability to accommodate all required Category 1 down cargo and the inability to accommodate the JEM ELM cargo.

COMPARISON OF ANNUAL RESUPPLY/RETURN REQUIREMENTS TO STS CAPABILITY



RETURN CATEGORIES

CATEGORY 1 - EXPERIMENT PRODUCTS
CATEGORY 2 - CLOTHING & SELECTION FAILED SPARES
CATEGORY 3 - WASTE & BALANCE OF FAILED SPARES

CO-MANIFESTING CONSIDERATIONS

One consideration to reduce STS demands and to alleviate logistics problems is co-manifesting Space Station and non-Station payloads. In this scenario, once a payload of SS cargo has been selected/arranged, any excess capacity would be taken up by non-SS cargo. Thus, the number of STS flights/year could conceivably be reduced by the Shuttle performing "double-duty" on some missions.

Some of the factors to be considered in this analysis include SS requirements, STS capacity, and non-SS requirements. In some cases, the downweight of an empty logistics module is crucial. Two types of empty modules are examined (18.5K lbs and 14.5K lbs).

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CO-MANIFESTING CONSIDERATIONS

- **STS SPACE STATION REQUIREMENTS**
  - RETURN EMPTY LOGISTICS MODULE (APPROX. 4/YEAR)
  - PERFORM CREW CHANGE OUT EVERY 45 DAYS (4 PERSONS)
- **EMPTY LOGISTICS MODULE EXAMINED FOR TWO CASES**
  - CASE 1 - 18.5 K LBS DOWNWEIGHT/34 FT. LONG
  - CASE 2 - 14.5 K LBS DOWNWEIGHT/26 FT LONG (PRESSURIZED PORTION ONLY)
- **STS CAPABILITY -**

ORBITER	ASCENT	DOWNWEIGHT*
OV-102	31.4 K	16 K
OV - 103	39.5 K	24 K
104		
105		

- **STS FLIGHT RATE - 16 FLTS/YEAR MAXIMUM (0-3 FLTS FROM VAFB)**
- **NON SPACE STATION STS REQUIREMENTS AS PER MIXED FLEET STUDY**

*POTENTIAL 3K IMPROVEMENT BASED ON 6.0 LOAD ANALYSIS

CO-MANIFESTING ASSESSMENT

Some of the most likely candidates for co-manifesting involve the return to ground of equipment, results, etc. The major constraint for these cases, as well as for SS logistics in general, is the downweight capacity of the STS. As was shown in the previous chart, there are two possible cases involving different-sized empty logistics modules to be returned to ground. Neither case provides a co-manifesting opportunity on Columbia (OV-102), but they do offer the possibility on other Shuttles (OV-103, 104, or 105).

Depending on the SS mission the STS is scheduled to perform (logistics module return or crew exchange), each co-manifesting candidate has a varying degree of likely success. Some of the constraints encountered in this analysis are downweight, crew skills, polar launch (vs. ETR launch for SS), and launch window. Another factor considered was the possibility of using a dedicated ELV for these missions.

CO-MANIFESTING ASSESSMENT

- DOWNWEIGHT IS CONSTRAINING STS PARAMETER
- OV-102 NOT VIABLE FOR MODULE RETURN
- RESULTING CO-MANIFESTING CAPABILITY ON OV-103, 104 OR 105 IS

CASE 1 - 5500 LBS
CASE 2 - 9500 LBS
} PLUS POTENTIAL 3K IMPROVEMENT

- CANDIDATE REQUIREMENTS (1993-1995) FOR CO-MANIFESTING

	COMPATIBILITY		
PAYLOADS	MODULE RETURN	CREW EXCHANGE	CONSTRAINT
SPACELAB (SLS, IML, ATLAS, ASTRO, SPL)	NO	NO	DOWNWEIGHT, UNIQUE CREW
OTHER MAJOR ATTACHED (HRSO, XRT, SHEAL, OAST, LAMDA PT, LYMAN-ALPHA)	NO	POTENTIAL	DOWNWEIGHT
REVISIT FLIGHTS (HST, GRO)	NO	NO	OMS, LAUNCH WINDOW
DEPLOYABLE PAYLOADS			
AXAF	MARGINAL	MARGINAL	OMS, LAUNCH WINDOW
TDRSS, LGO	NO	NO	PERFORMANCE
CFMFE, CLUSTER	POTENTIAL	POTENTIAL	STRONG ELV CAND.
NOAA, LANDSAT	NO	NO	POLAR
SMALL ATTACHED PAYLOAD (MSL, SPARTAN, COFS)	YES	YES	
DOD MISSIONS	?	?	COMPATIBILITY, SECURITY

CO-MANIFESTING OPPORTUNITIES ON PREVIOUS STS FLIGHTS

Past STS flights were examined to determine if there was capacity beyond that required by the scheduled mission. The potential each mission would have had for co-manifesting was determined, based on volume available, excess weight capacity, and launch inclination.

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ANALYSIS OF CO-MANIFESTING OPPORTUNITIES ON PREVIOUS STS FLIGHTS

			LAUNCH*	
NSTS FLT. NO.	INCLIN. DEGREES	ALTITUDE N.M.	CARGO BAY LENGTH AVAILABLE	EXCESS SCHEDULED PERFORMANCE
31D	28.5	160	NOT AVAIL.	16.6 K
41A	57.0	135	0.5'	2.0 K
41B	28.5	165	36.2'	15.0 K
41C	28.5	250	NOT AVAIL.	5.3 K
41D	28.5	160	14.7'	2.2 K
41G	57.0	190	31.5'	18.1 K
51A	28.5	160	NOT AVAIL.	17.9 K
51B	57.0	190	5.7'	2.5 K
51G	28.5	190	26.0'	0.6 K
51F	50.0	207	9.0'	0.0 K
10 FLIGHT TOTAL				80.2 K
WEIGHT PER FLIGHT				8.0 K

*GREEN BOOK VALUES

CO-MANIFESTING SUMMARY

Analysis of planned and previous STS flights showed that the opportunities for co-manifesting SS and non-SS payloads are limited. The potential for co-manifesting does exist with some small, attached payloads; however, they are not high priority items, nor will they greatly alleviate STS demands.

Enhanced Shuttle return capacity may be a more viable option than co-manifesting.

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CO-MANIFESTING SUMMARY

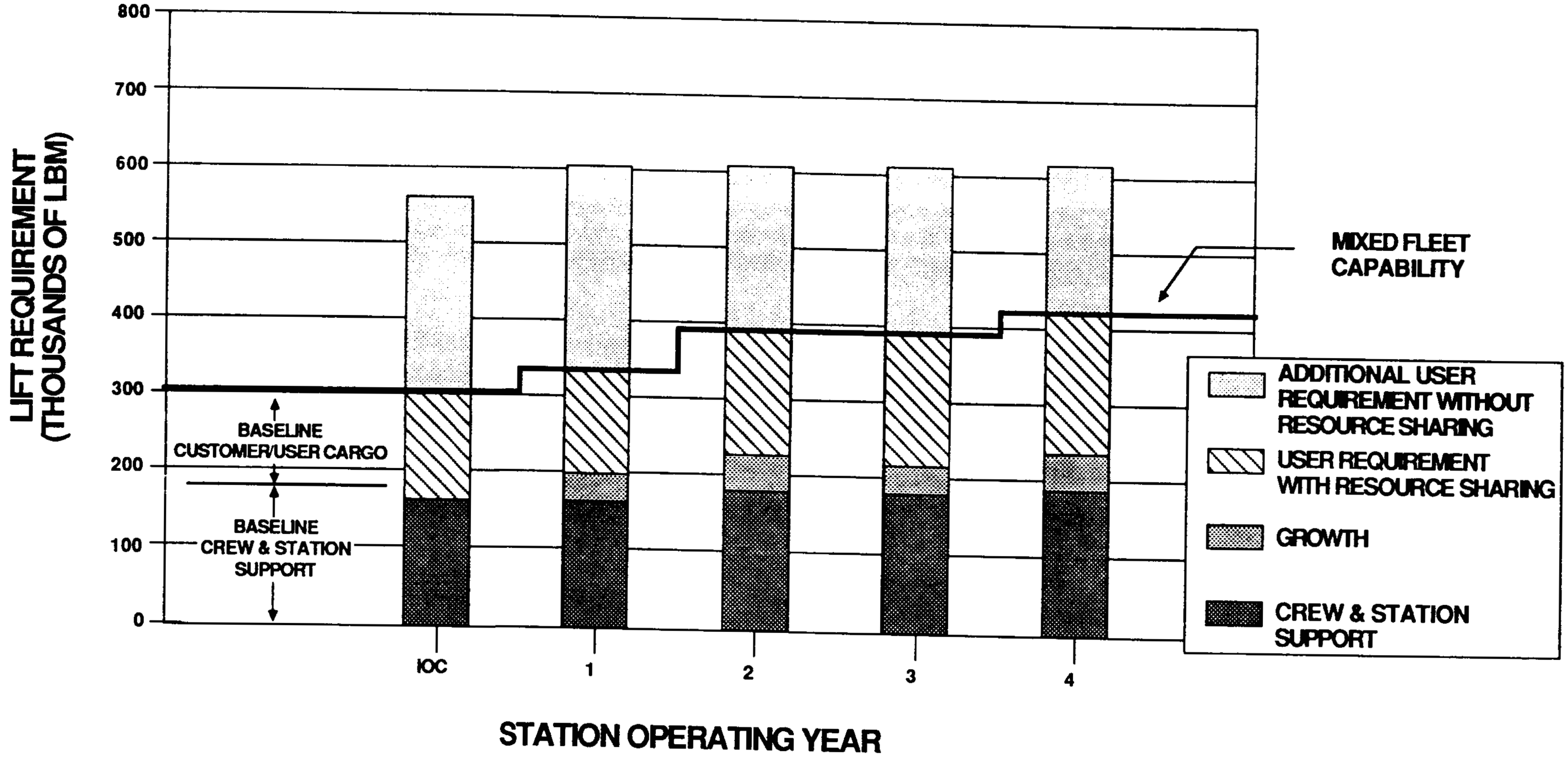
- LIMITED STS DOWNWEIGHT CAPABILITY
- MINIMAL IF ANY MAJOR SHUTTLE PAYLOADS COMPATIBLE WITH SPACE STATION CO-MANIFESTING/ CREW EXCHANGE
- SMALL ATTACHED PAYLOADS COMPATIBLE BUT:
    - NOT HIGH PRIORITY PAYLOADS
    - MANY WILL BE TRANSITIONING TO STATION
    - CANNOT BE USED AS SOLE JUSTIFICATION FOR HLLV
- MAXIMIZING SHUTTLE DOWNWEIGHT CAPABILITY WITH SPACE STATION EQUIPMENT APPEARS MORE EFFICIENT THAN CO-MANIFESTING

COMPARISON OF LIFT REQUIREMENTS TO MIXED FLEET CAPABILITY

Another potential solution to the logistics/resupply problem may be the use of mixed fleet capabilities using ELVs. If a mixed fleet option is selected for SS resupply, there will be a significant shortfall unless resource sharing is implemented. The concept of resource sharing means allocating reduced operating time to user experiments in order to bring requirements more in line with capabilities. In the first four years post-IOC, the mixed fleet scenario adequately covers both user needs and crew and Station support resupply, as long as resource sharing is implemented.

COMPARISON OF LIFT REQUIREMENTS TO MIXED FLEET CAPABILITY

FOR THE FIRST FOUR STATION OPERATING YEARS

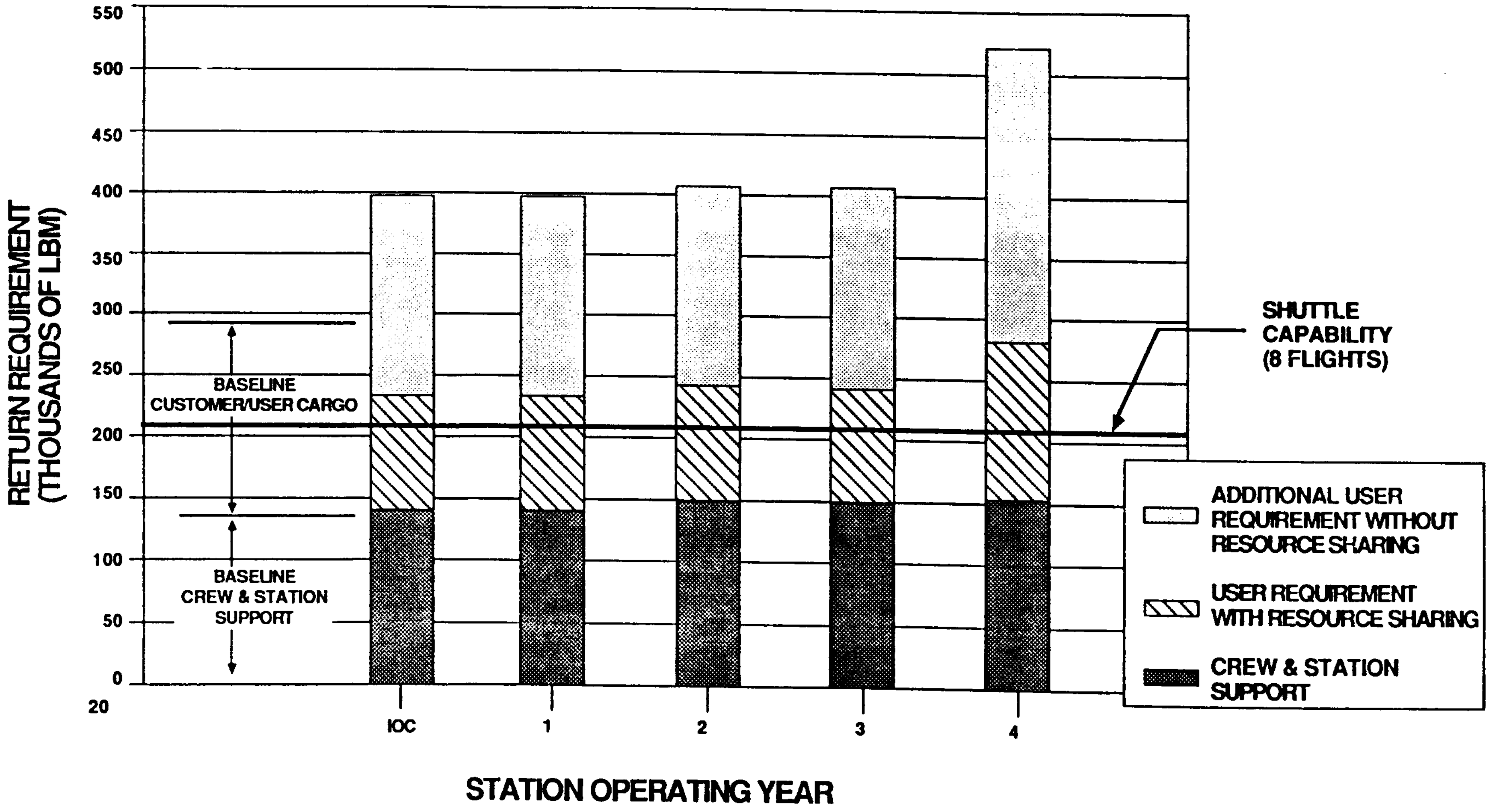


COMPARISON OF RETURN REQUIREMENTS TO MIXED FLEET CAPABILITY

A scenario using mixed fleet cargo return requirements based on full-scale operations and on resource sharing can be derived. The most significant finding of this analysis is that the mixed fleet scenario offers no increase in downweight capability. The SS is completely dependent on the STS for cargo return. At 8 flights per year, the STS cannot even meet return requirements when resource sharing is assumed.

COMPARISON OF RETURN REQUIREMENTS TO MIXED FLEET CAPABILITY

FOR THE FIRST FOUR STATION OPERATING YEARS



EVALUATION OF HLLV FOR SS LOGISTICS MISSIONS

After reviewing the major logistics issues, including crew rotation, resupply, return, and co-manifesting, it is concluded that the use of HLLVs for logistics missions is of little benefit. It is further concluded that using HLLVs for resupply will contribute to the already significant return cargo limitations and Station accumulation problems.

EVALUATION OF HLLV FOR SPACE STATION LOGISTICS MISSIONS

CREW ROTATION

- TO SATISFY CREW ROTATION FREQUENCY REQUIRES 8 STS FLIGHTS/YEAR
- HLLV CANNOT BE USED TO TRANSPORT CREW THEREFORE CANNOT SUPPLEMENT AVAILABLE STS CAPABILITY IF LESS THAN THE REQUIRED 8 STS FLIGHTS/YEAR

CREW, STATION, AND USER LOGISTICS

- RESUPPLY
  - RESUPPLY REQUIREMENTS ARE APPROXIMATELY 8 STS FLIGHTS/YEAR
  - HLLV CAN BE USED TO SUPPLEMENT AVAILABLE STS CAPABILITY BUT EFFECTIVE HLLV PAYLOAD CAPABILITY WILL BE REDUCED BY:
    - MANEUVERING/STATION-KEEPING
    - STRUCTURE FOR SUPPORTING PAYLOAD IN SHROUD
  - IF STS AVAILABILITY WERE MINIMUM (4 LAUNCHES/YR), APPROX. 2-3 HLLV/YR WOULD BE REQUIRED TO MEET REQUIREMENTS
- RETURN
  - STS RESUPPLY CAPABILITY EXCEEDS THE RETURN CAPABILITY THEREFORE ACCUMULATION ON THE STATION USING STS ONLY IS SUBSTANTIAL
  - HLLV HAS NO RETURN CAPABILITY THEREFORE USE OF THE HLLV FOR RESUPPLY ADDS TO THE STATION ACCUMULATION

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6.0 LAUNCH FACILITIES IMPACT

ETR IMPACTS

Another consideration for the use of HLLVs is the impact it will have on existing launch facilities. The Eastern Test Range (Kennedy Space Center) will be the primary launch site for the HLLVs, and several modifications and new capabilities will be required. Some of the highest impact items for the Vertical Assembly Building (VAB) are the need for new high-bay cells to accommodate stacking HLLVs, the need for design and construction of a HLLV rotation facility, and the need for additional ground facilities for the SS itself. The HLLV advantage of greater prelaunch integration and verification becomes a disadvantage when ground-based assembly capabilities are considered; this is especially true if any of the deployable structures HLLV options (Modified Transverse Boom, Integrated Race Track) are selected.

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ETR IMPACTS

FACILITY:

- **PAD**
  - MODIFY - EXTEND FIXED SERVICE STRUCTURE
- **VAB**
  - MODIFY - LOW BAY CELLS 1 & 2 FOR HLLV SSME & SUPPORT EQUIPMENT & STORAGE. ADDITIONAL SPACE REQUIRED FOR PROCESSING SRB'S.
  - NEW - TWO (2) ADDITIONAL HIGH-BAY CELLS REQUIRED FOR STACKING HLLV'S WITH CO-EXISTING STS.
  - * NOTE - HIGH BAYS 1 & 2 ARE DEDICATED STS
    - HIGH BAYS 3 & 4 ARE DEDICATED SRB PROCESSING (NEED TO FIND NEW HOME FOR THIS)
- **HLLV ROTATION FACILITY**
  - NEW - TRANSLATING PAYLOAD FROM HORIZONTAL TO VERTICAL FOR SHROUD INSTALLATION AND TRANSFER TO VAB
- **SS PROCESSING FACILITY**
  - MODIFY - INCREASE SIZE FOR FULL-UP ASSEMBLY OF FLIGHTS 1 AND/OR 2, ETC.
  - NEW - ADD-ON FOR HORIZONTAL PROCESSING OF HLLV PAYLOAD-GROWTH TO TWO (2) FOOTPRINTS.

ETR IMPACTS
(cont.)

To accommodate SS/HLLV integration, modifications to the Hazardous Facility will have to be made. Because of the increase in the number of launch vehicles, an additional mobile transporter will be required. A payload transporter will have to be designed for installation of the P/L carrier. One important note is that the mobile launcher modifications will be less if the side-mount configuration is used.

ETR IMPACTS

(CONT.)

FACILITY: (CONT.)

- **SS HAZARDOUS FACILITY**
  - MODIFY - ENTRY/EXIT WAYS FOR HLLV HORIZONTAL/VERTICAL PAYLOAD AND TRANSPORTER

EQUIPMENT:

- **MOBILE LAUNCHER**
  - MODIFY - DEPENDENT ON CONFIGURATION (INLINE OR SIDEMOUNT SSME'S)
    - SSME EXHAUST
    - LAUNCH UMBILICAL TOWER
  - NEW - ADDITIONAL MOBILE LAUNCHER REQUIRED TO SUPPORT GROWTH OF 8 PER YEAR
- **PAYLOAD TRANSPORTER**
  - NEW - VEHICLE FOR SUPPORTING VERTICAL INSTALLATION OF PAYLOAD AND SHROUD AND TRANSPORTING INTRA-SITE (SSPF TO HAZ FAC OR VAB, ETC.)

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7.0 HLLV ISSUES

ISSUES

This study has raised some important issues for consideration. The issue of logistics remains unresolved, since neither co-manifesting nor mixed fleet scenarios solve the problems of SS cargo weight accumulation on-orbit and crew rotation. Proximity operations and berthing are other areas which remain to be resolved and require new NASA flight demonstration initiatives. The complexity of the operations involved in the use of unmanned launch vehicles and three-body rendezvous need to be researched and methodologies and techniques developed. The key issues associated with proximity operations and berthing have been identified during this study and are documented here for future reference.

Heavy Lift Launch Vehicle Study

ISSUES

- ESTABLISHES NEW REQUIREMENTS FOR LOGISTICS & RESUPPLY
    - MIXED FLEET/CO-MANIFESTING OPPORTUNITIES MINIMAL
- PROXIMITY OPERATIONS AND BERTHING
    - RENDEZVOUS PAYLOAD WITH STATION
        - METHOD OF CONTROL
        - OMV CAPABILITY TO HANDLE LARGE MASSES
        - ON-ORBIT INCREASED SERVICING FREQUENCY OF OMV
    - BERTHING PAYLOAD TO STATION
        - METHOD OF CONTROL
        - ORBITER RMS REQUIRED TO HANDLE > 150 K
        - POSITION AND ORIENTATION OF PAYLOAD ON STATION
        - STATION CONTROLLABILITY
        - PAYLOAD ACCESS USING SS RMS
        - INTERFERENCES

ISSUES
(cont.)

Some of the potential methods for resolving the proximity operations/berthing problems are identified. The system need not to be entirely automatic which would reduce some of the complexity. The issue then becomes what type of manual control should be used and where it will be located. Of the options presented, the concept of manual control from the Orbiter is one which incorporates technology that is already required for the SS. The ground control concept would require significant development efforts, and the option to control prox ops/berthing from the SS itself is seen to be an unlikely consideration for the initial SS assembly flights.

ISSUES
(CONT.)

- **PROXIMITY OPERATIONS AND BERTHING CONTROL ISSUES**

METHOD

- AUTOMATIC SYSTEM NOT REQUIRED
- MANUAL
  - FROM STATION
    NOT PRACTICAL ON INITIAL FLIGHTS
  - FROM ORBITER
    CAPABILITY NEEDED FOR CETF BASELINE
- FROM GROUND
  - DEVELOP GROUND CONTROL STATION
  - DEVELOP OPERATIONAL TECHNIQUES AND EQUIPMENT TO OVERCOME 3 SECOND TIME LAG
  - SENSOR
  - VISABILITY

COST ISSUES - ASSEMBLY

Another issue raised by this study is that of cost. While the cost impact of HLLVs is significant for logistics, it is relatively minor for assembly. The reduction of assembly sequence length reduces costs sufficiently to almost outweigh the other factors that increase cost. These factors include launch repackaging, ground operations, and on-orbit operations. The greatest influence the use of HLLVs for assembly will have is an increase the early budget problems already affecting the program.

COST ISSUES

ASSEMBLY

- NO DRIVING ISSUES -- $ IMPACTS ARE RELATIVELY MINOR
  - MINOR DESIGN CHANGES ASSOCIATED WITH LAUNCH REPACKAGING
  - GROUND OPERATIONS INCREASES ASSOCIATED WITH NEW VEHICLE IN THE LOOP (KSC PRELAUNCH ACTIVITY, GROUND CONTROL)
  - ON-ORBIT OPERATIONS INCREASES DUE TO PROX. OPS ACTIVITY
  - REDUCTION IN COST DUE TO REDUCED LENGTH OF ASSEMBLY SEQUENCE
- HLLV OPTIONS INCREASE THE EARLY YEAR BUDGET PROBLEM

IMPACT OF HLLV ON SS LOGISTICS MISSIONS

Qualitative Cost Evaluation

A qualitative cost evaluation was performed to depict the cost trends which use of HLLVs would impact significantly. The only area where costs would decrease is seen to be in Station resupply. The launch facility, proximity operations and control, the redesign of logistics modules/elements, the use/design of OMVs, and cargo return all increase costs when compared with the STS baseline.

Heavy Lift Launch Vehicle Study

IMPACT OF HLLV ON STATION LOGISTICS MISSIONS

QUALITATIVE COST EVALUATION

	STS ONLY	STS + HLLV
• GROUND OPERATIONS	BASELINE	+ $
• GROUND CONTROL		+ $
• LOGISTICS ELEMENTS		
DESIGN		+ $
PRODUCTION		+ $
• OMV UTILIZATION		+ $
• TRANSPORTATION		
RESUPPLY		- $
RETURN/DISPOSAL		+ $

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8.0 HLLV ASSESSMENT SUMMARY

HLLV ASSESSMENT SUMMARY

A summary is presented of the key findings of this study relative to the issue of co-manifesting and to the effects of HLLVs on SS design, assembly, logistics, ground operations, and launch facilities. The programmatic impact of HLLVs is also assessed.

HLLV ASSESSMENT SUMMARY

- CO-MANIFESTING NOT PRACTICAL FOR STATION CREW ROTATION & LOGISTICS RESUPPLY/RETURN
  - ANALYSES OF PREVIOUS AND PLANNED STS MISSIONS INDICATES THAT THERE HAS BEEN AND WILL CONTINUE TO BE MINIMUM OPPORTUNITY FOR CO-MANIFESTING
- HLLV EFFECTS ON SPACE STATION PROGRAM
  - DESIGN
    - TEMPTATION EXISTS TO INCREASE THE SIZE OF STATION ELEMENTS. THEREFORE MAINTENANCE, REPLACEMENT, AND GROWTH WOULD NOT NECESSARILY REMAIN STS COMPATIBLE.
    - INTEGRATION OF STATION ELEMENTS NEEDS TO REMAIN COMPATIBLE WITH BOTH STS & HLLV TO REDUCE PROGRAM RISK
    - ALLOWS FOR MORE DESIGN FLEXIBILITY THEREBY REDUCING PROGRAM RISK

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Heavy Lift Launch Vehicle Station

HLLV ASSESSMENT SUMMARY

(CONT.)

- **ASSEMBLY**
  - SIMPLIFIES ASSEMBLY BECAUSE HLLV:
    - INCREASES GROUND VERIFICATION CAPABILITY, RESULTING IN FULLY OUTFITTED MODULE BEING LAUNCHED WITH PROBABILITY OF GREATER RELIABILITY & OPERATIONAL SUCCESS ON-ORBIT
    - REDUCES RISK OF EARLY ASSEMBLY FLIGHTS BECAUSE INTEGRATED CONFIGURATION REQUIRES LESS ON-ORBIT CONSTRUCTION, ALSO ASSEMBLY RISK DUE TO POSSIBLE ELEMENT INCOMPATIBILITY IS MINIMIZED
    - REQUIRES FEWER TOTAL FLIGHTS TO ACHIEVE ASSEMBLY MILESTONES
    - REDUCES NUMBER OF ELEMENTS TO BE ATTACHED
    - PROVIDES MORE POTENTIAL FOR UTILIZATION OF AUTOMATION IN DEPLOYMENT OF ASSEMBLIES
    - REDUCES EVA REQUIREMENTS
  - MORE COMPLEX ORBITAL FLIGHT OPERATIONS
    - POTENTIAL FOR MORE COMPLEX MULTI-BODY OPERATIONS
    - REQUIRES DEVELOPMENT & DEMONSTRATION OF SYSTEM (CARRIER/OMV) TO MANEUVER LARGER MASSES

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Heavy Lift Launch Vehicle Study

HLLV ASSESSMENT SUMMARY

(CONT.)

- **LOGISTICS**
  - HLLV ENHANCES RESUPPLY CAPABILITY, BUT DOES NOT HAVE CAPABILITY TO:
    - TRANSPORT CREW
    - RETURN CARGO
  - CAN BE USED TO PERFORM CONTINGENCY MISSIONS AND RESUPPLY OF HAZARDOUS ITEMS OR THOSE NOT COMPATIBLE WITH THE LOGISTICS ELEMENTS
  - INCREASES COST OF LOGISTICS
    - COST INCREASES LARGER THAN COST SAVINGS
- **GROUND OPERATIONS & LAUNCH FACILITIES**
  - REQUIRES ADDITIONAL GROUND HANDLING & LAUNCH FACILITIES

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Heavy Lift Launch Vehicle Study

HLLV ASSESSMENT SUMMARY

(CONT.)

PROGRAMMATIC

- EARLY HLLV START & CONCURRENT DEVELOPMENT OF HLLV ALONG WITH STATION REQUIRED FOR AVAILABILITY ON EARLY ASSEMBLY FLIGHTS
- STATION ASSEMBLY BECOMES DEPENDENT ON BOTH THE OMV & HLLV PROGRAMS

SUMMARY

Space Station Initial Operating Capability can be achieved by use of the STS alone. However, the risks associated with this baseline SS assembly plan can be significantly reduced by the introduction of HLLVs into the SS Program. Two major advantages derived from the use of HLLVs are (1) a reduction of the number of STS flights early in the SSP when risks are high and (2) an added capacity for SS growth. Current ongoing Manned Mars Accommodation Studies soon to be published indicate that the use of HLLVs at a rate of 3-4 flights per year from the years 2000 to 2004 need to be considered. The key issue for the Station Evolutionary Definition Plan for the late 1990s resides with the Shuttle capacity to carry the needed number of crew versus crew staytime on orbit.

Another issue requiring further study is SS cargo accumulation on orbit. HLLV utilization does not alleviate the problem of returning results and refuse to ground. This issue will have to be addressed in future studies related to down cargo carriers for Station utilization.

The biggest concern brought about by the planned use of HLLVs is parallel SS and HLLV design development. The commitment of technical and financial resources will have to be substantial and immediate if the HLLV program is to be successfully implemented in a time frame to be of any early advantage for Station utilization.

Heavy Lift Launch Vehicle Study

SUMMARY

- SPACE STATION IOC CAN BE ACHIEVED WITH SHUTTLE
- HLLV SAVES FIVE SHUTTLE FLIGHTS EARLY
- SHUTTLE PERFORMANCE LIMITS SPACE STATION GROWTH
- HLLV IS REQUIRED FOR MANNED MARS AND GROWTH SPACE STATION
- DOWN CARGO IS A MAJOR GROWTH PROBLEM
- PARALLEL HLLV DEVELOPMENT MAJOR CONCERN

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9.0 ACRONYMS

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ACRONYMS

CETF	Critical Evaluation Task Force
CMG	Control Moment Gyro's
COP	Co-Orbiting Platform
DOD	Department of Defense
DOF	Degrees of Freedom
ELM	Experiment Logistics Module
ELV	Expendable Launch Vehicle
EPS	Electrical Power System
ESA	European Space Agency
ET	External Tank
ETR	Eastern Test Range (KSC)
EVA	Extra Vehicular Activity
GD/C	General Dynamics/C
HLLV	Heavy Lift Launch Vehicle
IOC	Initial Operating Capability
JEM	Japanese Experiment Module
L	Logistics
MB	Manned Base
ME	Main Engine
MMD	(Mobile Servicing System) Maintenance Depot
MRDB	Mission Requirements Data Base
MSC	Mobile Servicing Centre
MTL	Materials Technology Laboratory
NM	Nautical Miles
NSTS	National Space Transportation System
OMS	Orbital Maneuvering System

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OMV	Orbital Maneuvering Vehicle
OTV	Orbital Transfer Vehicle
OV	Orbital Vehicle
P	Platform
PL	Pressurized Log
P/L	Payload
PMC	Permanent Manned Capability
PR	Platform Refurbishment
PV	Photovoltaic
RCS	Reaction Control System
S/C	Space Craft
SDV	Shuttle Derived Vehicle
SLM	Science Lab Module
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SS	Space Station
SSEMU	Space Station Extravehicular Maneuvering Unit
SSME	Space Shuttle Main Engine
SSP	Space Station Program
SSRMS	Space Station Remote Manipulator System
STS	Space Transportation System
TCS	Thermal Control System
TDRSS	Tracking & Data Relay Satellite System
ULC	Unpressurized Log Carrier
VAB	Vertical Assembly Building
VAFB	Vandenberg Air Force Base
WTR	Western Test Range (VAFB)

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16. Abstract

This study explores the utilization of Heavy Lift Launch Vehicles (HLLVs) for Space Station assembly, logistics, and resupply. The background of the Space Station Program and the evolution of the HLLV are described. Potential HLLVs, including those based on the Titan, and Shuttle-derived vehicles (SDV), are discussed. The baseline Critical Evaluation Task Force (CETF) Space Station assembly sequence is described and compared with assembly options made possible through the use of HLLVs. The issues of cost, dual compatibility with the Space Shuttle Space Transportation System (STS), co-manifesting of payloads with other science missions cargo return, and ground handling and launch facilities are also considered.

It is concluded that the main advantages achieved by using HLLVs are simplification of assembly procedures, added resupply capability, and increased assured access to space. The major disadvantages are increased orbital flight operations complexity, higher logistics costs, and additional ground handling/launch facility requirements. Also, there will not be any improvement in return cargo capacity, nor any addition to crew transport capabilities. Finally, it is determined that dual STS/HLLV compatibility should be maintained to minimize program risk and that the development of the HLLV and the Orbital Maneuvering Vehicsle (OMV) must be concurrent with that of the Space Station design.

17. Key Words (Suggested by Author(s))

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