NASA Conference Publication 10044

NASA - JSC
TECHNICAL
LIBRARY
Call No:
TL
797
.B49
1990
v.1
pt.1
c.1

# Beyond the Baseline

## *Proceedings of the Space Station Evolution Symposium*

Volume 1: Space Station Freedom

Part 1

TECHNICAL LIBRARY
BUILDING 45

FEB 21 1991

Johnson Space Center
Houston, Texas 77058

*Proceedings of a conference held at*
*South Shore Harbour Resort*
*and Conference Center*
*League City, Texas*
*February 6-8, 1990*

NASA

## Preface

This publication is a compilation of papers presented at the First Annual Space Station Evolution Symposium: Beyond the Baseline on February 6-8, 1990. The symposium focused on the presentation of results by the personnel responsible for advanced system studies and advanced development tasks within the Space Station Freedom Program. The symposium provided an opportunity for dialogue between the users, designers, and advanced planners for Station regarding the long-term utilization of Space Station Freedom.

The papers describe efforts included within the Level I Transition Definition Program to define and incorporate baseline design accommodations which satisfy the requirements associated with potential evolutionary paths, and to develop advanced technology which will enhance Space Station capabilities and enable its evolution. The papers describe work accomplished during fiscal year 1989 and were presented by those in Government, industry, and academia who performed the tasks.

This publication consists of two volumes. Volume 1 contains the results of the advanced system studies with the emphasis on reference evolution configurations, system design requirements and accommodations, and long-range technology projections. Volume 2 reports on advanced development tasks within the Transition Definition Program. Products of these tasks include: engineering fidelity demonstrations and evaluations on Station development testbeds and Shuttle-based flight experiments; detailed requirements and performance specifications which address advanced technology implementation issues; and mature applications and the tools required for the development, implementation, and support of advanced technology within the Space Station Freedom Program.

Dr. Earle K. Huckins III
Director, Space Station Freedom Engineering
Office of Space Flight
NASA Headquarters

Listed below are the persons who made this symposium possible.

## COMMITTEE MEMBERS

**Conference Chair:**

- Earle Huckins III
  *NASA Headquarters*

**Program Planning Committee Technical Chairs:**

- Stephen Cook
  *NASA Headquarters*
  Evolution Systems Studies and Analysis
- Gregg Swietek
  *NASA Headquarters*
  Advanced Development Program

**Session Chairs:**

- E. Brian Pritchard
  *NASA Langley Research Center*
- Barry Meredith
  *NASA Langley Research Center*
- Karen Brender
  *NASA Langley Research Center*
- Gregg Swietek
  *NASA Headquarters*
- Paul Neumann
  *Space Station Freedom Program Office*
- John Muratore
  *NASA Lyndon B. Johnson Space Center*
- Henry Lum
  *Ames Research Center*
- Wayne Zimmerman
  *NASA Headquarters*
- Dale Weathers
  *Space Station Freedom Program Office*

**Administrative Co-Chairs:**

- Glenn Freedman
  *UH-Clear Lake*
- Carla Armstrong
  *Barrios Technology*

**Graphics Coordinator:**

- Peter Colangelo
  *Omniplan Corporation*

CONTENTS – Volume 1, Part 1


| Title | Page |
|---|---|
| SPACE STATION FREEDOM OVERVIEW | 1 |
| **SESSION III: CONFIGURATION EVOLUTION**<br>**Session Chair: Mr. E. Brian Pritchard, NASA Langley Research Center** | |
| SPACE STATION FREEDOM INTEGRATED RESEARCH AND DEVELOPMENT GROWTH | 19 |
| SPACE STATION FREEDOM TRANSPORTATION NODE CONCEPTS AND ANALYSIS | 55 |
| SERVICING CAPABILITY FOR THE EVOLUTIONARY SPACE STATION | 125 |
| EVOLUTIONARY SPACE STATION FLUIDS MANAGEMENT | 165 |
| SPACE STATION EVOLUTION LOGISTICS | 207 |
| TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE | 233 |
| ACCOMMODATION OF NUCLEAR POWER AND PROPULSION CONCEPTS | 295 |
| PLATFORM EVOLUTION STUDIES | 329 |
| **SESSION V: SYSTEM EVOLUTION**<br>**Session Chair: Mr. Barry D. Meredith, NASA Langley Research Center** | |
| SYSTEM EVOLUTION INTRODUCTORY REMARKS | 369 |
| ASSURING DATA TRANSPARENCY THROUGH DESIGN METHODOLOGIES | 373 |
| SPACE STATION EVA SYSTEM EVOLUTION STUDY | 389 |
| DATA MANAGEMENT SYSTEM (DMS) EVOLUTION ANALYSIS | 427 |
| SPACE STATION FREEDOM CENTRAL THERMAL CONTROL SYSTEM EVOLUTION | 449 |
| EVOLUTIONARY SPACE STATION GN&C STUDY | 481 |
| COMMUNICATIONS AND TRACKING DISTRIBUTED SYSTEMS EVOLUTION STUDY | 505 |

Title Page

DYNAMIC CHARACTERISTICS OF SPACE STATION FREEDOM MARS AND LUNAR EVOLUTION REFERENCE CONFIGURATIONS ..... 535

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM EVOLUTION ..... 579

SPACE STATION FREEDOM ELECTRIC POWER SYSTEM-SEI (LUNAR MARS MISSION) ACCOMMODATION STUDY ..... 611

**SESSION VII: OPERATIONS EVOLUTION**
**Session Chair: Ms. Karen Brender, NASA Langley Research Center**

OPERATIONS ANALYSIS FOR EVOLUTION STATION CONCEPTS ..... 623

OPERATIONS MODELING FOR SSF EVOLUTION ..... 629

ON-ORBIT ASSEMBLY TASK DEFINITION STUDY ..... 651

ADVANCED ROBOTICS FOR IN-SPACE VEHICLE PROCESSING ..... 677

ADVANCED AUTOMATION FOR IN-SPACE VEHICLE PROCESSING ..... 695

SPACE VEHICLE DEPLOYMENT FROM SPACE STATION ORBIT ..... 725

GRAPHICAL ANALYSIS OF MARS VEHICLE ASSEMBLY ..... 749

| Time | Topic | Presenter |
|---|---|---|
| **Monday February 5, 1990** | | |
| 6:00 p.m. - 9:00 p.m. | Registration | |
| **Tuesday February 6, 1990** | | |
| 7:30 a.m. | Registration | |
| 8:30 | OPENING SESSION | |
| | Welcoming Remarks | Dr. Aaron Cohen<br>*Director, NASA Johnson Space Center* |
| 9:00 | Keynote Address | Dr. William B. Lenoir<br>*Associate Administrator for Space Flight and Acting Associate Administrator for Space Station* |
| 9:30 | Space Station Freedom Program Overview | Mr. Richard H. Kohrs<br>*Director, Space Station Freedom* |
| 10:00 | Break | |
| 10:30 | Human Exploration Mission Planning | Dr. Franklin D. Martin<br>*Associate Administrator for Exploration* |
| 11:00 | Mission to Planet Earth | Dr. Shelby G. Tilford<br>*Manager, Geostationary Observations, Mission to Planet Earth* |
| 11:30 | Space Station Freedom Evolution | Dr. Earle K. Huckins III<br>*Director, Strategic Plans and Programs Division Office of Space Station, NASA Headquarters* |
| 12:00 - 1:30 | Lunch - Harbour Club | |
| 1:30 - 4:30 | SESSION I — EVOLUTION MISSION AND PLANNING<br>Session Chair: Mr. E. Brian Pritchard<br>*NASA Langley Research Center* | |
| | Long-range Planning for Science Utilization on Space Station | Mr. Robert C. Rhome<br>*NASA Headquarters* |
| | Space Station Accommodation of Lunar/Mars Exploration Program | Mr. Lewis Peach<br>*NASA Headquarters* |
| | Advanced Transporation Systems | Mr. Darrell R. Branscome<br>*NASA Headquarters* |
| | Future European Manned Space Infrastructure | Mr. Jacques Collet<br>*European Space Agency* |
| | Break | |
| | Japan's Future Space Activities | Mr. Masatoshi Saito<br>*National Space Development Agency of Japan* |
| | Canadian Space Activities in the 21st Century | Mr. R. Brian Erb<br>*Canadian Liaison Office* |
| | Space Station as a Technology Testbed | Dr. Judith Ambrus<br>*NASA Headquarters* |
| | Life Sciences Planning for Manned Missions | Dr. Arnauld E. Nicogossian<br>*NASA Headquarters* |
| 1:30 - 4:30 | SESSION II — TECHNOLOGY AND ADVANCED DEVELOPMENT OVERVIEW<br>Session Chair: Mr. Gregg Swietek<br>*NASA Headquarters* | |
| | Office of Aeronautics and Space Technology (OAST) Programs | Dr. Judith Ambrus<br>*NASA Headquarters* |
| | OAST Systems Autonomy and Telerobotics Programs | Dr. Mel Montemerlo<br>*NASA Headquarters* |
| | Office of Space Flight Advanced Development Activities | Ms. Pat Connor<br>*NASA Headquarters* |
| | Space Station Freedom (SSF) Flight Telerobotic Servicer | Dr. Harry McCain<br>*NASA Goddard Space Flight Center* |
| | SSF Advanced Development Program Overview | Mr. Gregg Swietek<br>*NASA Headquarters* |
| 5:30 | Reception | |
| 6:30 | Banquet with Speaker | |

| Time | Topic | Presenter |
|---|---|---|
| **Wednesday February 7, 1990** | | |
| 8:30 - 12:00 | SESSION III — CONFIGURATION EVOLUTION<br>Session Chair: Mr. E. Brian Pritchard<br>*NASA Langley Research Center* | |
| | Space Station Freedom Integrated Research and Development Growth | Mr. Rudy Saucillo<br>*McDonnell Douglas, Washington, D.C.* |
| | Space Station Transportation Node Concepts and Analysis | Mr. William Cirillo<br>*NASA Langley Reserach Center* |
| | Servicing Capability for the Evolutionary Space Station | Mr. Ted Grems<br>*McDonnell Douglas Greenbelt, MD* |
| | Evolutionary Space Station Fluids Management | Mr. Steve Stevenson<br>*NASA Lewis Research Center* |
| | Space Station Logistics Systems Evolution | Mr. Michael Tucker<br>*NASA Marshall Space Flight Center* |
| | Space Transfer Vehicle Accommodations at Transportation Nodes | Mr. Uwe Hueter<br>*NASA Marshall Space Flight Center* |
| | A Radiological Assessment of Space Nuclear Power Operations Near Space Station | Mr. Steve Stevenson<br>*NASA Lewis Research Center* |
| | Platform Evolution Studies | Ms. Barbara Walton<br>*NASA Goddard Space Flight Center* |
| 8:30 - 12:00 | SESSION IV — FLIGHT SYSTEMS AUTOMATION<br>Session Chair: Mr. Paul Neumann<br>*Space Station Freedom Program Office* | |
| | Autonomous Power Management and Distribution (PMAD) | Mr. Jim Dolce / Mr. Gale Sundberg / Mr. Jim Kish<br>*NASA Lewis Research Center* |
| | Laboratory/Habitation Module PMAD Automation | Mr. Bryan Walls<br>*NASA Marshall Space Flight Center* |
| | Environmental Control and Life Support System (ECLSS) | Mr. Brandon Dewberry<br>*NASA Marshall Space Flight Center* |
| | PI-in-a-Box | Dr. Larry Young / Dr. Silvano Colombano<br>*Massachussetts Institute of Technology / NASA Ames Research Center* |
| | RCS/RMS Automation using Procedural Reasoning | Mr. H. K. Hiers<br>*NASA Johnson Space Center* |
| | Thermal Control Expert System | Dr. John Bull / Ms. Kathy Healey / Mr. Jeff Dominick<br>*NASA Ames Research Center / NASA Johnson Space Center* |
| | Summary of Astronauts' Inputs Concerning Automation | Mr. Dave Weeks<br>*NASA Marshall Space Flight Center* |
| 12:00 - 1:00 | Lunch - Harbour Club | |
| 1:30 - 4:30 | SESSION V — SYSTEM EVOLUTION<br>Session Chair: Mr. Barry D. Meredith<br>*NASA Langley Research Center* | |
| | Assuring Data Transparency Through Design Methodologies | Mr. Allen Williams<br>*Harris Corporation* |
| | EVA Systems | Mr. Michael Rouen<br>*NASA Johnson Space Center* |
| | Data Management Systems | Ms. Katherine Douglas<br>*NASA Johnson Space Center* |
| | Active Thermal System | Mr. Richard L. Bullock<br>*NASA Johnson Space Center* |
| | Break | |
| | Guidance Navigation and Control | Mr. Jerry Kennedy<br>*TRW, Inc.* |
| | Communications and Tracking | Mr. William Culpepper<br>*NASA Johnson Space Center* |
| | Structural Analysis of Evolution Station Concepts | Mr. Paul Cooper<br>*NASA Langley Research Center* |
| | Environmental Control and Life Support System | Mr. Paul Wieland<br>*NASA Marshall Space Flight Center* |

| Time | Topic | Presenter |
|---|---|---|
| **Wednesday February 7, 1990** *(continued)* | | |
| 1:00 - 4:30 | SESSION VI — GROUND OPERATIONS AUTOMATION<br>Session Chair: Mr. John Muratore<br>*NASA Johnson Space Center* | |
| | Real Time Data Systems for Mission Control | Mr. John Muratore / Mr. Troy Heindel<br>*NASA Johnson Space Center* |
| | Transition Flight Control Room Automation | Mr. Al Brewer<br>*NASA Johnson Space Center* |
| | Intelligent Computer-Aided Training Environment | Mr. Bob Savely<br>*NASA Johnson Space Center* |
| | Platform Management System (PMS) Evolution | Mr. John Hartley / Mr. Mike Tilley<br>*NASA Goddard Space Flight Center* |
| | Automated PMS Scheduler | Dr. Larry Hull<br>*NASA Goddard Space Flight Center* |
| | Concepts in Distributed Planning and Control | Dr. Elaine Hansen / Dr. Larry Hull<br>*NASA Goddard Space Flight Center* |
| **Thursday February 8, 1990** | | |
| 8:30 - 11:00 | SESSION VII — OPERATIONS EVOLUTION<br>Session Chair: Ms. Karen Brender<br>*NASA Langley Research Center* | |
| | Operations Analysis for Evolution Station Concepts | Ms. Karen Brender<br>*NASA Langley Research Center* |
| | Vehicle Processing Operations Database (VPOD) | Mr. George Ganoe<br>*NASA Langley Research Center* |
| | On-orbit Assembly and Servicing Task Definition | Mr. Rick Vargo<br>*McDonnell Douglas, Kennedy Space Center* |
| | Advanced Robotics for In-Space Vehicle Processing | Dr. Jeffrey Smith<br>*NASA Jet Propulsion Laboratory* |
| | Advanced Automation for In-Space Vehicle Processing | Dr. Michael Sklar<br>*McDonnell Douglas, Kennedy Space Center* |
| | Space Vehicle Deployment form Space Station | Mr. Paul Henry<br>*NASA Jet Propulsion Laboratory* |
| | Graphical Analysis of Mars Vehicle Assembly | Mr. Kevin Lewis<br>*NASA Johnson Space Center* |
| 8:30 - 11:00 | SESSION VIII — SPACE STATION INFORMATION SYSTEMS<br>Session Chair: Mr. Del Weathers<br>*Space Station Freedom Program Office* | |
| | Data Management System Advanced Automation | Ms. Katherine Douglas / Mr. Terry Humphrey<br>*NASA Johnson Space Center* |
| | Operations Management System (OMS)<br>Global Fault Detection / Isolation | Mr. Matt Hanson |
| | OMS Event Evaluator and Scheduler | Mr. Rick Eckelkamp<br>*NASA Johnson Space Center* |
| | Automated Software Development Workstation | Mr. Ernie Fridge<br>*NASA Johnson Space Center* |
| | Technical and Management Information<br>System Design Knowledge Capture | Dr. John Boose / Dr. Jeff Bradshaw /<br>Dr. David Sheema / Dr. Stanley Covington<br>*Boeing Advanced Technology Center* |
| | Evolution Paths for Advanced Automation | Ms. Kathy Healey<br>*NASA Johnson Space Center* |
| 11:00 - 12:00 | Lunch - Harbour Club | |
| 12:00 - 4:00 | SESSION IX — ADVANCED AUTOMATION ENVIRONMENTS<br>Session Chair: Dr. Henry Lum<br>*Ames Research Center* | |
| | CLIPS/Ada Programming Tool | Mr. Chris Culbert<br>*NASA Johnson Space Center* |
| | ART/Ada Programming Tool | Mr. Chris Culbert<br>*NASA Johnson Space Center* |

| Time | Topic | Presenter |
|---|---|---|
| **Thursday February 8, 1990** *(continued)* | | |
| | Knowledge-Based System Verification and Validation | Ms. Sally Johnson<br>*NASA Langley Research Center* |
| | Intelligent Systems Engineering Methodology | Dr. Bruce Bullock<br>*ISX, Inc.* |
| | Software Support Environment Design Knowledge Capture | Mr. Tom Dollman<br>*NASA Marshall Space Flight Center* |
| | Advanced DMS Architectures Testbed | Mr. Terry Grant<br>*NASA Ames Research Center* |
| | Spaceborne Autonomous Multiprocessor System | Mr. Alan Fernquist<br>*NASA Ames Research Center* |
| | Information Sciences Experiment System Architecture | Mr. Nick Murray / Mr Steve Katzberg<br>*NASA Langley Research Center* |
| 12:00 - 3:00 | SESSION X — TELEROBOTICS TECHNOLOGY AND APPLICATIONS<br>Session Chair: Mr. Wayne Zimmerman<br>*NASA Headquarters* | |
| | JPL Shared Control Architecture | Dr. Paul Backes / Dr. Samad Hayati<br>*NASA Jet Propulsion Laboratory* |
| | JPL/KSC Robotic Inspection | Mr. Brian Wilcox / Mr. Leon Davis<br>*NASA Jet Propulsion Laboratory / NASA Kennedy Space Center* |
| | Robotic Assembly of Large Space Structures | Mr. Ralph Will / Mr. Marvin Rhodes<br>*NASA Langley Research Center* |
| | Space Station IVA Payload Robot | Mr. E. C. Smith<br>*NASA Marshall Space Flight Center* |
| | Advanced Human-System Interface | Dr. Mike McGreevey<br>*NASA Ames Research Center* |

NASA
National Aeronautics and
Space Administration

FREEDOM

# SPACE STATION FREEDOM OVERVIEW

Presentation to

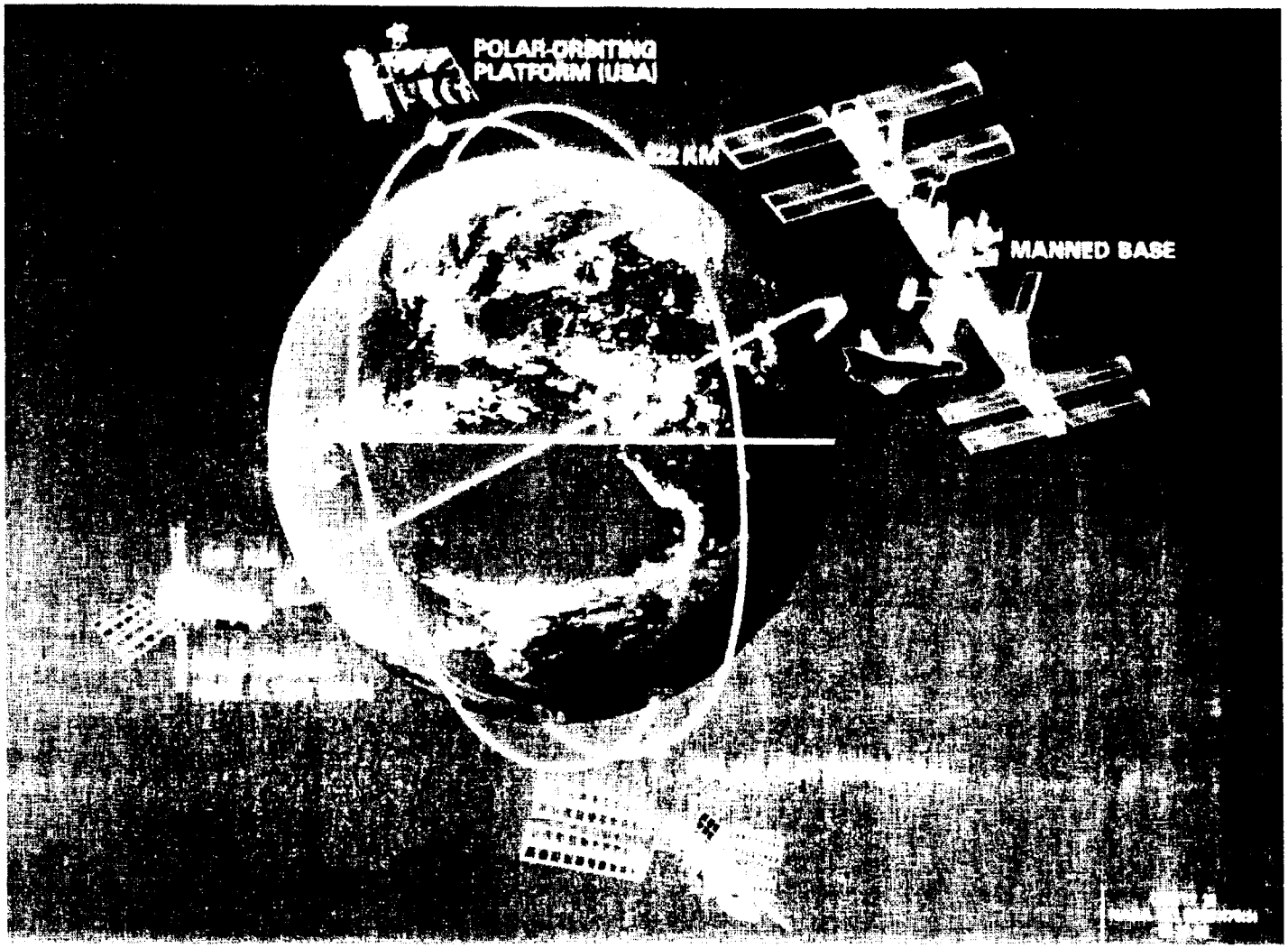
SPACE STATION EVOLUTION

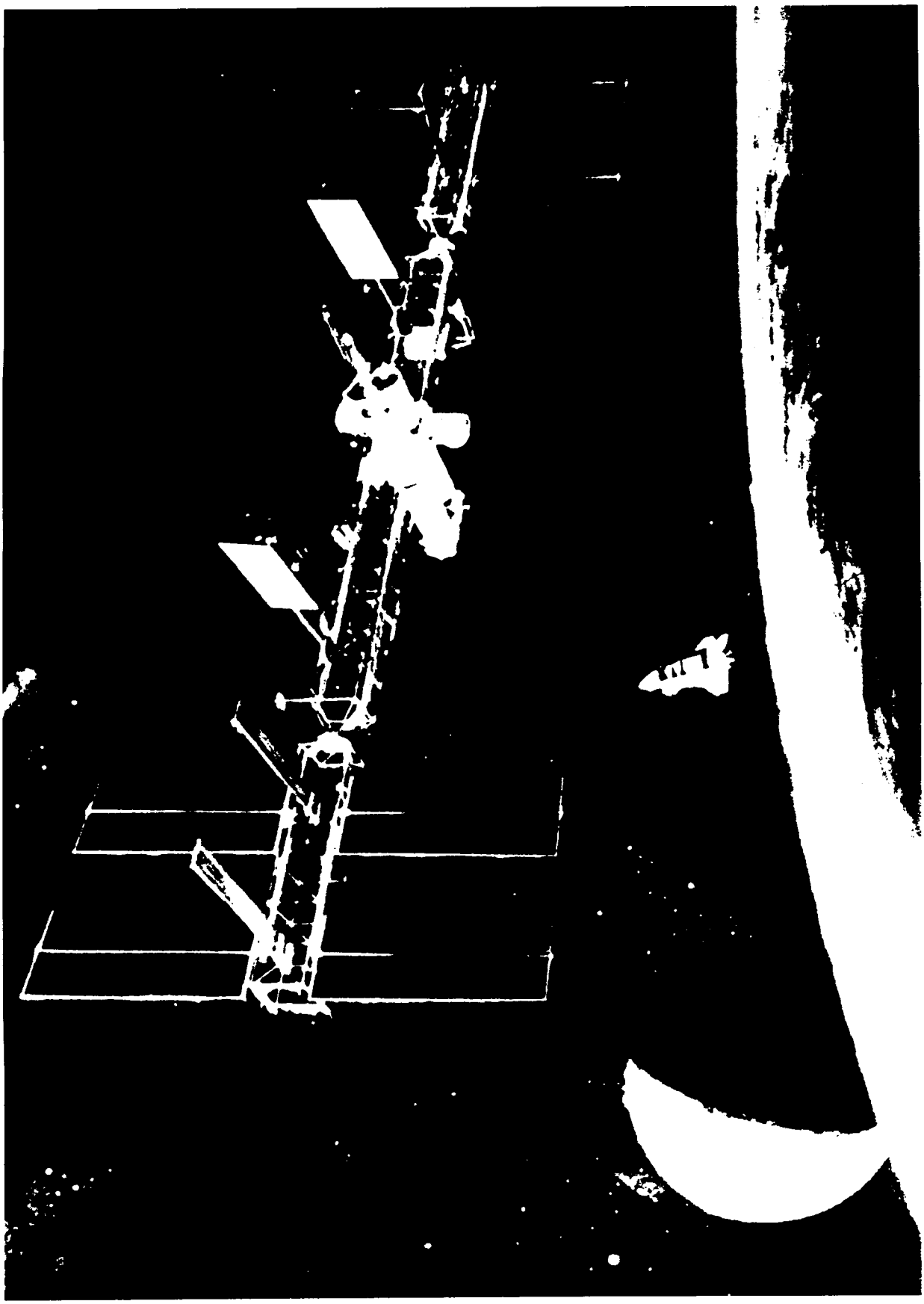
*BEYOND THE BASELINE*

RICHARD H. KOHRS
Director
Space Station Freedom

FEBRUARY 6, 1990

# INTERNATIONAL SPACE STATION COMPLEX





# SPACE STATION FREEDOM PROGRAM OBJECTIVES

- Provide a permanently manned presence in space
- Enhance capabilities for space science and applications
- Stimulate advanced technologies
- Promote international cooperation
- Encourage private sector participation and utilization
- Provide options for future endeavors in space

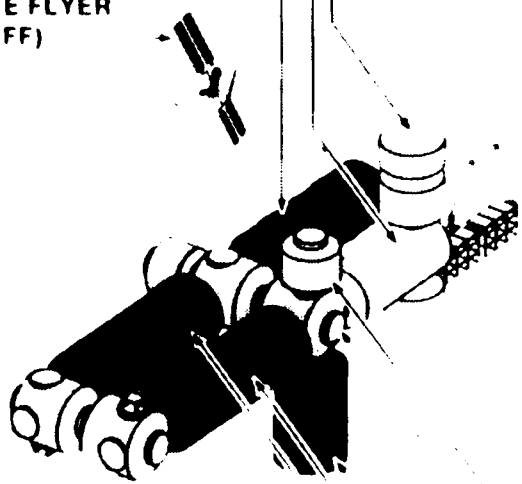
# SPACE STATION FREEDOM

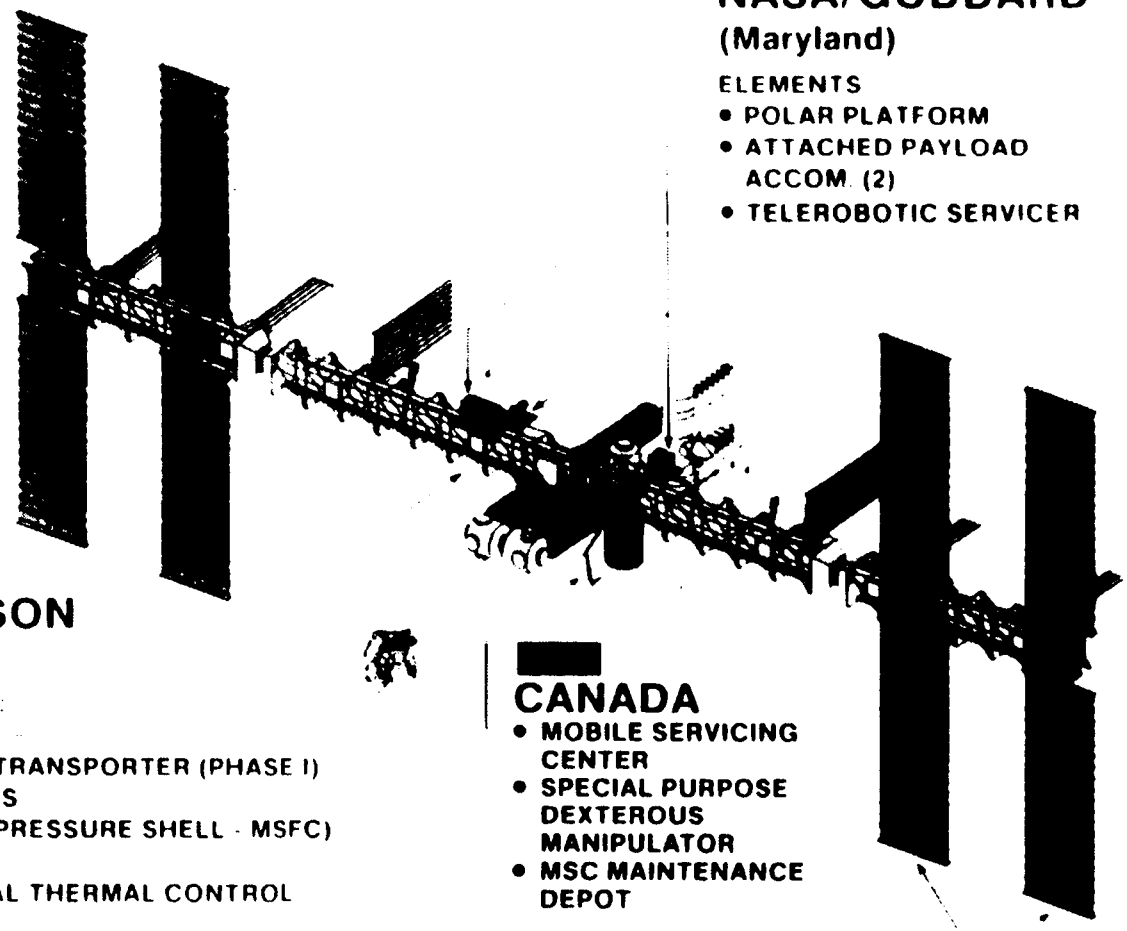
## ESA

ELEMENTS:
- PRESSURIZED LABORATORY MODULE
- POLAR PLATFORM
- MANNED-TENDED FREE FLYER (MTFF)

## JAPAN

ELEMENTS:
- PRESSURIZED LABORATORY MODULE & EXPOSED FACILITY
- EXPERIMENT LOGISTICS MODULE





## NASA/GODDARD (Maryland)

ELEMENTS
- POLAR PLATFORM
- ATTACHED PAYLOAD ACCOM. (2)
- TELEROBOTIC SERVICER

## NASA/ JOHNSON (Texas)

ELEMENTS:
- TRUSS
- MOBILE TRANSPORTER (PHASE I)
- AIRLOCKS
- NODES (PRESSURE SHELL - MSFC)

SYSTEMS:
- EXTERNAL THERMAL CONTROL
- EVA
- DATA MANAGEMENT
- COMMUNICATIONS & TRACKING
- GUIDANCE, NAVIGATION & CONTROL
- PROPULSION (THRUSTER TD BY MSFC)
- NSTS SS ATTACHMENT SYSTEMS

## CANADA

- MOBILE SERVICING CENTER
- SPECIAL PURPOSE DEXTEROUS MANIPULATOR
- MSC MAINTENANCE DEPOT

## NASA/MARSHALL (Alabama)

ELEMENTS:
- PRESSURE SHELLS FOR NODES
- LABORATORY MODULE
- HABITATION MODULE (OUTFITTING TD BY JSC)
- LOGISTICS MODULE (PRESS & UNPRESS)

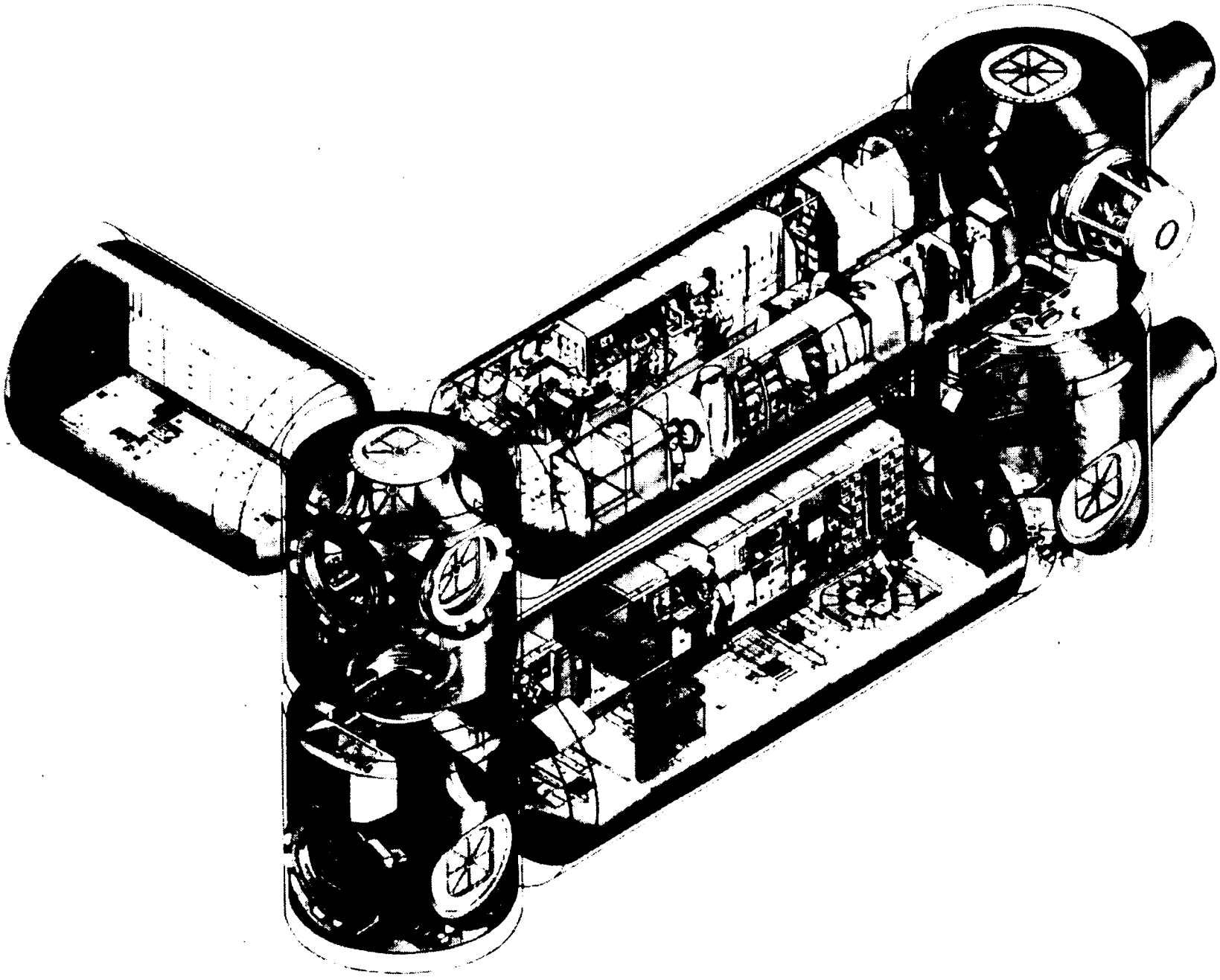
SYSTEMS
- ECLSS
- INTERNAL THERMAL CONTROL
- INTERNAL AUDIO & VIDEO

## NASA/LEWIS (Ohio)

ELEMENTS:
- POWER MODULES - PV

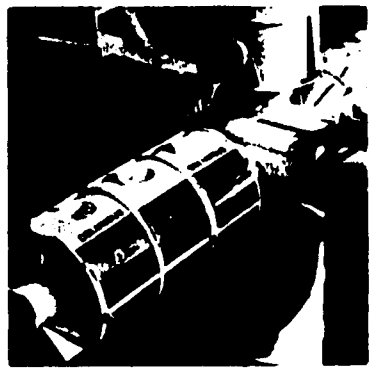
SYSTEM:
- ELECTRICAL POWER DISTRIBUTION

# U.S. SPACE STATION PRESSURIZED MODULES



# INTERNATIONAL PARTICIPANTS IN THE SPACE STATION FREEDOM PROGRAM

| WHO | WHAT |
| --- | --- |
| EUROPEAN SPACE AGENCY (ESA) BELGIUM, DENMARK, FRANCE, GERMANY, ITALY, THE NETHERLANDS, NORWAY, SPAIN, SWEDEN, UNITED KINGDOM | ATTACHED PRESSURIZED MODULE<br>POLAR PLATFORM<br>MAN-TENDED FREE FLYER |
| JAPAN SCIENCE AND TECHNOLOGY AGENCY OF JAPAN | JAPANESE EXPERIMENT MODULE |
| CANADA CANADIAN SPACE AGENCY | MOBILE SERVICING CENTER<br>SPECIAL PURPOSE DEXTEROUS MANIPULATOR<br>MSC MAINTENANCE DEPOT |



COLUMBUS

MOBILE SERVICE CENTRE

JAPANESE EXPERIMENT MODULE

# SPACE STATION FREEDOM BASELINE

FREEDOM

## Changes

- All direct current power system
- Shuttle suits exclusively
- Hydrazine propulsion
- One airlock (Hyperbaric)
- Passive cooling of external payloads
- Lab support equipment
- Solar dynamic power generated system test deleted
- Polar Platform unique hardware

# SPACE STATION FREEDOM BASELINE (Continued)

FREEDOM

## Deferrals

- Full 75 kilowatt power from Feb 97 to Nov 97
- Crew habitability
- Closed loop oxygen and carbon dioxide
- Washer, dryer, freezer, etc; until 75 kW power available
- User ultra-pure water
- KSC 8 flight/year processing from March 95 to Jan 97
- Three 0-100 MBPS lines to single bus increased to 300 MBPS dual bus system at Assembly Complete
- Global Position System deferred until required to support ESA man-tended free flyer

# SCHEDULE

| | Rephased Baseline | Prior |
|---|---|---|
| First Element Launch | March 95 | (March 95) |
| Manned Tended Capability | April 96 | (Nov 95) |
| Permanent Manned | July 97 | (Dec 96) |
| Δ 37.5 kW | Sept 97 | (March 97) |
| Japanese Experimental Module (JEM) | Feb 98 | (June 97) |
| ESA Module | July 98 | (Aug 97) |
| Assembly Complete | Aug 99 | (Feb 98) |

# SPACE STATION FREEDOM EVOLUTION

- Freedom is a permanent facility
  - -- Upgrades and configuration changes will take place on-orbit
- During the operational life of the Space Station
  - -- National priorities will change
  - -- User needs and mission requirements will change
  - -- Technology will evolve and components will become obsolete

# SPACE STATION FREEDOM EVOLUTION (Continued)

- Evolution is a key design consideration
  - -- To meet anticipated user needs and advanced mission requirements
  - -- To improve the productivity and efficiency of flight/ ground systems
  - -- To avoid component and system obsolescence
- A Space Station evolution program is in place
  - -- Transition Definition Program managed by the Strategic Plans and Programs Division at Level I
  - -- This Symposium will review the results of FY 88 - 89 tasks

# SPACE STATION FREEDOM EVOLUTION (Continued)

FREEDOM

- Good progress is being made
  - -- User needs and resource requirements have been identified for a range of advanced mission scenarios
  - -- Primary evolution design accommodations (hooks & scars) have been identified
  - -- Preliminary reference configurations for evolution have been established
  - -- Advanced Development Program tasks have transitioned OAST-developed technology to the baseline station
  - -- Direct participation in the Human Exploration Initiative Tiger Team established preliminary Transportation Node requirements

# SPACE STATION FREEDOM EVOLUTION (Continued)

- Future efforts will focus on definitizing
  - -- Assembly Complete evolution design accommodations
  - -- Phase II configuration and phasing
  - -- Lunar/Mars Transportation Node configuration, technology requirements, and phasing
  - -- Advanced Development tasks in enabling technology for station evolution

# SESSION III
# CONFIGURATION EVOLUTION

Session Chair:
Mr. E. Brian Pritchard
NASA Langley Research Center

# SPACE STATION FREEDOM INTEGRATED RESEARCH AND DEVELOPMENT GROWTH

P.R. Ahlf and R.J. Saucillo
McDonnell Douglas Space Systems Company - Engineering Services Division
Washington SI&I

B.D. Meredith
NASA Langley Research Center

**SPACE STATION EVOLUTION - BEYOND THE BASELINE**
**February 6 - 8, 1990**
**League City, Texas**

# ABSTRACT

Space Station Freedom is designed to be an Earth-orbiting, multidiscipline research and development (R&D) facility capable of evolution to accommodate a variety of potential uses. One evolution scenario is growth to an enhanced R&D facility. In support of the Space Station Freedom Program Preliminary Design Review (PDR), the NASA Langley Research Center Space Station Office is analyzing growth requirements and evaluating configurations for this R&D utilization. This paper presents a summary of FY1989 study results including time-phased growth plans, R&D growth issues and configurations, and recommendations for the program baseline design which will facilitate evolutionary R&D growth.

This study consisted of three major areas of concentration: mission requirements analysis; Space Station Freedom systems growth analysis; and growth accommodations and trades. Mission requirements analysis was performed to develop a realistic mission model of post-Phase 1 R&D missions. A systems-level analysis was performed to project incremental growth requirements of Space Station Freedom needed to support these R&D missions. Identification of growth requirements and specific growth elements led to the need for special accommodations analyses and trades. These studies included identification of hooks and scars on the baseline design, determination of an optimal module growth pattern, analysis of the dual keel length, and determination of an optimal location for the customer servicing facility.

Results of this study show that Space Station Freedom must be capable of evolving to a dual keel, 8 pressurized module configuration (2 growth habs and 2 growth labs); providing 275 kW power (for experimenters and station housekeeping); accommodating a crew of 24; and supporting other growth structures and special facilities to meet projected R&D mission requirements.

# OVERVIEW

# OVERVIEW
## STUDY OBJECTIVES

- Develop Space Station Freedom growth concepts and perform mission accommodations analyses in order to identify major resource requirements for an evolutionary Space Station which has as its primary emphasis, multidisciplinary Research and Development

- Perform trades and analyses related to major configuration issues

- Develop and maintain an Evolution Mission Model for use in the various trades and analyses related to reference configuration development

- Identify hooks and scars and major technology needs to guarantee the Space Station's ability to evolve into a growth configuration which meets mission requirements

- Develop reference configurations for incremental growth phases of the Space Station

## Overview - Study Approach

This study consisted of three major areas of concentration; mission requirements analysis, systems growth analysis, and growth accommodations analysis and trades.

Mission requirements analysis was performed to develop a realistic mission model. This process included gathering data from a number of documents as well as discussion with principal investigators and attendance of various Space Station users meetings and conferences. A Phase 1 mission set was developed using data from the NASA Level II Trial Payload Manifest (November 1987 version).

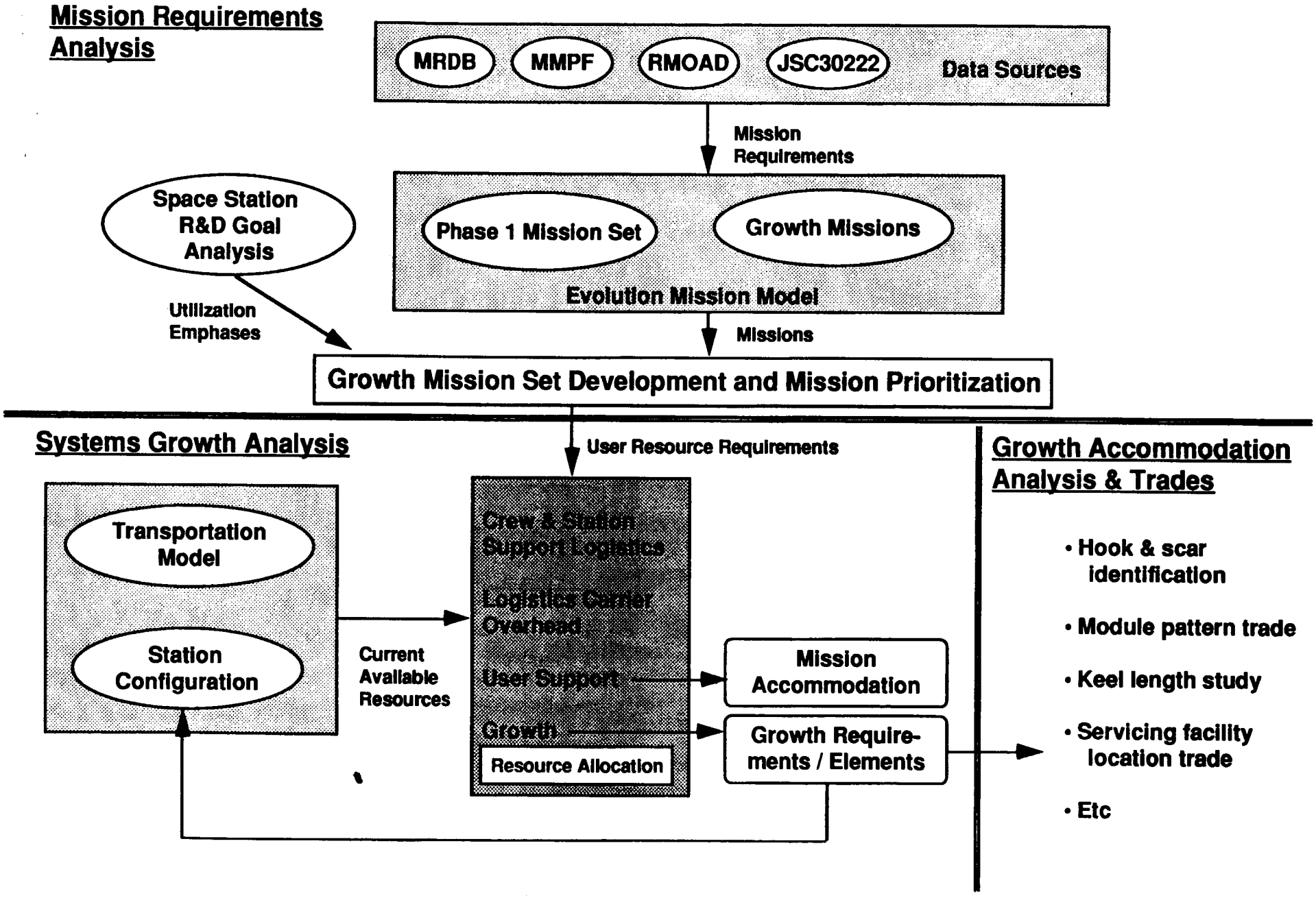
Mission data sets were developed based on the goal of accommodating research and development "missions" on an evolutionary Space Station Freedom. In order to establish resource requirement envelopes, multiple mission accommodation analyses were performed emphasizing several different R&D disciplines. These disciplines included: microgravity research, microgravity research with materials production, life sciences, and observational sciences.

A systems level analysis was performed to project the growth of Space Station Freedom. Major assumptions of this analysis were:

- point of departure was the Phase 1 configuration defined in the Level II Engineering Data Book
- constrained resources included: launch mass, power, crew time, internal pressurized volume, and external attach points
- station return mass requirements were tracked but not constrained
- destinction between carrier requirements for ELVs and the Shuttle is not made. Alloction of life requirements between ELVs and the Shuttle is examined but not constrained.

Identification of growth requirements and specific growth elements led to the need for special accommodations analyses and trades. These studies included identification of hooks and scars on the baseline design, determination of optimal growth module pattern and pattern buildup, analysis of the length of the dual keel, and determination of an optimal location for the customer servicing facility.

# OVERVIEW
## STUDY APPROACH



## Overview - R&D Utilization of Space Station Freedom

Research and development activities on Space Station Freedom are broadly classified as: microgravity research, commercial materials production, life sciences research, and attached & observational payloads.

Requirements for the microgravity research experiments were derived primarily from the Microgravity and Materials Processing Facility (MMPF) Study Data Release (Contract No. NAS8-36122, Teledyne Brown Engineering and Boeing Aerospace Co., Feb. 2, 1987). This report describes a fully outfitted laboratory consisting of 30 facilities which represent 47 missions in the Mission Requirements Data Base (MRDB). Resource requirements for these facilities are highly dependent upon equipment utilization assumptions. 100% equipment utilization (i.e., all facilities operating all of the time) is not a practical assumption due to high resource requirements of individual facilities. The MMPF Study provides data on realistic equipment utilization (run duration and frequency) and corresponding resource requirements.

Resource requirements for the General Life Sciences Lab and the 1.8-meter centrifuge were based on data from the Reference Mission Operational Analysis Document (RMOAD) for the Life Science Research Facilities. This document divides the outfitting of a dedicated Life Sciences Module into 5 phases.

Mission specifications for the Great Observatories (Hubble Space Telescope, Advanced X-ray Astrophysics Facility [AXAF], and the Space Infrared Telescope Facility [SIRTF]) were derived from the Customer Servicing Requirements Data Book (JSC 30222, March 15, 1986). The launch dates for these missions were based on the October 1987 Payload flight Assignments, NASA Mixed Fleet. The Gamma Ray Observatory (GRO) was not included because its end-of-life is expected to be reached prior to Space Station Freedom Assembly Complete.

The technology development missions represent a wide range of disciplies and programs within disciplines. Missions include both pressurized and external attached facilities. Examples of attached technology development missions include in-space assembly, tether operations, and robotics.

# OVERVIEW
## R&D UTILIZATION OF SPACE STATION FREEDOM

- **Microgravity Research**
  - Basic research in such areas as **Electronic Materials, Glasses and Ceramics, Combustion, Fluid Dynamics & Transport Phenomena, and Metals & Alloys**
  - Will use facilities within the pressurized modules such as **Modular Containerless Processing** Facility, **Modular Multizone Furnace** Facility, **Biotechnology** Facility, **Advanced Protein Crystal Growth** Facility, **Modular Combustion** Facility, and a **Fluid Physics/Dynamics** Facility

- **Commercial Materials Processing**
  - **Pilot production facilities** for testing processing involved in large scale manufacturing in space
  - Housed either on **unpressurized attached pallets,** or within pressurized **"pocket labs"**
  - Potential applications include **Electro-epitaxial Crystal Growth** Production Units, **Biological** Production Units, **Electrophoresis** Production Units, and **Containerless Processing** Production Units

- **Life Sciences**
  - Basic research in such areas as **Gravitational Biology, Biomedical Research, Environmental Factors, Operational Medicine, Biospherics Research, Physiochemical and Bioregenerative Life Support Systems, and Exobiology**
  - Will use facilities within the pressurized modules such as a **Human Physiology Lab**, **Plant & Animal Vivarium**, **Centrifuge** Facilities, and **Closed Life Support Systems Test Bed** Facilities; will also use attached payloads such as a **Cosmic Dust Collection** Facility

- **Attached and Observational Payloads**
  - Servicing of the **Great Observatories** & construction of large facilities like the **Large Deployable Reflector** and **Geostationary Earth Observing System Platforms**
  - Unpressurized attached payloads such as **Astromag, Solar Terrestrial Observatory,** and the **Tropical Rainfall Mapping Mission**
  - Technology development in areas like **in-space assembly, tether ops,** and **robotics**

## Overview - Transportation Model

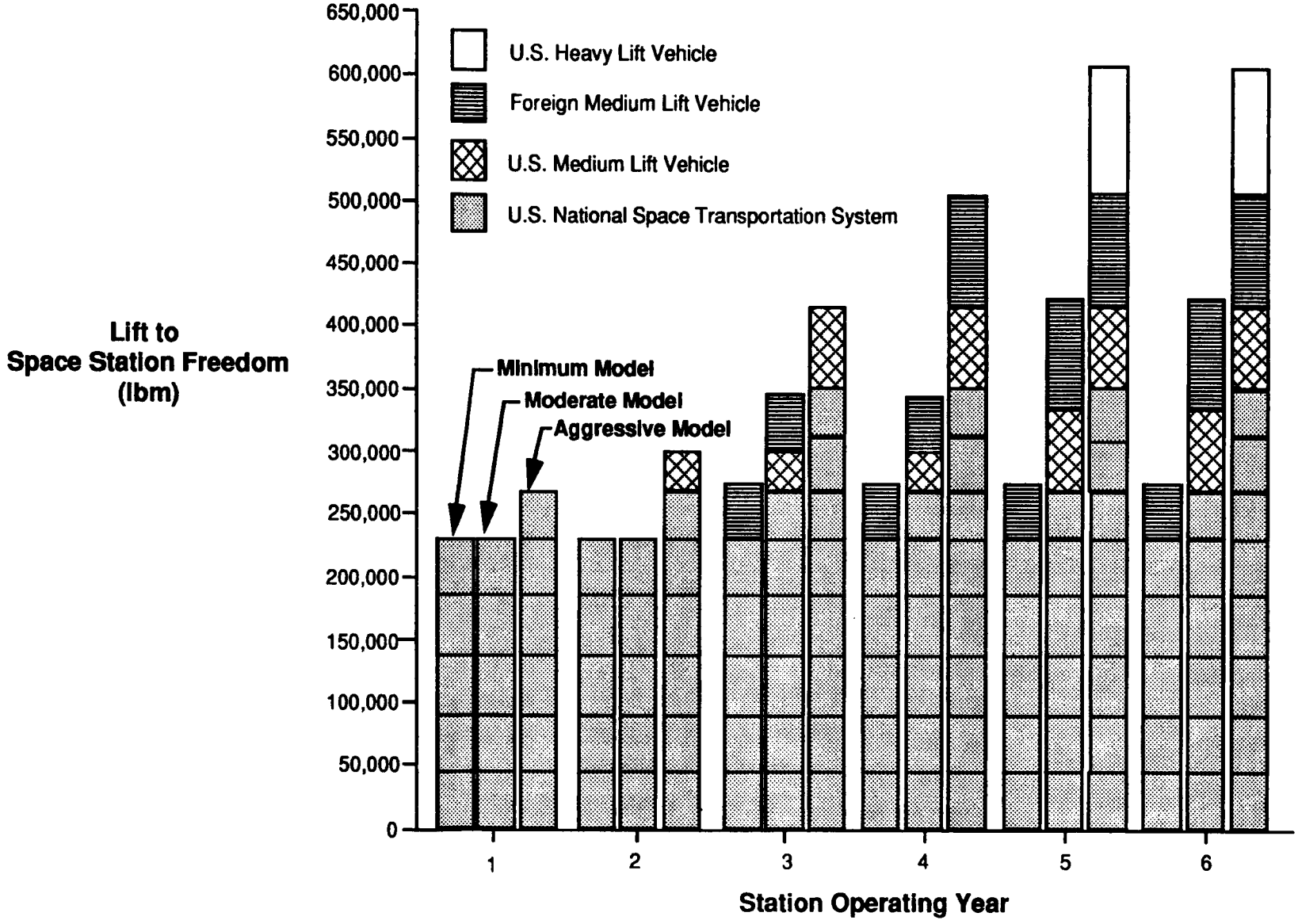
The most constraining resource on the level of activity on and potential growth of Space Station Freedom is the amount of Earth-to-station launch support. Rather than predict this level of support, a range of scenarios (i.e., transportation models) was developed for this analysis. These models cover the range of likely launch support to Space Station Freedom, from minimal support using primarily Shuttle-only, to aggressive support using Shuttle, Expendable Launch Vehicles, and a Heavy Lift Launch Vehicle.

The minimal transportation model used in this study assumes no increase of Shuttle support over the baseline of 5 flights to Space Station Freedom per year for logistics resupply and crew rotation. A contribution from internationals in the form of expendable launch vehicles is assumed, beginning several years after Assembly Complete.

The moderate transportation model assumes a small increase of Shuttle support over the baseline as well as a substantial augmentation by U.S. and international ELVs. The Shuttle flight rate is assumed to build to 6 flights per year several years after Assembly Complete. ELV support includes U.S. Titan IVs and ESA & Japanese contributions.

The aggressive transportation model assumes that a Heavy Lift Launch Vehicle is available for Space Station Freedom support. A 2-SSME Shuttle-C was used for Earth-to-orbit performance assumptions. The Shuttle flight rate for the model was also aggressive increased to a level of 8 flights per year five years after Assembly Complete. Additionally, a complement of U.S. and international medium-class ELVs was included.

# OVERVIEW
## TRANSPORTATION MODEL



# SYSTEM GROWTH REQUIREMENTS

## System Growth Requirements - Power / Thermal

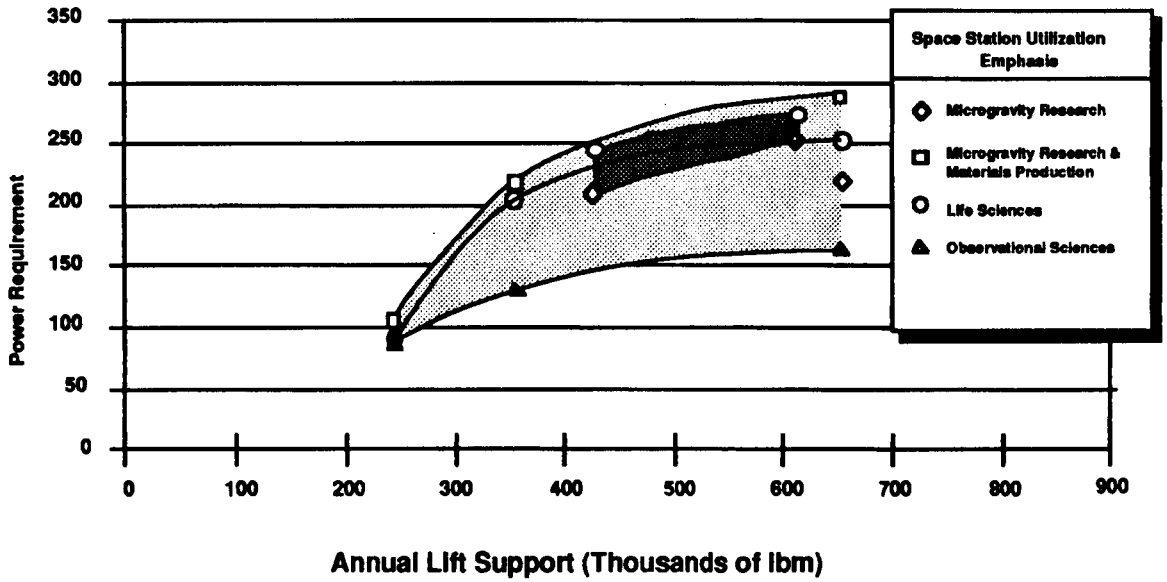
Analysis of fourteen scenarios which consisted of combinations of transportation support and utilization emphasis resulted in an envelope of power requirements. In order to protect for the maximum projected power requirement (aggressively supported microgravity research and materials production), eventual power growth to 275 kW must be possible. Design features in structures & mechanical systems, thermal control, and electrical power system must be included to permit this growth.

The anticipated method of increasing power generation capability is through the addition of solar dynamic modules. Each module pair will provide an additional 50 kW of electrical power. Primary scars to allow this growth involve the alpha gimbal roll rings and the utility distribution system (trays, cables, and breakouts).

The active thermal control system must keep pace with the growth of the power generation capability. Additional radiator panels will be required (i.e., a volume scar needed for space station element clearance), and eventually, forward radiator "wings" will be added.

# SYSTEM GROWTH REQUIREMENTS
## POWER / THERMAL

**Growth power requirements are a function of utilization emphasis and annual lift support; scarring for power growth to 275 kW will allow aggressive microgravity research on SSF**




| Resource | Recommended Growth Rqmt | Growth Implementation | Scars |
|---|---|---|---|
| Power | 275 kW | Addition of Solar Dynamic Power Modules | • Alpha Joint roll rings<br>• EPS (lines, trays, breakouts) |
| Thermal | Consistent with 275 kW power generation | Additional aft radiators<br>Addition of forward beta gimbals and radiators | • Forward gimbal<br>• Transport lines<br>• Radiator growth volume |

## System Growth Requirements - Pressurized Modules

Growth of the pressurized module pattern is required for additional laboratory space and crew habitation. The common module, used for the initial U.S. lab and U.S. hab of Space Station Freedom, provides standard growth elements for lab volume and crew quarters.

Analysis of mission requirements has led to the identification of a new pressurized module element which is not included in the baseline program: the pocket lab. A pocket lab is a pressurized mini-module which attaches to berthing ports on the resource nodes. Features of the pocket lab include:

- physical separation from the common modules which promotes safety for applications such as a quarantine facility
- ability to accommodate equipment which is not adaptable to the common module due to size or configuration incompatibilities (e.g., the 2.5-meter and 4-meter centrifuge), and
- ease of detachability for return to Earth, desirable for temporary facilities and materials production resource modules

Pressurized laboratory volume growth is anticipated to occur in three increments. The first increment will allow the evolution of the original multipurpose U.S. lab into two dedicated or near-dedicated modules. One for life sciences and one for microgravity research. Utilization of the second increment of lab volume will be highly dependent upon R&D requirements of Space Station Freedom. Pursuing a life sciences emphasis, this increment would allow the life sciences module to evolve into two facilities; one for human physiology research, and one for plan and animal research. The final increment along this path would add a facility for closed life support systems (CLSS) development including physiochemical processing and bioregenerative processes. If the utilization emphasis for Space Station Freedom is on microgravity research, the second laboratory increment would add another microgravity research module. The final step would involve the addition of one or more pilot processing plants for the testing of commercial production processes.

# SYSTEM GROWTH REQUIREMENTS
## PRESSURIZED MODULES

**Pressurized volume includes common modules, resource nodes, and pocket labs; Space Station Freedom design must allow growth to a maximum of eight common modules**

- Crew growth beyond eight requires addition of a habitation module
- Advantages of pocket labs for lab volume growth include:
  - Physical separation from common modules
  - Size and outfitting flexibility
  - Detachability
- Additional resource nodes provide interconnect to growth modules and additional berthing

| SSF Lab Volume Growth | | | |
|---|---|---|---|
| **Phase 1** | **Increment 1** | **Increment 2** | **Increment 3** |
| Multipurpose US Lab | Life Science Lab | Human Physiology Lab<br>Plant & Animal Lab<br>Microgravity Research Lab<br>***Life Sciences Emphasis*** | Human Physiology Lab<br>Plant & Animal Lab<br>CLSS / CELSS Lab<br>Microgravity Research Lab |
| | Microgravity Research Lab | Life Science Lab<br>Microgravity Lab #1<br>Microgravity Lab #2<br>***Microgravity Research Emphasis*** | Life Science Lab<br>Microgravity Lab #1<br>Microgravity Lab #2<br>Materials Processing Pilot Plant |
| Internationals | Internationals | Internationals | Internationals |

## System Growth Requirements - Crew Support

Analysis of mission requirements has revealed trends in the ratio of crew to pressurized laboratory volume for an R&D utilization of Space Station Freedom. For each lab module, a number of crew between four and four and a half is required to fully utilize the laboratory capabilities. This implies that for the Assembly Complete configuration of three lab modules, the total Space Station crew size should optimally be between 12 and 14. Growth to five lab modules and 2 or more pocket labs will require crew growth to as many as 24.

A significant issue associated with increasing the size of the permanent Space Station Freedom crew is the requirement to rotate the crew (i.e., return and replace station crew once their tour of duty is complete). The burden crew rotation places on the Space Shuttle in terms of visits to Space Station Freedom each year is driven by the tour of duty length for each station crew member (i.e., the stay time on station) and the size of the Space Station crew. The ability of the Space Shuttle to rotate crew is measured by the number of station crew it can rotate with each visit to the Space Station. Crew tour of duty must be extended to at least 180 days through the validation of effective microgravity countermeasures and the number of crew rotated per Shuttle flight must be increased to at least 5 to support station crew growth to 16 and beyond.

# SYSTEM GROWTH REQUIREMENTS
## CREW SUPPORT

**The Space Station Freedom crew size may grow as large as 24 in support of multidisciplinary R & D activities and core station maintenance**

- Between 4 and 4.5 crew (total) are needed to fully utilize each laboratory module
  - •• Phase 1 configuration requires 12 to 14 crew for full utilization (with Phase 1 crew size of 8, an average of less than 1 crew person will be working in each module at any one time)
  - •• A growth configuration including 5 laboratory modules will require between 20 and 24 crew for maximum utilization
- Ability to rotate crew depends upon frequency of Shuttle visits, number of crew rotated per Shuttle flight, and crew stay time at Space Station Freedom

| SSF Crew Size | Crew rotated per STS | Stay time (days) 90 | 120 | 180 |
|---|---|---|---|---|
| 4 (PMC) | 4 | 4 | NA | NA |
| | 5 | 4 | NA | NA |
| 8 (AC) | 4 | 8 | 6 | NA |
| | 5 | 7 | 5 | NA |
| 16 | 4 | 16 | 12 | 8 |
| | 5 | 13 | 10 | 7 |
| 24 | 4 | 24 | 18 | 12 |
| | 5 | 20 | 15 | 10 |

# INTEGRATED GROWTH CONCEPT

## Integrated Growth Concept - Growth Deltas

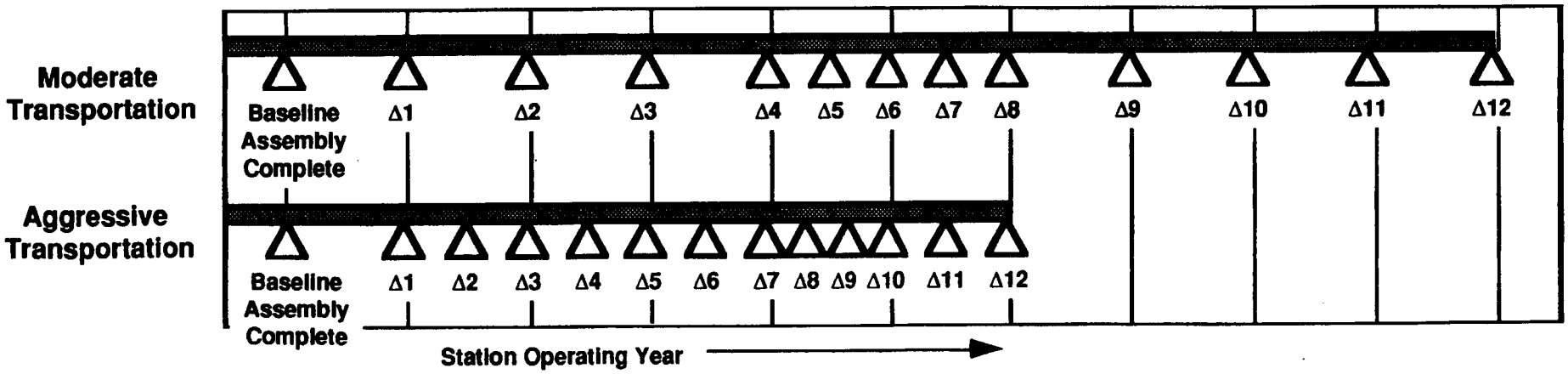
Incremental growth analysis of Space Station Freedom led to the development of a generic set of "growth deltas" (i.e., additions of station hardware which provide an increment in capability). These growth deltas were derived from a synthesis of growth requirements from the 14 scenarios examined.

The level of transportation support to Space Station Freedom affects the growth deltas in two ways. First, the speed at which the station grows (how quickly the deltas are achieved) is driven by the transportation model. Secondly, the number of achievable deltas is limited by the transportation model which supports station logistics resupply and new user accommodation in addition to station growth elements.

Assuming a moderate transportation model, one to two deltas are met with each year of station operation, with all deltas being accommodated within 10 years of Assembly Complete. An aggressive transportation model will allow growth through delta 12 in just 6 years.

# INTEGRATED GROWTH CONCEPT
## GROWTH DELTAS

- Δ 1 - Solar Dynamic Module Pair; 2 - 25m Transverse Boom Extensions, Space-based OMV & OMV Accommodations
- Δ 2 - Upper/Lower Keels & Booms
- Δ 3 - 1 Hab Module; 2 Resource Nodes
- Δ 4 - 1 Solar Dynamic Module Pair; Servicing Facility Phase 1
- Δ 5 - 1 Large Pocket Lab; 1 Lab Module; 2 Resource Nodes; Servicing Facility Phase 2
- Δ 6 - STV / STV Hangar; Assembly Platform; Servicing Facility Phase 3 (Competed Servicing Facility)
- Δ 7 - 1 Lab Module; Back Porch (if needed); 1 Resource Node (if needed)
- Δ 8 - 1 Solar Dynamic Module Pair; 2 - 25m Transverse Boom Extensions
- Δ 9 - 1 Hab Module; 1 Resource Node (if needed)
- Δ 10 - 1 Small Pocket Lab
- Δ 11 - 1 Solar Dynamic Module Pair
- Δ 12 - 1 Large Pocket Lab

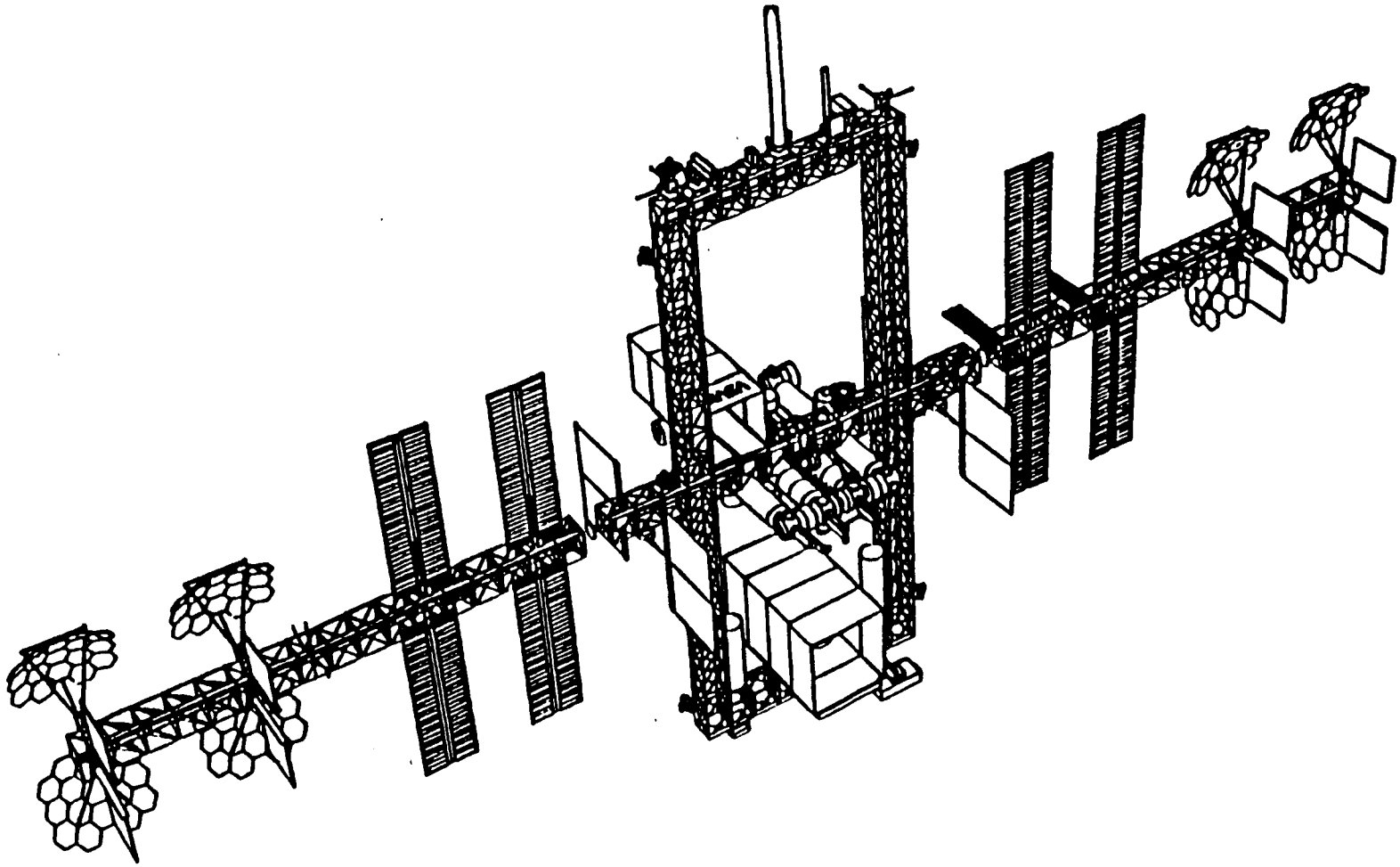


## Integrated Growth Concept - Configuration

The "end-of-growth" R&D configuration includes the following features:

- Dual keels with the upper boom providing attach volume for solar and stellar viewing payloads and the lower boom providing attach volume for Earth viewing payloads in addition to an STV accommodations facility
- Additional power provided by 8 solar dynamic power modules which are mounted on extensions of the transverse boom
- Enhancement of the active thermal control system including increased umber of radiators on the aft panels and a second set of radiator wings projecting forward of the transverse boom
- Two additional habitation modules to permit an increase of the crew size to 24
- Two additional laboratory modules and two to three pocket lab modules to allow a greater volume of pressurized experimentation
- A customer servicing facility to allow servicing of free flyers and provide storage for spare ORUs.

# INTEGRATED GROWTH CONCEPT CONFIGURATION



## Integrated Growth Concept - Keel Length & Scars

A trade study was performed to examine dual keel length requirements. The following drivers were examined in determining the required keel lengths: Shuttle docking clearances, large space structure assembly, technology development mission accommodations, space transfer vehicle (STV) accommodations, and microgravity environment (i.e., center of gravity location).

"Tail down" Shuttle approach and docking at one of the forward resource nodes is the baseline procedure. For the current configuration, a lower keel length of 6 truss bays provides adequate clearance between the orbiter tail and the lower boom. However, a seventh bay protects against potential configuration changes (e.g., attach point of the modules to the transverse boom or specific dimensions of the docking mast) which could result in violation of clearance requirements. The shuttle may also have the ability to dock tail up at Space Station Freedom. A minimum upper keel length of six truss bays is required to provide adequate clearance between the orbiter tail and the upper boom.

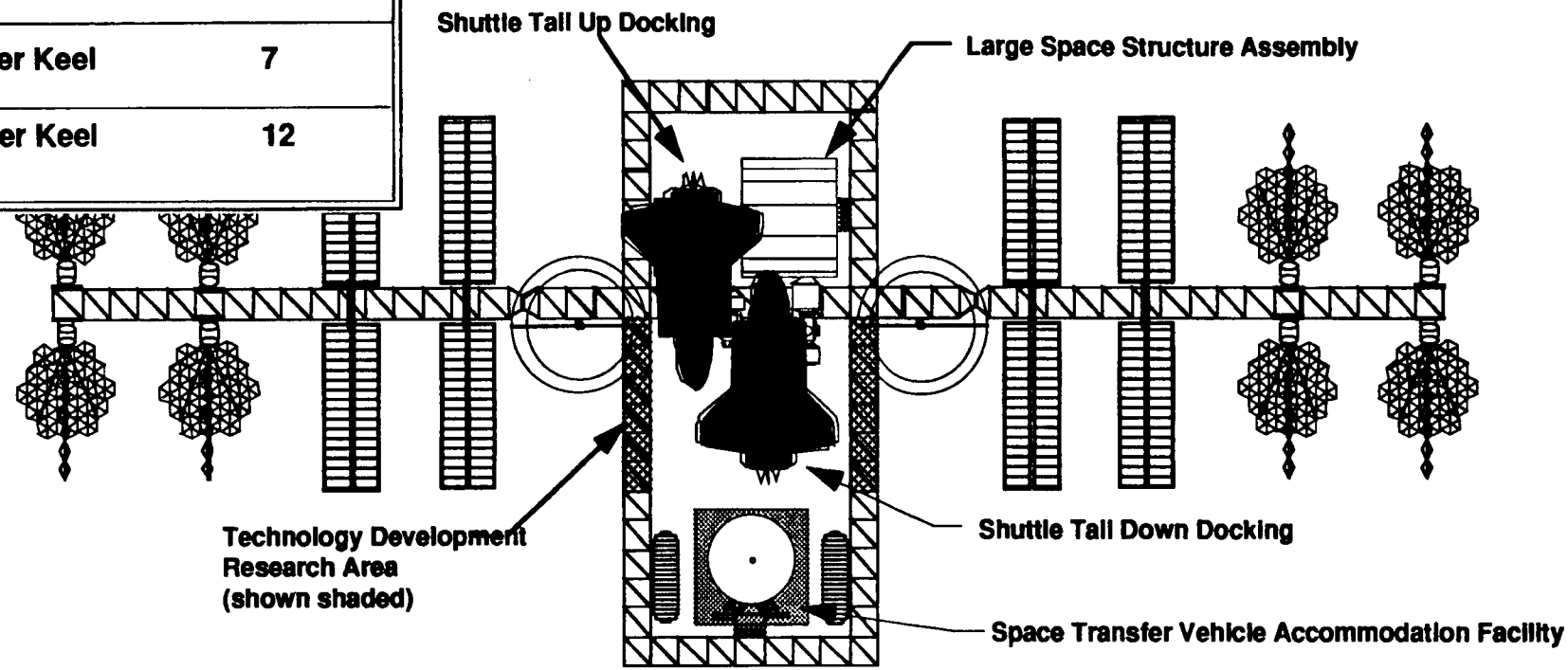
The area between the upper keels provides a location for assembly and construction of large space structures. The Large Deployable Reflector (LDR) is an example of a planned assembly structure and was used as a reference mission to size the upper keel. LDR is a 20 meter diameter by 17 meter long cylindrical payload. Allowing for a working clearance between the LDR and the upper and transverse booms, an upper keel length of 7 truss bays is required.

A technology Develop Mission (TDM) facility is being considered which would provide resources for the accommodation of a number of experiment. This facility may be housed within the truss structure of the keels and requires 6 continuous truss bays in either both upper keels or both lower keels. A lower keel placement was assumed for this analysis. The actual placement will be driven by Space Station Freedom mass properties considerations at the time of accommodation which in turn have an impact on microgravity levels in the pressurized modules and space station flight attitude (i.e., torque equilibrium attitude).

The STV accommodation facility is a structure capable of housing an STV with an aeroshell. This structure is centered on the zenith face of the lower boom. A lower keel length requirement of 12 truss bays is based on providing clearance between the STV accommodation facility and the docked Shuttle. For a space station configuration with the STV accommodation facility attached to the lower boom, a minimum lower keel length of 7 truss bases is required for Shuttle clearance.

# INTEGRATED GROWTH CONCEPT
## KEEL LENGTH & SCARS

| Recommended Keel Lengths (5 meter truss bays) | |
|---|---|
| Upper Keel | 7 |
| Lower Keel | 12 |




| | Upper Keels / boom | Lower Keels / boom |
|---|---|---|
| Structure (keel length) | 7 bays | 12 bays |
| EPS | 77 kW peak | 78 kW peak |
| TCS | 77 kW peak | 78 kW peak |
| DMS | Yes, rate TBD | Yes, rate TBD |
| C & T | Yes | Yes |
| ECLSS | No | No |
| FMS | | |
| Integrated Nitrogen System | Yes | Yes |
| Integrated Water System | Yes | Yes |
| Integrated Waste Gas System | TBD | TBD |
| EVA - Crew Access | CETA required | CETA required |

**Integrated Growth Concept - Module Pattern Development**

The objective of this study was to examine options for module patterns on a growth Space Station in order to:

- Identify any issues related to module growth
- Specify scars, if any, to the Phase 1 station required to allow ease of module growth
- Develop supporting data for baselining a reference growth module configuration

Module growth requirements used in this study are the product of the Transition Definition Program, sponsored by the Level 1, Strategic Plans and Programs Office. These requirements have been reviewed and endorsed by the Evolution Working Group (EWG) and the User Accommodations Panel (UAP) and have been submitted as a change request to the SSP.

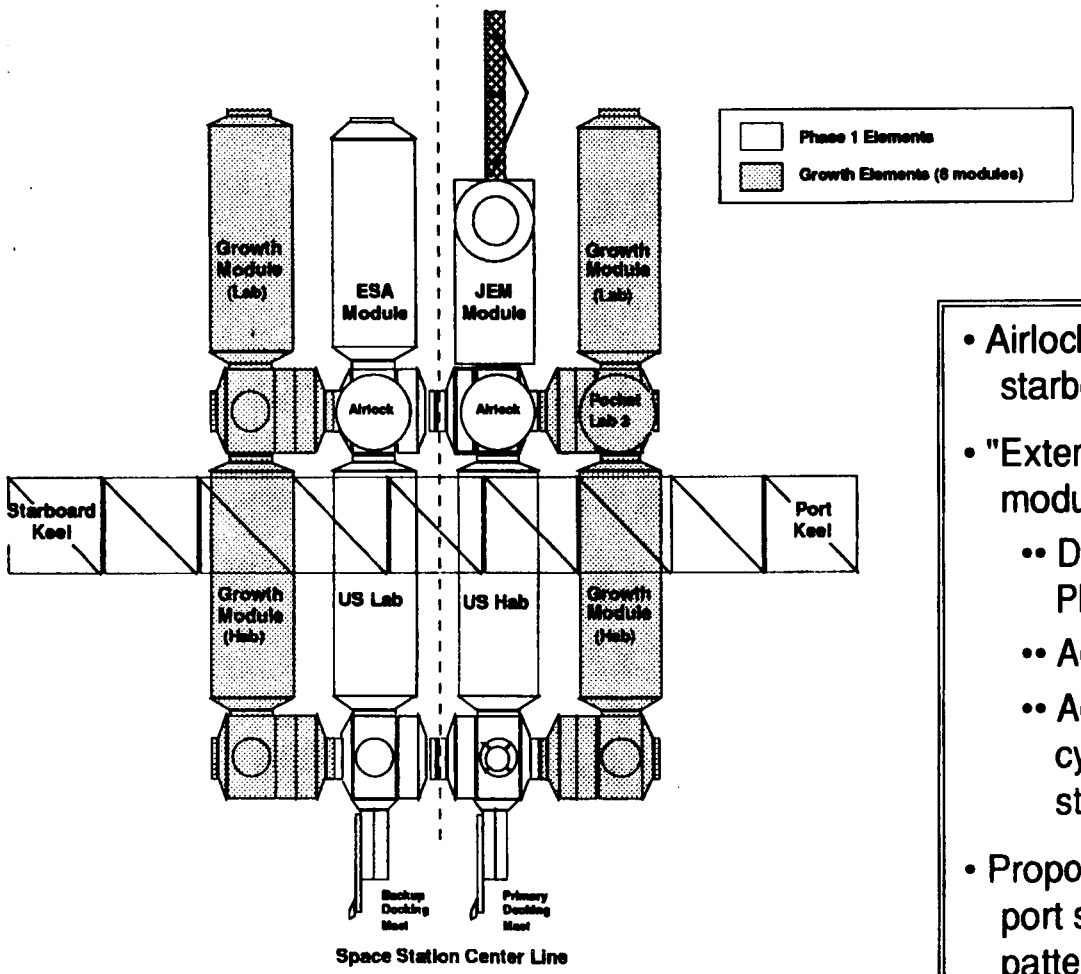
Maximum pressurized facility requirements, derived from analyses of both multidisciplinary science and new initiative support evolution options and including Phase 1 elements, include the following:

| | |
|---|---|
| 4 U.S. Laboratory Modules | 1 Human Life Science;<br>1 Animal & Plant Science; and<br>2 Materials Processing OR 1 Materials Processing + 1 CELSS |
| 1 ESA Laboratory Module | |
| 1 JEM Module | |
| 3 Habitation Modules | |
| 3 Attached Pressurized Payloads (pocket or mini lab modules) | 1 Sample Quarantine Facility; and<br>1 Commercial Materials Processing Facility + 4-Meter Centrifuge<br>OR<br>2 Commercial Materials Processing Facilities |

The total pressurized (common) module requirement of nine is one greater than the baseline growth requirement used in the Space Station Program Phase B definition studies.

# INTEGRATED GROWTH CONCEPT
## MODULE PATTERN

**The module pattern for eventual growth to eight common modules will include four modules abreast forward and four modules abreast aft**




- Airlock located on starboard axial port of aft starboard node must be relocated
- "Extended" resource nodes needed for growth module interconnect
  - Due to unsymmetric berthing of modules on Phase 1 pattern
  - Additional 42" length required
  - Additional length can be achieved with two cylindrical sections rather than one (no new structural design)
- Proposed location for customer servicing facility on port side of the US hab does not allow module pattern development

## Integrated Growth Concept - Customer Servicing Facility Location

The objective of this study was to perform a systems level evaluation of alternate locations for the customer servicing facility. This was done in order to make recommendations for placement which will provide flexibility for module pattern growth. Specifically, study objectives included:

- Identifying operational impacts of alternate locations for the customer servicing facility
- Identifying Space Station interface and scar requirements for Phase 2 support of the customer servicing facility in order to insure adequate scarring for a growth location during Space Station evolution
- Identifying any Phase 1 Space Station configuration issues which may impact customer servicing facility relocation
- Identifying customer servicing facility design issues, if any, which may limit location alternatives
- Developing supporting data for baselining a growth location for the servicing facility

This study assumes initial placement of the customer servicing facility on the transverse boom during Phase 2 operations. No evaluations were made of alternate Phase 2 locations away from the pressurized modules.

The approach to the customer servicing facility location analysis included:

- Identifying customer servicing facility operational constraints which limit location and orientation alternatives
- Proposing feasible customer servicing facility location options
- Identifying location discriminators and performing trades comparing the location options

# INTEGRATED GROWTH CONCEPT
## CUSTOMER SERVICING FACILITY LOCATION

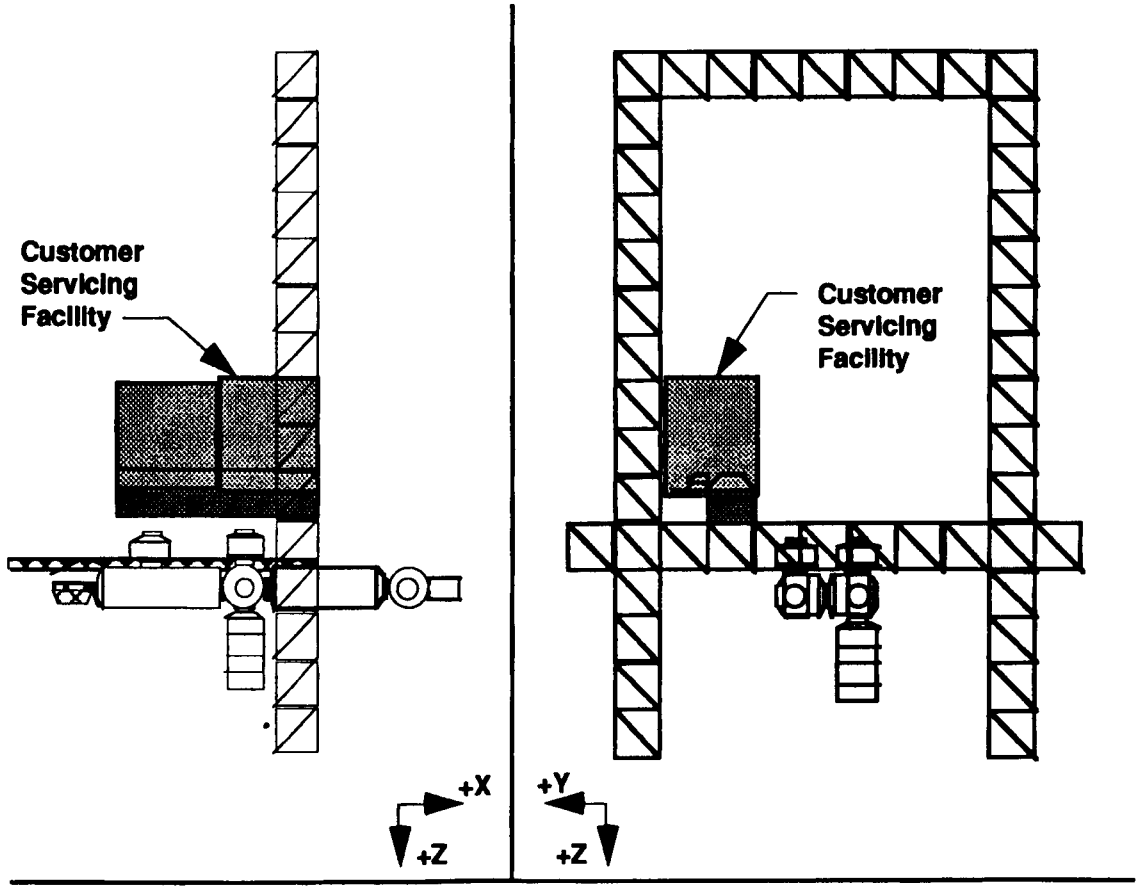
**The Customer Servicing Facility (CSF) will be located on the zenith side of the transverse boom against the starboard keel (attached at upper starboard bay #3)**

**Advantages**

- Minimal EVA travel time for access
- Capability to transfer payloads directly from the Shuttle cargo bay to the CSF with the CSF manipulator assuming orbiter tail-up docking capability
- Minimal impact to Space Station operational environment (pointing and control, μ-gravity environment, attached payloads viewing, aerodynamic considerations)

**Issues**

- Degraded CSF passive heat radiation capability caused by proximity to the main thermal radiators and the growth module pattern; potential thermal radiator sweep envelope clearance issues
- Hardware issues involved with a tail-up Shuttle final approach and docking required for direct Shuttle-to-CSF cargo transfer



## Recommendations

The following recommendations are a subset of the recommendations and suggested Space Station Freedom Program requirements resulting from this FY1989 study. These recommendations pertain primarily to current configuration issues associated with the baseline program which impact evolutionary configuration development.

# RECOMMENDATIONS

- Monitor changes to the baseline location of the TCS (Thermal Control System) radiator and recommend against any move to relocate inboard of truss bays SB7, PB6 (i.e., 2 bays inboard of the alpha joint)
  - TCS radiator sweep envelope during growth may be obstructed by other growth elements
  - Initial placement of the TCS radiator pallets should consider impact of module pattern growth, dual keel attach location, and location of other growth elements

- Relocate the hyperbaric airlock from the starboard side to the zenith side of resource node 1
  - The baseline location of the hyperbaric airlock is in the module growth path
  - Change to the baseline location will prevent a need to relocate on-orbit prior to module pattern growth

- Provide an area on the truss structure for unpressurized cargo and OMV storage
  - No storage area currently is planned within the baseline for unpressurized ORU storage
  - A storage and maintenance facility is required for a Space Station-based OMV

- Insure that the axial berthing ports of the baseline resource nodes can accommodate berthing of additional resource nodes allowing passage of crew and utilities
  - Outfitting concepts of the baseline nodes show the life sciences 2.5-m centrifuge mounted against an axial berthing port
  - Design of baseline nodes and equipment layout must not preclude module pattern growth

- Insure that attached payloads, antennas, pallets, carriers, and other equipment attached to the transverse boom are relocatable so that the module growth path and the dual keel attach locations are not obstructed

- Provide adequate internal volume within the baseline nodes and modules to accommodate pressurized system elements needed to support truss, power and attached payload growth

# Space Station Freedom Transportation Node Concepts and Analysis

William M. Cirillo
Langley Research Center
February 7,1990

# Overview

- Study Objectives
- Lunar Evolution Case Study Assessment
- Mars Evolution Case Study Assessment
- Lunar/Mars Exploration Initiative Assessment
- Technology Needs Assessment
- Summary

# Transportation Node Concepts and Analysis Study Objectives

The objective of the Transportation Node Concepts and Analysis study task element of the Space Station Freedom Transition Definition program is to pursue those activities necessary to define and prepare for Space Station evolution in keeping with the needs of users and long-term national goals. The overall objectives are:

a. To define Station Station Transportation Node evolution configurations consistent with user requirements and program constraints

b. To define and incorporate baseline design accommodations (hardware "scars" and software "hooks") to satisfy evolution requirements

c. To identify advanced technology that ensures technology readiness to enhance station capabilities and to enable station evolution

The strategy chosen to implement the objectives relies on understanding future space options and the implications of these on today's decisions. The challenge to plan for Space Station Freedom evolution is to understand the probable evolution paths and the corresponding infrastructure options to the extent that current resources can be wisely allocated to the enabling design provisions (hooks and scars) and to the appropriate advanced development efforts. Thorough understanding of the forces and constraints requires close coupling of evolution mission requirements, space and ground infrastructure planning, technology development, and external policy imperatives.

The challenge to provide for Space Station Freedom evolution takes the form of keeping the options open to support future missions. Therefore, planning for evolution is necessarily conducted in parallel with the design and development of the baseline station. The aim is to preserve all dimensions of Space Station Freedom evolution: technology improvements / obsolescence avoidance; expansion of baseline capabilities; addition of new functional capabilities. To that end, this task leads the development of the transportation node reference evolution configurations in response to each OEXP case study, and the associated engineering data required to support the baseline preliminary design process. To ensure the design is capable of evolution, evolution design requirements are developed and advocated in program documentation and assessments are made of the evolutionary capability of baseline system designs. Further, the advanced technology needs required to support each case study will be identified.

Specifically, for the FY89 study period, two Office of Exploration (OEXP) case studies were analyzed to define Space Station Transportation Node growth configurations. A third OEXP case study had no Space Station Freedom user requirements an was not investigated to any depth.

## Transportation Node Concepts and Analysis Study Objectives (concluded)

The first OEXP case study dealt with the establishment of a permanent lunar base on the near side of the moon beginning in 2004. This Lunar Evolution case study placed a large number of requirements on Freedom including accommodating and servicing two lunar transfer vehicles, storing large quantities of cryogenic propellants, and providing an orbital test facility for the development and demonstration of adavnced vehicle and base systems.

The other FY89 OEXP case study assessed the feasibility of by-passing the development of a lunar base and placing a permanent outpost on the surface of Mars in 2004. The SRD requirements levied on Space Station were not as great in this case study. No direct Mars transfer vehicle basing was mandated on Space Station. Instead a separate, co-orbiting assembly and processing facility was required. Space Station Freedom was stll required to provide an orbital facility for the testing and development of vehicle and base systems. In addition, Freedom was required to provide the capability to conduct research into the area of long-term crew exposure to a micro-gravity environment.

In addition to the two OEXP FY89 Case Studies, this task helped assess the role of Space Station Freedom in the Lunar/Mars Exploration Initiative. This 90 day study was conducted from August through October 1989 and presented five options for establishing a manned prsesence on both the lunar and Mars surface. Initial results indicate that the present Space Station Freedom assembly complete configuration is capable of evolving to meet the requirements of the Lunar/Mars Exploration Initiative if augmentations to the SSF program are made and the proper hooks and scars are implemented in the rephased program.

## Objectives

- Develop Space Station growth concepts and perform human exploration misssion accommodation analyses to determine resource requirements for use of Freedom as a Transportation Node.

- Establish SSF Evolution Reference Configuration(s) for the Transportation Node emphasis.

- Develop design requirements for the SSF PDR which enable evolution of the Phase I configuration.

- Define Hooks & Scars for SSF Evolution Reference Configuration.

- Identify technology needs required to accomplish mission requirements

# Lunar Evolution Case Study Assessment

# Lunar Evoultion Case Study Outpost Capabilities*

The principle feature of this case study is the emplacement of a human-tended facility on the Moon that evolves into a permanently inhabited outpost capable of supporting crews of up to 12 people with significant self sufficiency. The lunar outpost is established through three phases of development: emplacement, consolidation, and utilization.

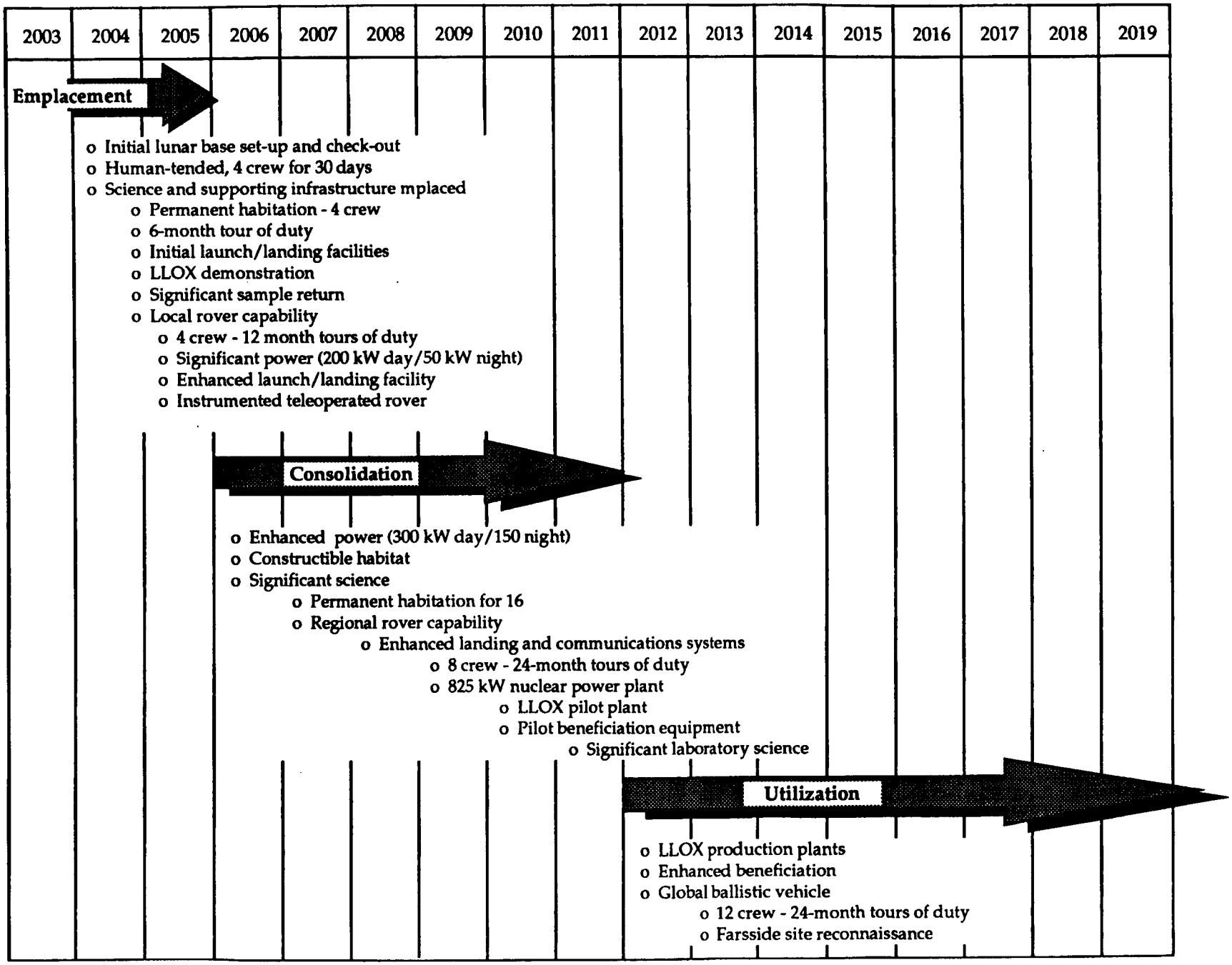
*Emplacement Phase.* The objective of the emplacement phase is to establish a permanent presence on the Moon and begin developing the knowledge base on how to work and live on a non-terrestrial body. Emphasis is placed on emplacing simple equipment and instrumnts on the lunar surface and laying the foundation for later, more complex surface operations by testing prototypes of more sophisticated systems. Operations on the lu nar surface are restricted to a range of tens of kilometers. Concurrently, the Earth-Moon transportation infrastructure is emplaced, and preparations are made to reuse the transportation elements and service these elements on the lunar surface and at Space Station Freedom.

*Consolidation Phase.* The objective of this phase is to consolidate permanent presence on the Moon and expand the knowledge base on how to live and work on a non-terrestrial body. Emphasis is placed on constructing surface systems, providing large pressurized volumes, and setting up more complex scientific instruments and laboratories on the lunar surface. Surface operations are expanded to a distance of hundreds of kilometers. Of paramount importance is reducing the supply line from Earth in both a fiscal sense, "exploration wedge", and in developing confidence in operational strategies and element subsystems for future exploration objectives. This is accomplished by relying on more efficient and reliable systems for life support and outpost operations and by testing prototypes of in-situ resource production plants to be operated during the utilization phase.

*Utilization Phase.* The objectives of this phase are to utilize in-situ resources and to continue to expand the knowledge base of how to live and work on a non-terrestrial body. Production of lunar oxygen reaches a sufficient level to begin fueling lunar based transportation vehicles. At the completion of this phase, further expansion of the outpost is curtailed to allow other planetary exploration missions to begin within a steady level of funding.

* This overview of the Lunar Outpost was taken from an Office of Exploration FY89 Annual Report draft.

# Lunar Evolution Case Study Outpost Capabilities



## Lunar Evolution Case Study Requirements

In order to better understand the relationship and interaction between Space Station Freedom and the other Office of Exploration (OEXP) program elements (e.g. ETO vehicles, STV's, propellant storage/transfer methods) the utilization of Freedom has been intentionally varied from case study to case study. For the Lunar Evolution case study the OEXP Study Requirements Document (SRD) specifies a major utilization of the Space Station's functional capabilities and resources. The detailed list of requirements is given in the following table.

## SRD Specified Lunar Evolution Case Study Space Station Freedom Requirements

- o Provide capability to support advanced development systems for lunar base and space transportation.
- o Provide capability for housing transient mission crew, support crew, and mission equipment.
  - Transient mission crew: (Outbound) — Pre-experimental phase support mission crew of 4; Experimental phase and beyond support mission crew of 8
  - Transient mission crew: (Inbound) — Accommodate a crew of 8
  - Mission support crew: — Accommodate a support crew of 6, for 6 month tours of duty, twice per year
  - Mission equipment: — Accommodate 5 metric tons of cargo
- o Provide Space basing accommodations to satisfy LEO traffic requirements for STV's.
- o Provide the capability to store lunar mission equipment awaiting transport to the lunar system. In addition SSF shall provide the capability for mission equipment:
  - State of health monitoring
  - Assembly
  - Integration
  - Check-out
  - Preparation for transport by STV
  - Other on-orbit processing, as required
- o Provide capability to process space transfer vehicles on-orbit by supporting the following:
  - Vehicle mating/assembly and demating/disassembly
  - Space Construction of elements of STV's
  - Element and integrated vehicle on-orbit check-out
  - Maintenance and servicing of departed and returning lunar STV's
  - Deployment and retrieval of lunar STV's
  - Ground communications with STV's (while berthed?)
  - Provide housekeeping resources and services to STV's and nodes
  - Loading and unloading of mission equipment from STV's and/or ETO vehicles

  * Maximum vehicle processing time is currently TBD.
- o Provide the capability to support on-orbit supply and resupply of:
  - Life support system fluids
  - Cryogenic and storable propellants
  - Mission equipment

  This includes providing for:
  - Fluid storage
  - Determination of fluid quantities
  - Fluid transfer interface capability
  - Operational control
- o Provide debris protection for STV's and mission equipment while resident at SSF.

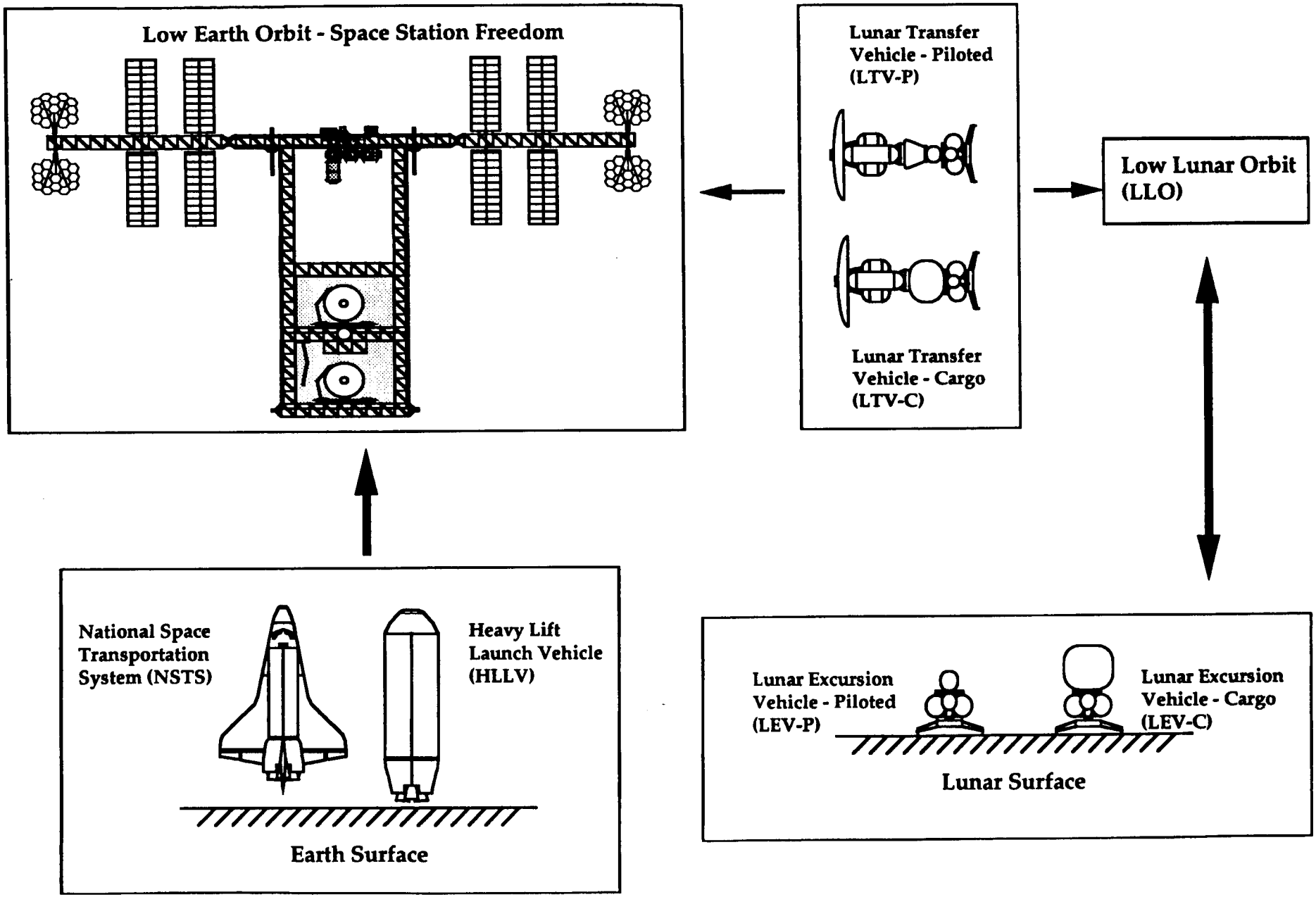
# Lunar Evolution Case Study Mission Architecture

The overall Lunar Evolution case study mission architecture is illustrated. Earth-to-Orbit (ETO) transportation is accomplished with Space Shuttle (STS) flights delivering personnel and a small amount of payload, while a Shuttle-C system delivers the Lunar Transfer Vehicle (LTVs) systems, heavy payloads, and the mission propellants to Space Station Freedom.

Upon delivery to the Space Station, the lunar base payloads (habitat's, laboratories, rovers, etc.) are mated to a space-based LTV. Once mating, and checkout of all vehicle systems has occurred, the LTV is loaded with Shuttle-C delivered cryogenic propellants. The LTV the departs Low Earth Orbit (LEO) for a Low Lunar Orbit (LLO) rendezvous with the lunar surface based Lunar Excursion Vehicle (LEV). After LLO orbital operations have been completed (payload, crew, and propellant transfer) the LEV returns to the lunar surface and the LTV returns to the Space Station for any required servicing and/or refurbishment.

Based on currently designed mission manifests, 6 Shuttle-C flights and 2 Space Shuttle flights are required each year to support the 2 LTV delivery missions to LLO.

# Lunar Evolution Mission Architecture



## Lunar Evolution Case Study Resource Requirements

The magnitude of effort needed to support the Lunar and Mars Evolution case studies requires that the Space Station provide increased resources and capabilities. This expansion of the performance envelope includes such basic resources as crew, power, interior volume, and exterior work space. The plan for accommodating the case studies called for using the requirements specified in the Office of Exploration (OEXP) Study Requirements Document (SRD) to establish evolutionary Freedom resource and facility requirements. These requirements were initially submitted as part of the baseline Preliminary Requirements Review (PRR) that was held in May and June of 1988. The transportation node growth requirements are presently being refined and combined with the Multidisciplinary Research and Development reference configuration growth requirements into a set of composite evolution growth requirements. This composite set of growth requirements will be submitted to the Space Station Freedom Preliminary Design Review (PDR) in 1990. The specific resource requirements for the Lunar Evolution case study are shown in the accompanying figure.

Additional habitable volume will be required on Freedom to accommodate both the lunar transfer vehicle (LTV) mission crew and vehicle processing crew. Vehicle processing analysis results indicate that a processing crew of 4, working 8 hour shifts is capable of meeting the yearly lunar mission flight rate of 1 cargo and 1 crew flight per year. Adding this processing crew to the 4 transient mission crew indicates the need for an additional Space Station habitation module. In order to mate the additional habitat module to the existing module cluster two resource nodes, greater in length than the presently designed node, are required. The extended resource node is required to satisfy the current Freedom requirement of maintaining enough clearance (2.1 meters) between Freedom modules to allow an EVA astronaut to pass inbetween and make repairs if necessary.

In addition to the habitat module, addional truss and utility runs are required to provide resources (power, fluids, data, etc.) to the LTV processing facilities located on a lower keel and boom structure. This processing facility will eventually evolve to accommodate 2 LTVs on-orbit at the same time. The processing facility will have a docking/berthing attachment, an assesmbly/mating/servicing track along which a teleoperated remote manipulator system can operate, and will be enclsed by a combination aluminum/multi-layer insulation (MLI) blanket to provide micrometeoroid and thermal protection.

100 kW of dynamic power is required to provide the additional power for the habitat, resource nodes, and LTV processing facilities.

The ability to evolve to these levels of capabilities preserves the option to accommodate, at a top level of functionality, the OEXP Lunar Evolution case study which requires Space Station Freedom as a part of the overall infrastructure.

# LUNAR EVOLUTION CASE STUDY
# TRANSPORTATION NODE RESOURCE REQUIREMENTS

| Station Resource | Current Recommendation |
|---|---|
| Power | |
| Average | 175 kW |
| Peak | NA |
| Crew | 18 |
| Pressurized Modules | |
| US Habitation | 2 |
| US Laboratory | 1 |
| ESA Laboratory | 1 |
| JEM Laboratory | 1 |
| Pocket Laboratory | 0 |
| Resource Nodes | 6 |
| **Transverse Boom** | |
| Dual Keel | Scar for distributed systems |
| Servicing Facility | Scar for facility and distributed systems |
| Power Modules | Scar for addition of power modules at boom ends |
| **Payloads** | |
| APAE | TBD |
| Location points for APAE | TBD |
| Tether Payloads | 2 |

## Lunar Evolution Time-Phased Space Station Freedom Growth Deltas

The time-phased Space Station Freedom growth augmentations, or growth deltas, are shown. These growth deltas reflect major incremental increases in various resources including power, habitable volume, truss, payload attach points, etc. The growth deltas do not reflect the actual hardware manifesting on a flight-by-flight basis, but instead illustrate major incremental increases in various resources including power, habitable volume, structure, etc. The growth increments are shown in this manner because the time-phasing of the additional Space Station hardware elements are directly related to the amount of transportation support that Space Station receives after assembly complete.

## LUNAR EVOLUTION CASE STUDY TIME-PHASED SPACE STATION FREEDOM GROWTH DELTAS

- Δ1 (2 - 25 kW) Solar Dynamic Modules; (2) 25 meter Transverse Boom Extensions; Space Based OMV & Space Based OMV accommodations
- Δ2 Lower Keels & Booms; Utility Trays
- Δ3 (1) Habitat Module; (2) Resource Nodes
- Δ4 (2 - 25 kW) Solar Dynamic Modules; Servicing Facility Phase 1
- Δ5 Servicing Facility Phase 2
- Δ6 Phase 1 STV Processing Facility; Phase 3 Servicing Facility (Completed CSF); (1) MSC; Shuttle-C Docking Adapter
- Δ7 Additional Lower Keel and Boom Truss Structure; Utility Trays
- Δ8 Phase 2 STV Processing Facility (STV Processing Facility complete)

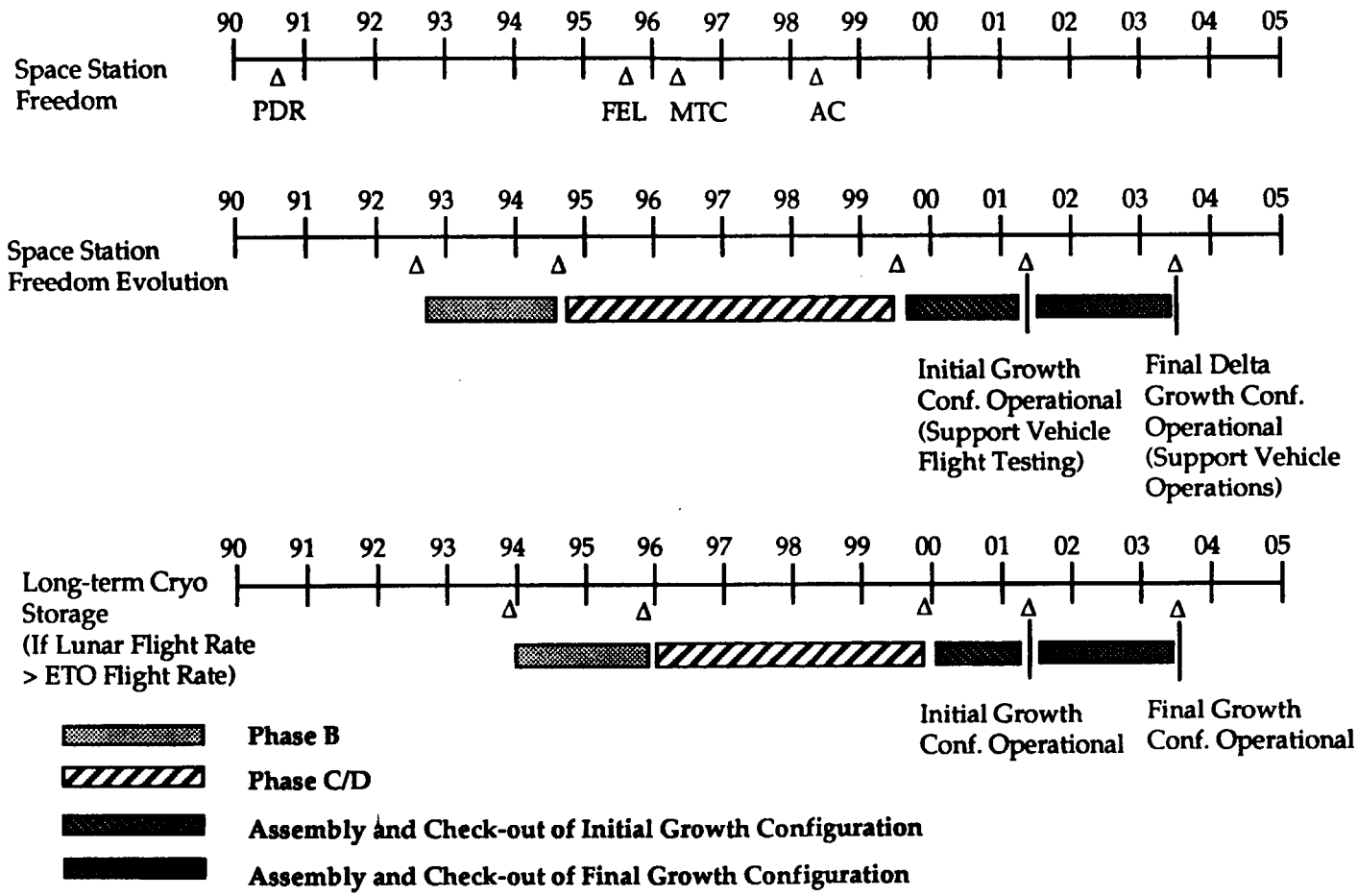
## Lunar Evolution Case Study Programmatic Schedule

Based on the currently proposed Lunar Outpost mission scenario a two phase Space Station evolution process has been developed. T he first phase, growth deltas 1 through 6, will provide the Space Station with the capability to process 1 expedable LTV/LEV system with accompanying payload. The second phase when complete, growth delta 8, will have the capability to accommodate 2 reusable LTV/LEV systems and associated mission payload.

It is important to note that initial growth hardware delivery must begin in 1999 in order to support the defined Lunar Outpost mission. Any additional delays in the current baseline Freedom program could impact the Space Station's ability to meet the designated mission requirements.

Space Station Freedom Transportation Node Concepts and Analysis

## Lunar Evolution Case Study Programmatic Schedule



## Growth Configuration Analysis

Several candidate evolution configuration options were analyzed using the ten discriminators listed below The discriminators with the greatest weighting factor were the controllability, operability, and the static micro-gravity environment for each option. It is desirable to have an evolution Space Station that would serve primarily as a transportation node, and yet provide a quiescent research and development environment when no major vehicle processing activities are occurring. To this end, configurations were sought which would provide all of the functional capabilities of a transportation node (LTV processing, propellant storage and transfer, payload accommodation, etc.), minimize operational impacts on Freedom (controllability, reboost propellant, crew time, etc.) and still provide a suitable microgravity environment.

In order to determine which configuration(s) would be most suitable for each phase of evolution the following analyses were conducted on each configuration:

a. Generation of solid computer models using IDEAS$^2$ software system
b. Mass properties determination including, center of mass and moments of inertia
c. Open-loop control system sizing including secular and cyclic momentum determination and torque equilibrium angle (TEA) determination
d. Closed-loop control system sizing including secular and cyclic momentum determination and TEA determination
e. Microgravity envelope calculation
f. Orbital decay and propellant reboost assessment
g. Space Station growth element and STV/payload clearance analysis
h. Module cluster field of view determination
i. Electrical Power and thermal rejection determination
j. Structural dynamic characterization including, system modes, forced response (only on selected configurations)

The Interactive Design and Evaluation of Advanced Spacecraft (IDEAS**2) Computer Aided Engineering (CAE) system was used to assess spacecraft design capabilities to meet mission goals and requirements by performing analytical simulations of spacecraft performance in the dynamic environment of space. The IDEAS**2 computer software modules include structural synthesizers; orbital mechanics simulators; aerodynamics, gravity gradient and solar-pressure orbital environmental synthesizers; solid geometry and finite element modelers; on orbit static, dynamic and structural analyzers; thermal analyzers; structural element design modules; subsystem design database; performance parameters; and cost and reliability analysis algorithms. These multidisciplinary analytical tools are interfaced such that data from one module can be accessed by other modules in an interactive process which provides the capability to evaluate spacecraft systems design concepts whose performance predictions include disciplinary interaction.

# SPACE STATION GROWTH DISCRIMINATORS

| Discriminator | Measures of Effectiveness |
|---|---|
| Space Station Control | TEA, CMG momentum storage requirements<br>Roll magnitude to dump secular momentum |
| Structural Capability | Truss member structural integrity under reboost loads<br>Controls-Structures Interaction acceptability |
| Operational Capability | Ability to perform all vehicle processing requirements |
| Microgravity Environment | Highest microgravity level in the US Lab module<br>TEA (affects micrgravity gradient along the Space Station x-axis) |
| Viewing | Stellar viewing from the JEM exposed facilties:<br>% viewing blockage<br>Greatest field of view<br>Average swath angle |
| Main Radiator Interference | Clearance between radiator wing and growth elements |
| Module Closure / Dual Egress | Number and length of time with modules having less than half closure (racetrack) or lack of dual egress (two ways out) |
| Structure / Ease of Assembly | Number of modules along the transverse boom<br>Number of modules within MSC reach |
| Ability to Accommodate Further Growth | Number of free and useable berthing ports on the final configuration |
| Growth Mass | Total weight of growth elements (approximate measure of cost) |

## Recommended LTV Configurations

As was described earlier, Space Station evolution occurs in two phases. The first phase will accommodate both an initial Lunar Transfer Vehicle (LTV) verification flight and then several expendable LTV flights. To support the initial LTV verification flight a preliminary servicing track assembly is attached to a lower keel and boom truss structure. This configuration, figure 1, provides (1) gravity gradient flight stabilization, and (2) Space Shuttle docking/berthing clearance. Also, an additional habitat module and two solar array modules are required to support LTV processing operations. In order to accommodate the next several expendable LTV flights a hanger is attached to the servicing track assembly to provide orbital debris protection as illustrated in figure 2.

The second phase of Space Station evolution requires the addition of a second LTV processing facility, figure 3, to accommodate the two reusable LTVs that are stored permanently in low Earth orbit.

## Recommended LTV Verification Configuration

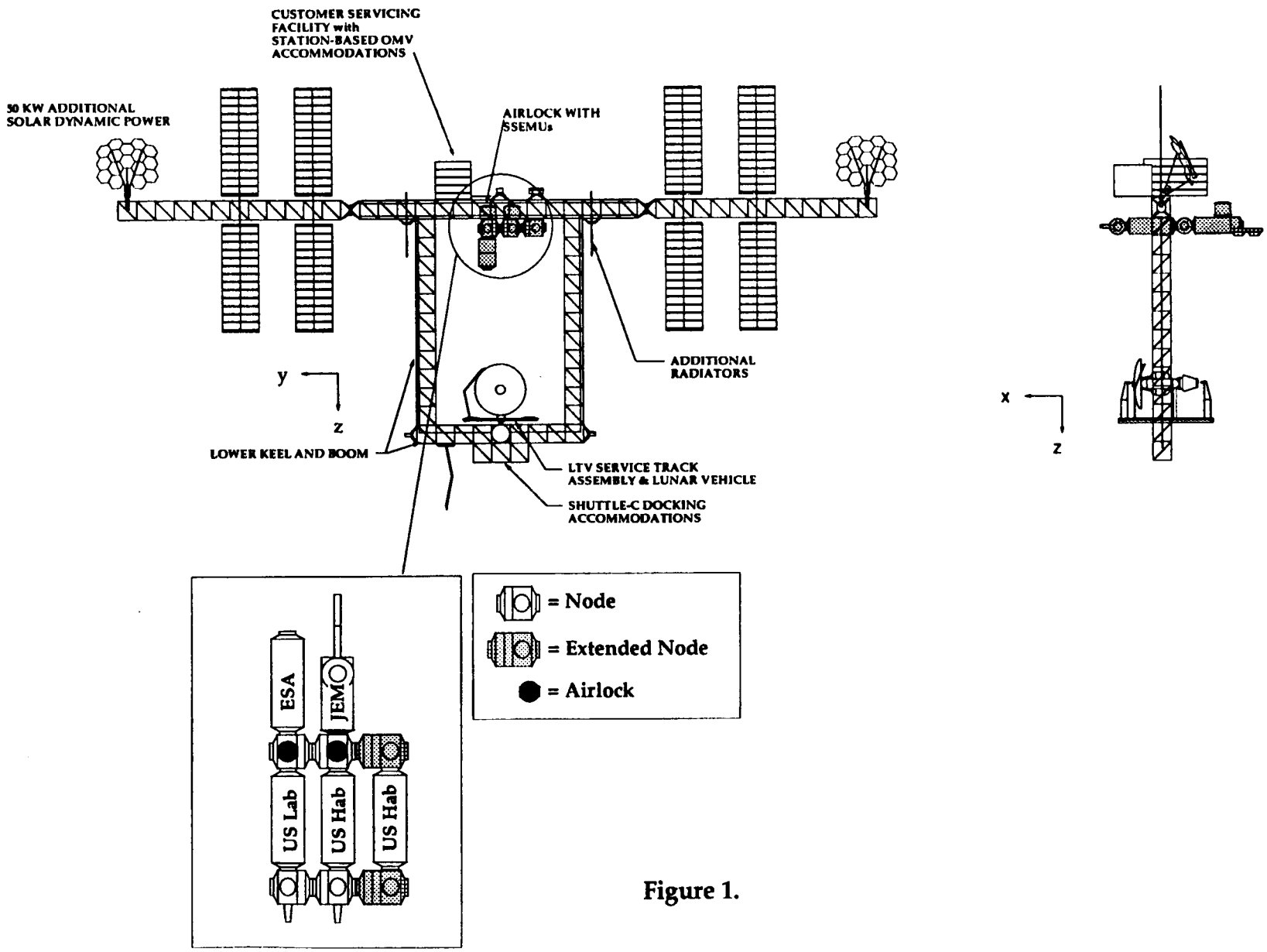



Figure 1.

## Recommended LTV Processing Configuration (1 LTV)

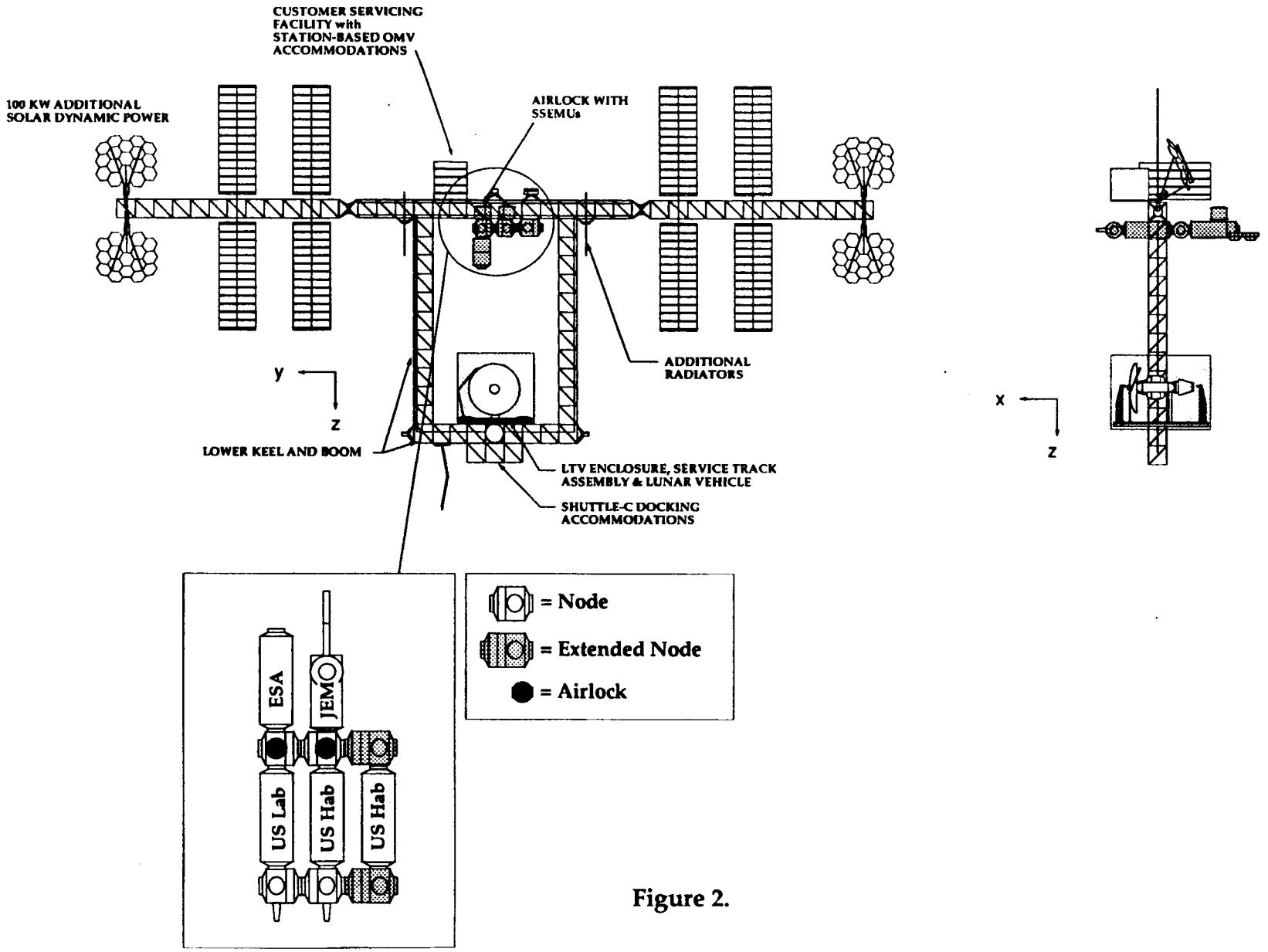



Figure 2.

Space Station Freedom Transportation Node Concepts and Analysis

## Recommended LTV Processing Configuration (2 LTV's)

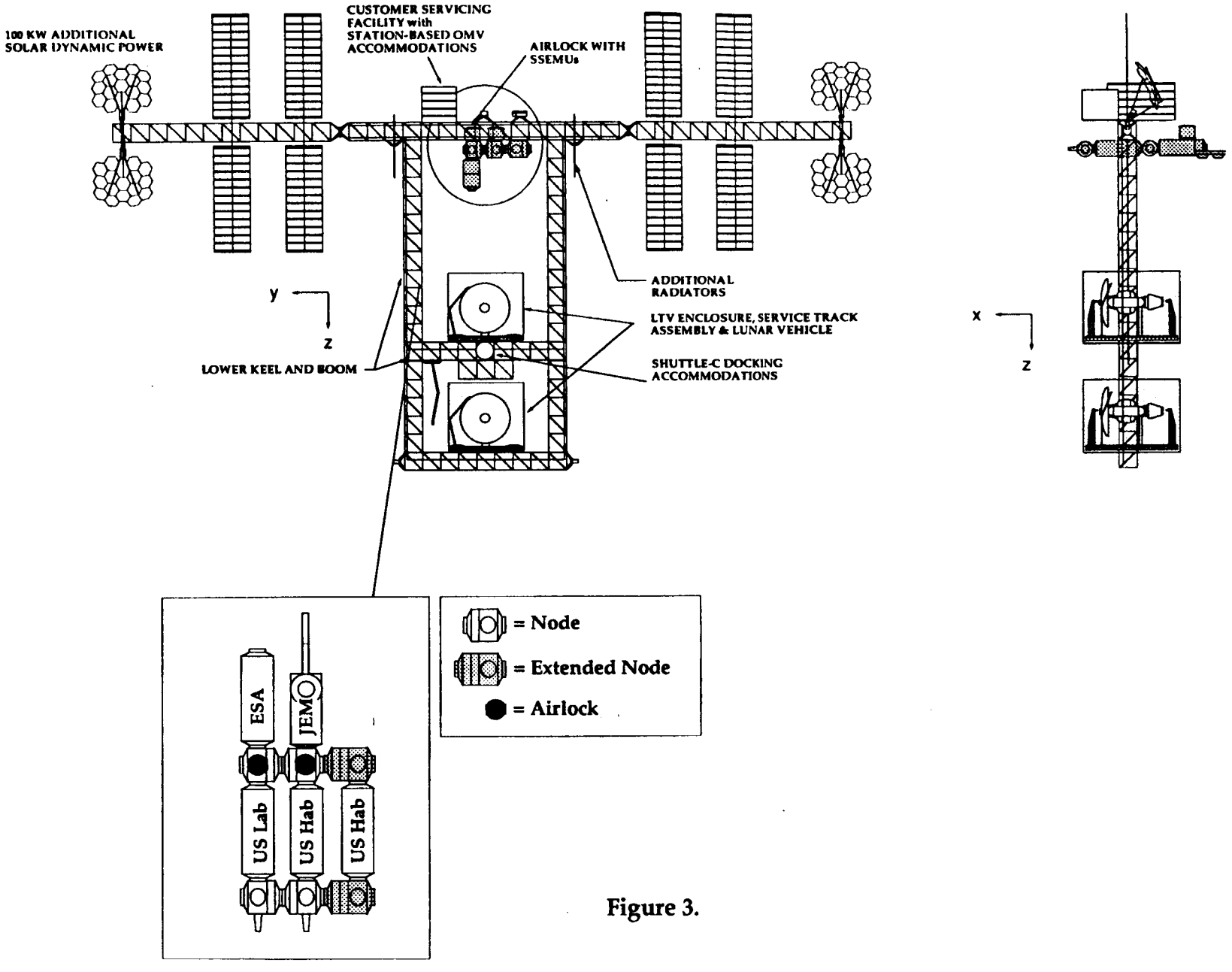



Figure 3.

## Earth to Orbit Manifest Options for Space Station Freedom Growth Harware

A top-level assessment of the manifesting of ETO launches required to achieve the final growth delta is shown below, for both an Advanced Solid Rocket Motor (ASRM) enhanced Space Shuttle launch system, and an expendable Shuttle-C launch vehicle. As anticipated, a greater number of Space Shuttle flight is required to launch the Freedom growth hardware than would be required if a Shuttle-C launch vehicle was used. However in this preliminary study, the Shuttle-C configuration chosen was under utilized in its available launch mass capability for a majority of launches. This result indicates that a detailed assessment of the design and manifesting of an alternative ETO launch system to the Space Shuttle is required to optimize ETO payload launches.

# Earth to Orbit Manifest Options for Space Station Freedom Lunar Evolution Case Study Growth Hardware

| SEQUENCE \ FLIGHT | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Lunar Evolution Configuration 3 Manifest Using Space Shuttle | Mass | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| | Volume | ● | ● | ● | ○ | ● | ● | ● | ● | ● |
| Lunar Evolution Configuration 3 Manifest Using Shuttle-C | Mass | ● | ○ | ○ | ○ | ○ | ○ | | | |
| | Volume | ● | ● | ● | ● | ● | ● | | | |

● - Greater than 90% of available launch vehicle mass/volume utilized for cargo deleivery

○ - Less than 90% of available launch vehicle mass/volume utilized for cargo deleivery

# Lunar Transfer Vehicle Processing Operations

The overall timeline for lunar vehicle refurbishment (lunar vehicle berthing at SSF through deployment from the propellant depot for launch) is shown below. This timeline is a summation of the timelines discussed above for the refurbishment of each major engineering systems.

**Post Flight Operations:** Upon return to SSF from the lunar mission, a self-diagnostic health check will be performed on all vehicle systems to verify a safe condition (no fluid/gas leaks, etc.) and a visual inspection (similar to an arriving STS) will be performed prior to entering the SSF servicing hangar. Appendages will be retracted (high gain antenna, etc.). An advanced OMV will bring the vehicle within grappling range of one of the servicing hangar manipulator arms, which will then berth the vehicle. This phase also includes the vehicle deservicing flows. After berthing in the SSF hangar, the vehicle will be connected and switched to SSF facility power, fluids, gases, and data system. Vehicle systems will be powered down, and residual propellants will be drained. Vehicle inspection will be performed.

**Refurbishment Operations:** For the purpose of determining on-orbit timelines, manpower, and resource requirements, the refurbishment of the lunar vehicle was broken down into six engineering systems:

*Aerobrake Refurbishment.* Deployable aerobrake configuration is used which requires replacement every five flights. TPS repair is performed "as needed" between aerobrake replacement. Tile cavities are repaired using the spray-on/fill-in ablative repair kit developed for Shuttle. Fabric tears and punctures are repaired with patches.

*Propulsion System Refurbishment.* Aerobrake will be removed to provide access for engine replacement. The only propulsion ORU's identified for EVA/RMS operations are the engines, cryogenic tanks, pneumatic tanks and regulator panels, RCS thrusters and some instrumentation. Other EVA/RMS required servicing consists of engine internal inspections, engine drying, minor nozzle cooling tube repair, and turbo pump gear box oil servicing. System pressure decay tests will be used to verify system integrity. Individual valve and joint leak checks will be done on a contingency basis. Other engine and pneumatic regulator panel components can be serviced if done in a shirt sleeve environment of a pressurized pocket lab, and will be studied at a later date.

*Fuel Cell Refurbishment.* Fuel cells can be serviced in-place via access panel. Crew Module (CM) battery removal, charging, and open circuit voltage checks will be performed post flight. Batteries will be reinstalled during vehicle closeout activities.

*Thermal System Refurbishment.* Radiator panels are located on exterior of avionics bays which allows for modular replacement and coolant loop servicing by EVA or robotic operations. MLI replacement or repair is performed on an "as needed" basis.

## Lunar Transfer Vehicle Processing Operations (continued)

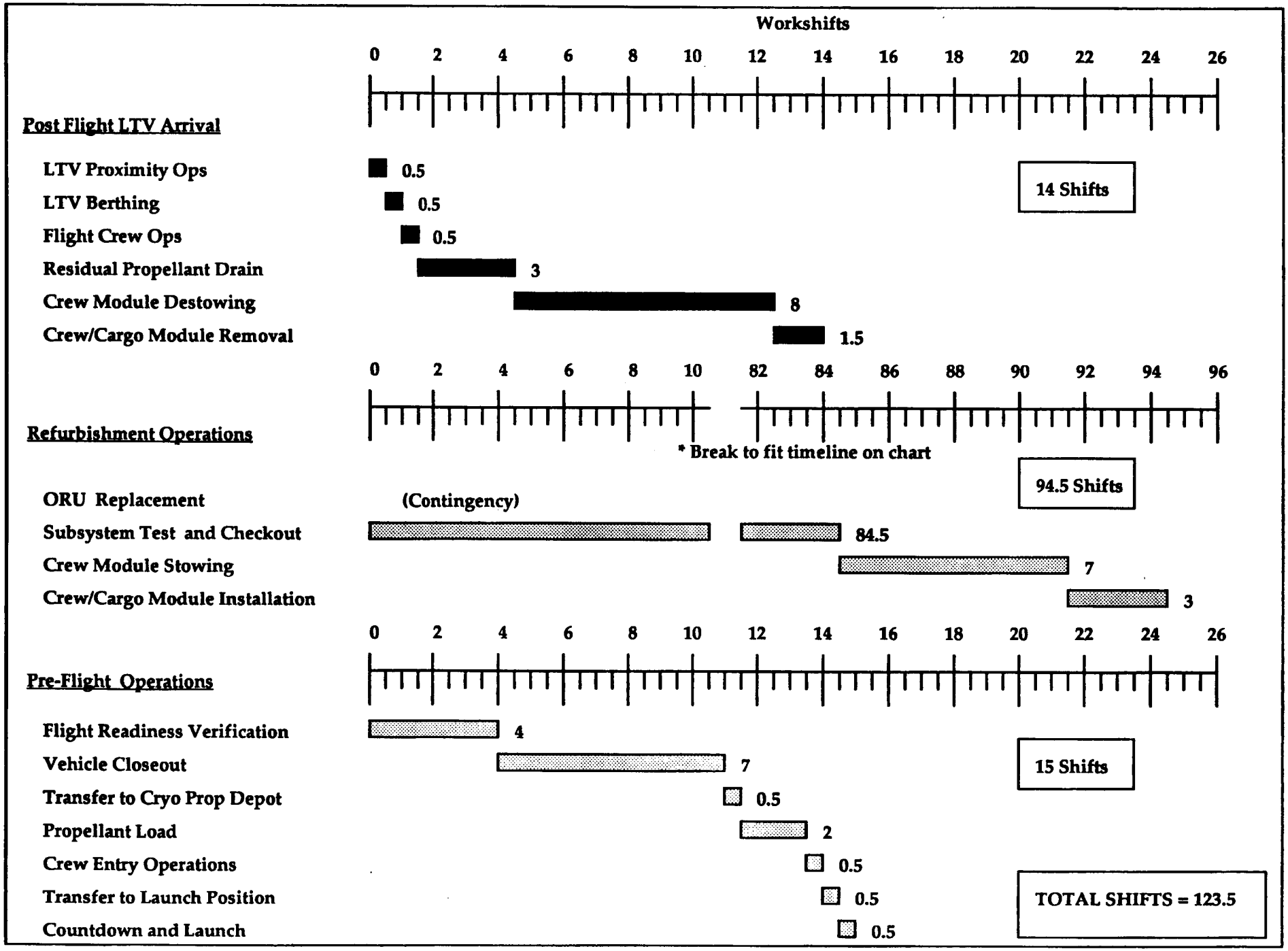
*Avionics System Refurbishment.* ORU replacement of avionics ring boxes may require cargo or crew module removal unless ORU is accessible through access panel or by radiator panel removal. Crew module avionics boxes will be replaced IVA as required. Antenna repair / replacement will be performed on an "as needed" basis.

*Crew Module Refurbishment.* Refurbishment of crew module is visualized as being very much the same as Shuttle refurbishment operations. Lunar missions and shuttle missions are approximately the same duration with similar crew size and crew module internal space. Replacement of crew consumables is by lockers and pre-packs. Flight crew, waste management containers, lockers, trash (wet & dry) and required equipment will be removed prior to vehicle refurbishment. Crew module waste management system is serviceable (drain & flush) in place. EVA suits will be exchanged as required.

**Pre-Flight Operations:** Following ORU replacement and vehicle system servicing, integrated testing will be performed on the transfer vehicle (and crew module if a piloted mission is being prepared). Portions of the flight sequence will be simulated to verify functional integrity of vehicle systems. For an LCV mission, the cargo will be mated to the transfer vehicle prior to leaving the SSF servicing hangar. Fluids and gases will be topped-off. For an LPV mission, final crew equipment, food, film, etc. will be stowed, followed by flight crew ingress.

The vehicle will then be transferred by an advanced OMV to the propellant depot for cryogenic loading, and then deployed by OMV to the stand-off position for the trans-lunar injection burn.

# Lunar Vehicle Processing Operations.



# Propellant Tethered to Space Station Freedom

An option for the refueling of reusable Space Transfer Vehicles in the vicinity of the Space Station involves the use of a propellant depot which is tethered to the Space Station. The propellant tanks are tethered away from the Space Station in either the zenith or nadir directions. Having the tanks attached to the station allows the tanks to be under station control, but decreases the risks of having large amounts of propellant close to the station. The tanks experience a slight acceleration at the end of the tether which can be used to simplify propellant storage and transfer operations. Tether lengths of roughly 200 m provide accelerations at the tanks of roughly 0.0001 g, which is sufficient to allow fluid settling in LOX and LH2 tanks.

Two different tether configurations have been analyzed to determine their impacts on Space Station. The first case, as illustrated in the figure below, deals with using a tether to store and transfer propellant for lunar mission flight 1, which is an expendable cargo flight. The second case, shown in the figure on the following page, shows the use of a tether system to store and transfer propellant during the lunar operational phase, where two reusable LTV's are based at Freedom.

The study assessed the feasibility of locating Transfer Propellant Tank (TPT) platforms remote from the Space Station through the use of tethers. One major objective of the study was to determine the dynamic environment of the Space Station-tethered tank platform system. This included evaluating attitude motion, system center of mass migration, microgravity sensed at the Space Station center of mass, microgravity sensed at the tanks, tether tension, and the impact of a departing vehicle on the motion of an empty tank platform.

For the purposes of the initial study, certain assumptions were made:

1) The tether used was stainless steel, 1 mm in diameter, 200m in length.

2) The Space Station center of mass orbit was at 220 Nm altitude, $28.5^{o}$ inclination.

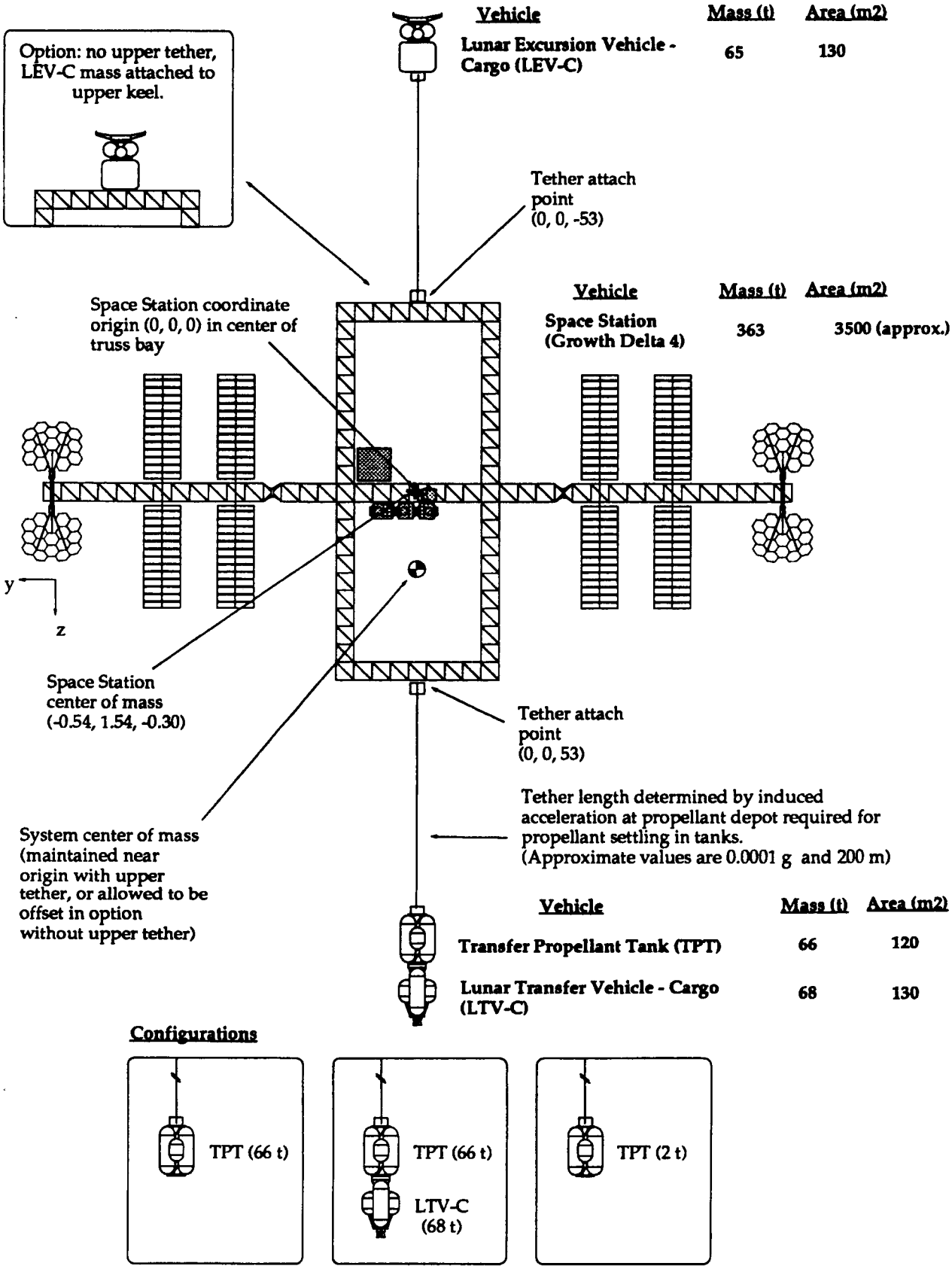
3) The Space Station center of mass (CM) was at (0, 0, 0) in Space Station coordinates and the tether attach points were at ±53m on the Space Station z-axis.

4) Due to software constraints, the Space Station and tank platforms were treated as point masses (except for drag calculations where drag surface areas are included).

5) The mass and drag surface area of the tether were included in the mass and area of the tank platforms in the 2 body simulations (also in the lower platform in the 3 body simulations). The mass and area of the upper tether were added to the Space Station mass and area in the 3 body simulations.

6) Full tank steady state conditions were used as the starting point for the study of the impact of a departing vehicle (released empty tank simulation).

# Lunar Evolution Space Station with Tethered Propellant Depot - Flight 1



## Propellant Tether to Space Station Freedom (continued)

Two Space Station configurations were tested. The first had mass of 363 tons and surface of 3500 $m^2$ (Figure 7.4-1). The second had mass of 380 tons and surface area of 5000 $m^2$. For each Space Station configuration, several combinations of propellant tanks, fuel and vehicles were simulated as listed below.

Cases involving Space Station tether configuration 1 (363t, 3500 $m^2$) with downward deployed tethers included:

1a) Full Tank Platform (66t, 120$m^2$);
1b) Full Tank Platform and Lunar Transfer Vehicle Cargo (LTV-C) (134t, 250$m^2$);
1c) Empty Tank Platform (2t, 120$m^2$);
1d) Empty Tank Platform at time of "release" by LTV-C (2t, 120$m^2$).

Cases with upward deployed tethers included:

1e) Lunar Excursion Vehicle-Cargo (LEV-C) (65t, 130$m^2$);
1f-h) combined upward deployed tether with each downward deployed tether case, except "released" platform.

Cases involving Space Station tether configuration 2 (380t, 5000$m^2$) with downward deployed tethers included:

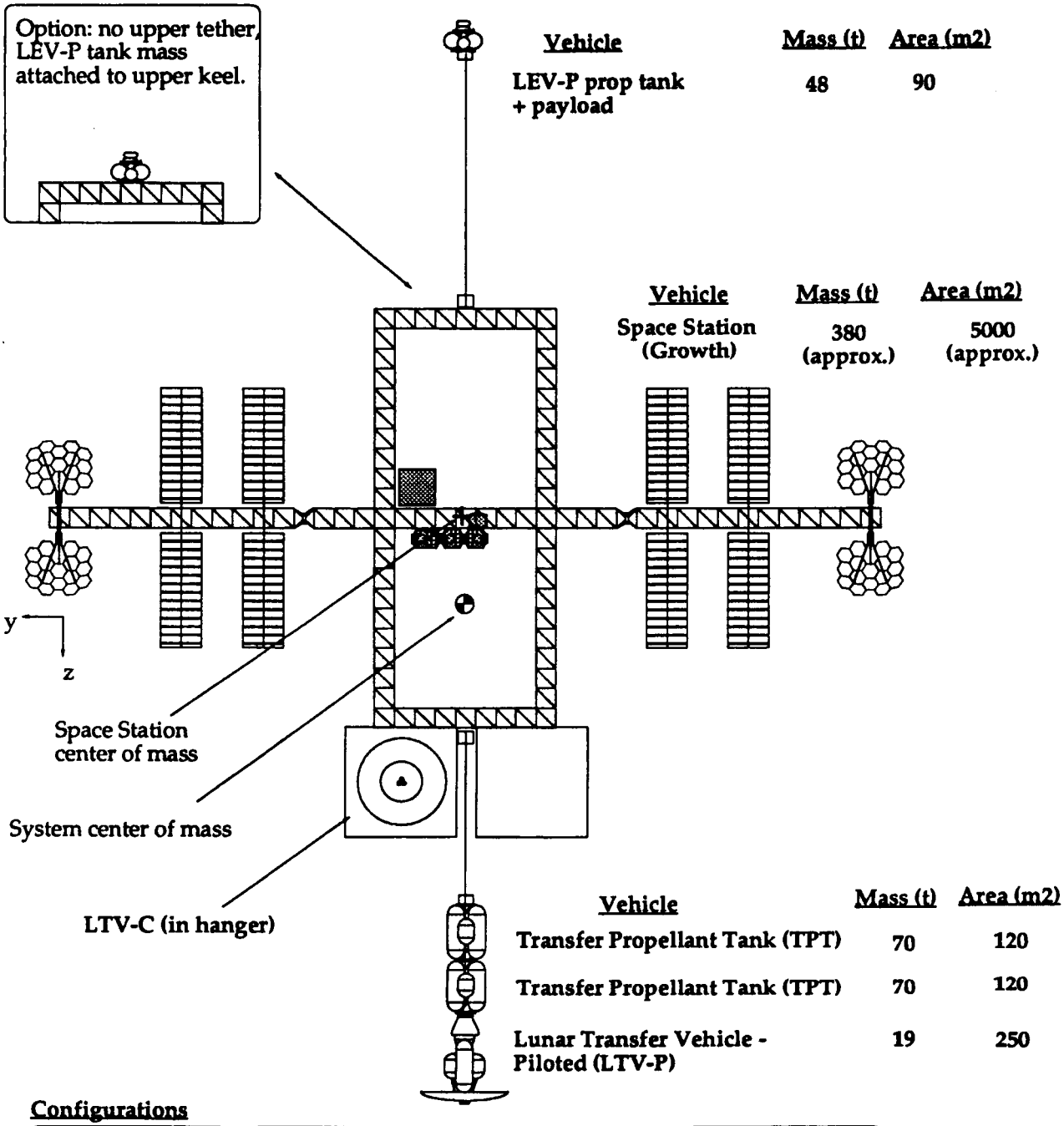
2a) One Full Tank Platform (70t, 120$m^2$);
2b) Two Full Tank Platforms (140t, 240$m^2$);
2c) Two Full Tank Platforms and Lunar Transfer Vehicle Piloted (LTV-P) (159t, 490$m^2$);
2d) Two Empty Tank Platforms (4t, 240$m^2$);

Cases with upward deployed tethers included:

2e) Lunar Excursion Vehicle - Prop Tank and payload (LEV-P) (48t, 90$m^2$);
2f-i) combined upward deployed tether with each downward deployed tether case, except "released" platforms.

The various downward deployed configurations were simulated in a 2 body system with the space station. These simulations showed a stable system, even though beginning in an artificial state (i.e., deployed mass directly below Space Station CM, at full deployment length). During the course of the study, it was observed that small initial relative velocity errors between the deployed tanks and the Space Station resulted in large amplitude oscillations; further studies are needed to determine control parameters to accomplish actual deployment of the platforms.

# Lunar Evolution Space Station with Tethered Propellant Depot - Flight 8

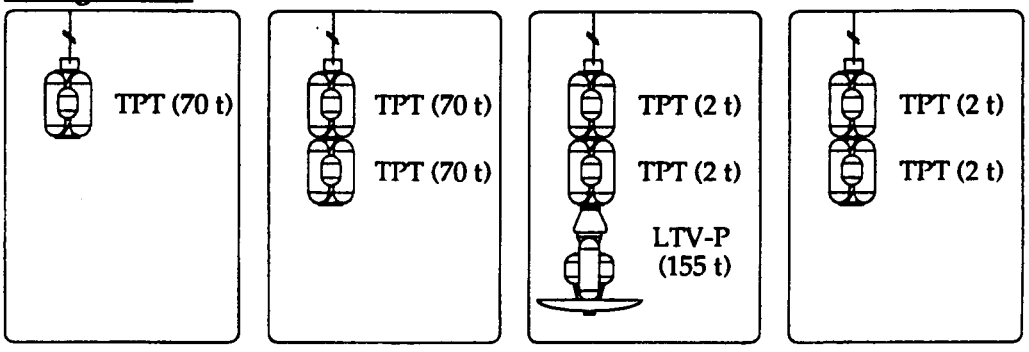



| Vehicle | Mass (t) | Area (m2) |
|---|---|---|
| LEV-P prop tank + payload | 48 | 90 |

| Vehicle | Mass (t) | Area (m2) |
|---|---|---|
| Space Station (Growth) | 380 (approx.) | 5000 (approx.) |

| Vehicle | Mass (t) | Area (m2) |
|---|---|---|
| Transfer Propellant Tank (TPT) | 70 | 120 |
| Transfer Propellant Tank (TPT) | 70 | 120 |
| Lunar Transfer Vehicle - Piloted (LTV-P) | 19 | 250 |

**Configurations**



## Propellant Tethered to Space Station Freedom (concluded)

The steady-state gravity gradient sensed acceleration at the platform ranges from 70-97 micro-g in the various 2-body simulations, and from 2-29 micro-g at the Space Station CM. In addition, there is a cyclic tether acceleration sensed at the tank. This acceleration is a damped elastic effect with peaks of 5-56 micro-g, depending on the mass deployed. The tether/space station system had a steady state in-plane oscillation of less than 2 degrees. This motion is depicted in the figure below, which shows radial displacement of the tank from the station versus in-plane position of the tank relative to the station for the 66 ton platform. The upper symbol in the figure represents
the space station, while the lower represents the tank platform. The movement of the space station is an arbitrary representation of the plotting program which allows a better visual representation of the in-plane motion over a period of time (in this case, 10,000 seconds).

Similar results were obtained in the upward deployed 2 body simulations and the 3 body (upward and downward deployed) simulations. The steady state gravity gradient sensed acceleration at the tank platforms ranged from 80-114 micro-g, while those at space station CM ranged from 0.2-19 micro-g.

All tether tensions are well within the stainless steel capacities at the tether diameters studied.

# Meteoroid and Orbital Debris Shielding for Hangers

The protection of space transfer vehicles from meteoroids and orbital debris while at the Space Station involves balancing the benefits of additional protection against the costs of adding significant mass to the hanger walls. A hanger wall thickness was selected to provide some additional protection to EVA astronauts while operating in the unpressurized hanger. An aluminum alloy hanger wall and bumper with a (combined) thickness of 1 mm was selected. This wall is capable of stopping the small, paint flake size particles and would provide roughly ten times more protection than an astronaut in the current EMU. The amount of protection is not large, yet it involves a significant addition of mass to the hangers - 2.8 metric tons for 1000 square meters.

The SRD requirement states that "SSF shall provide debris protection for space transfer vehicles and mission equipment while resident at SSF". The Lunar transfer vehicles will have some shielding themselves. For example, the current Lunar vehicle tank design has a 30 mil (0.76 mm) Al-Li alloy wall and a 15 mil (0.38 mm) bumper with multi-layer insulation (MLI) in the gap. The protection requirements for the vehicle components, such as the aerobrake, must be determined. Since the specific requirements of the space transfer vehicles for additional protection while in LEO were not available, a hanger wall design was selected to protect the EVA crew servicing the transfer vehicle.

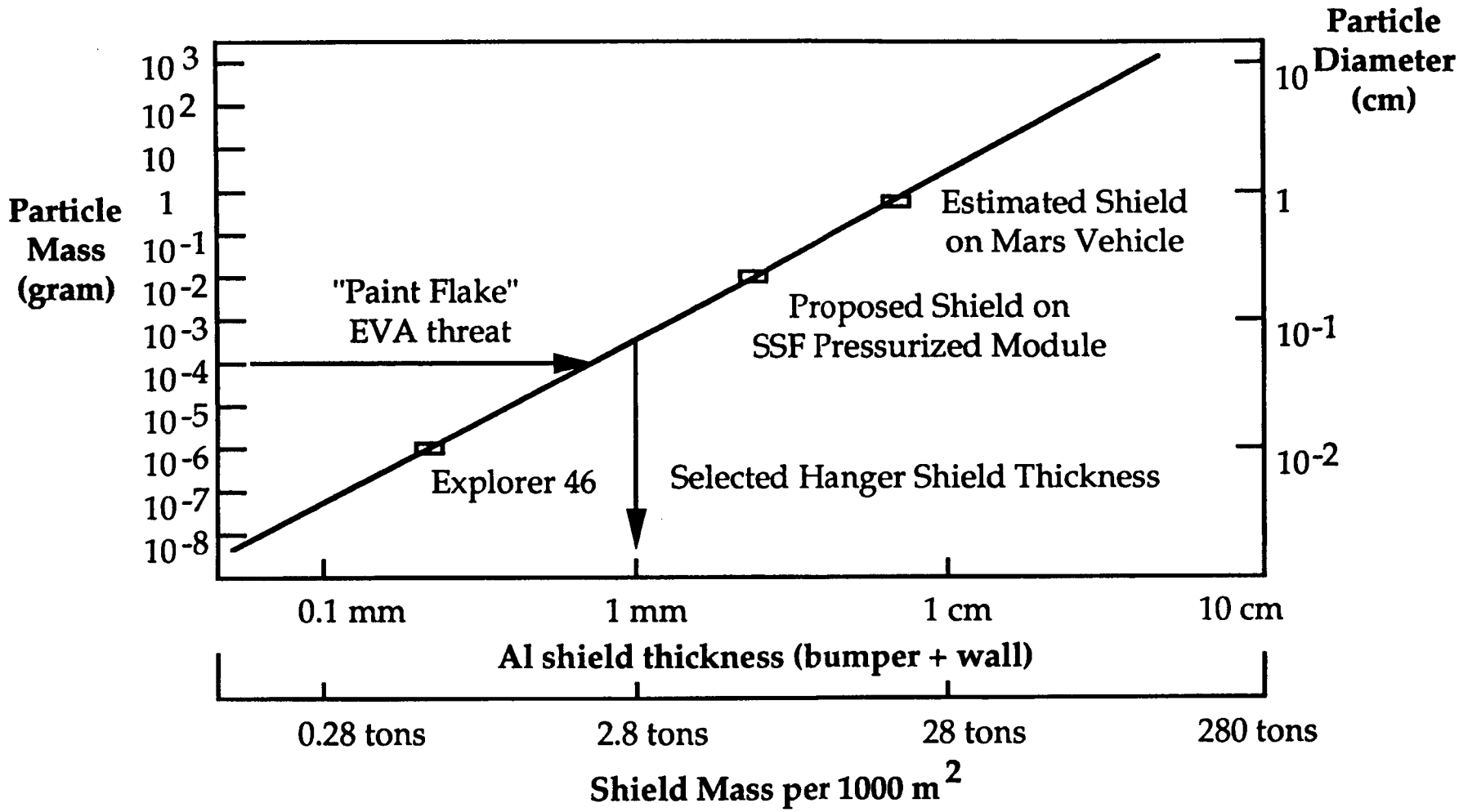
The protection requirements for SSF EVA astronauts is stated as: "..the SSPE should be designed and operated in a manner such that the individual crewman would not be exposed to a risk of more than 0.0005 (1 per 2000) accidental deaths per year as a consequence of meteoroid and debris strikes." (Space Station Program Natural Environment Definition for Design, JSC 30425, Sec. 13.1) The above requirements place a specific limit on the risk to an EVA astronaut. In the absence of additional protection, this requirement would limit the total amount of time a crew member could spend on EVA.

Natural meteoroids include low density cometary material in periodic meteor showers, and higher density asteroidal material. Meteoroids have high velocities (10 - 60 km/s) and would arrive at SSF with directions randomly distributed across the hemisphere above the horizon.

Artificial orbital debris consists of large objects - which are tracked optically and with radars, and the more numerous small objects and particles. There is limited data on the number of small objects. The model distributions are extrapolated from the numbers of larger objects and are uncertain by a factor of ten for the current environment. In the coming decades, the amount of debris is projected to increase by a factor of 2 to 10 depending of future space activity and debris countermeasures. Orbital debris impact directions are concentrated in the x-y (horizontal) plane. Typical impact velocities of orbital debris (10 km/s) , while lower than meteoroids, are more capable of penetrating shields since particle fragments may survive impact with the bumper shield. A retrieval of the Long Duration Exposure Facility (LDEF) satellite would significantly add to the understanding of the current environment.

The current space suit can be penetrated by particles as small as 0.5 mm diameter at orbital velocities. The probability of such an impact on an EVA astronaut in the current environment is roughly $2 \times 10^{-6}$ per hour of EVA time. Without additional protection, the SSF risk limit would require an operational limit of 3-5 EVA days per month for an astronaut.
The selected meteoroid/debris includes a main wall of 0.8 mm of Al alloy, an exterior bumper wall of 0.2 mm at a distance of 3 cm, with the gap between the walls partially filled with layers of multilayer insulation (MLI). The effectiveness of shields of various thicknesses is illustrated in the figure below. The figure compares the thin shield of the Explorer 46 satellite, able to stop microgram size particles, to the heavier shields for SSF modules. The 1 mm shield selected would stop particles just under 1 mm in diameter and reduce the threat to EVA astronauts by roughly a factor of ten. This would remove the debris risk as an operational limit to EVA time in the hanger. The resulting mass penalty for the hanger walls is 2.8 metric tons per 1000 square meters of hanger wall.

# Selection of 1 mm Al Shield for Vehicle Hanger Wall



# Mars Evolution Case Study Assessment

## Mars Evolution Case Study Outpost Capabilities*

The emplacement of a permanent, self-sufficient outpost on the surface of Mars is planned to follow an evolutionary path as illustrated. The outpost will develop through a series of phases, each with its own distinct objectives. Just as in the Lunar Evolution case study, the three mission phases for the Mars Evolution are (1) emplacement, (2) consolidation, and (3) utilization. The objectives and characteristics of each phase are:

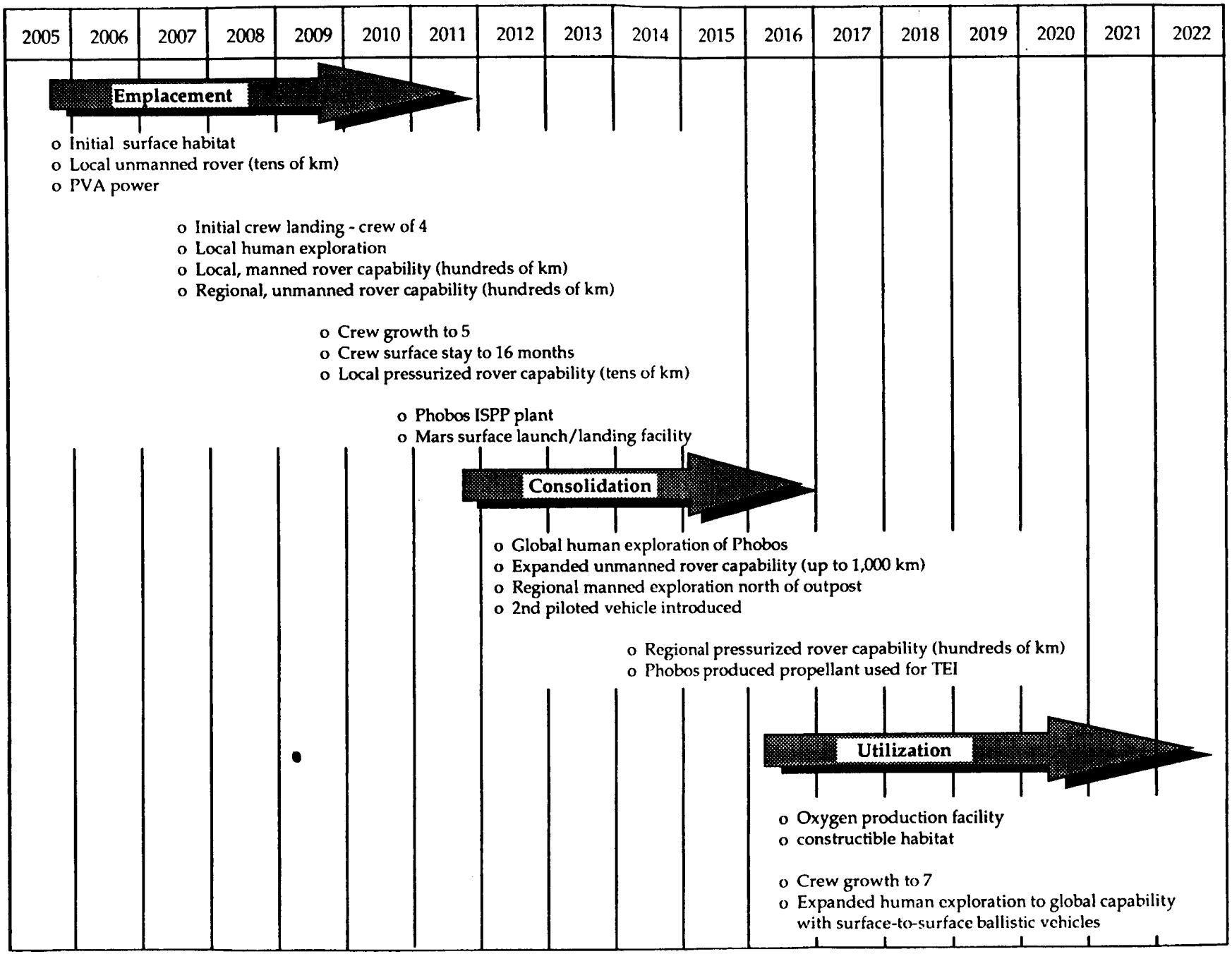
*Emplacement Phase.* Accomplish the initial human landing, deployment, and check-out of the surface habitat module. Initiate local human exploration activities and regional semiautonomous exploration capability.

*Consolidation Phase.* Begin to exploit local resources with the introduction of a gateway propellant plant to produce oxygen for outpost and vehicle resupply. Expand the surface crew size and stay time, and increase both human and robotic exploration capabilities.

*Utilization Phase.* Establish outpost permanence with expanded surface facilities, greater use of Mars resources, and advanced space transfer vehicle propulsion technologies. Demonstrate global exploration of Mars.

* This overview of the Mars Outpost was taken from an Office of Exploration FY89 Annual Report draft.

# Mars Evolution Case Study Outpost Capabilities



## SRD Specified Mars Evolution Case S[redacted]Freedom Requirements

As in the Lunar Evolution Case Study, Space Station Freedom will be required to support advanced development of base and space transportation systems. In addition, life science research will be conducted to investigate long-duration crew exposure to a mico-gravity environment. It is important to note that for the Mars Evolution Case Study no space transfer vehicle processing activities are done directly on Space Station Freedom. Iinstead, a separate free-flying assembly fixture is used to assemble, process, and fuel the Mars Transfer Vehicle (MTV).

# Mars Evolution Case Study Resource Requirements

The magnitude of effort needed to support the Lunar and Mars Evolution case studies requires that the Space Station provide increased resources and capabilities. This expansion of the performance envelope includes such basic resources as crew, power, interior volume, and exterior work space. The plan for accommodating the case studies called for using the requirements specified in the Office of Exploration (OEXP) Study Requirements Document (SRD) to establish evolutionary Freedom resource and facility requirements. These requirements were initially submitted as part of the baseline Preliminary Requirements Review (PRR) that was held in May and June of 1988. The transportation node growth requirements are presently being refined and combined with the Multidisciplinary Research and Development reference configuration growth requirements into a set of composite evolution growth requirements. This composite set of growth requirements will be submitted to the Space Station Freedom Preliminary Design Review (PDR) in 1990. The specific resource requirements for the Mars Evolution case study are shown in the accompanying figure.

Additional habitable volume will be required on Freedom to accommodate the Mars transfer vehicle (MTV) mission crew , MTV processing crew, and the life science research crew. In order to mate the additional habitat module to the existing module cluster, two resource nodes, greater in length than the presently designed node, are required. The extended resource node is required to satisfy the current Freedom requirement of maintaining enough clearance (2.1 meters) between Freedom modules to allow an EVA astronaut to pass inbetween and make repairs if necessary.

In addition to the habitat module, an addional life science laboratory module is required to conduct research into long duration crew exposure to a micro-gravity environment, along with a plant and animal vivarium. Also, 3 pocket laboratory modules (short labs) are required to conduct research on advanced chemical-physical life support systems, artificial gravity effects on animals and humans, and possibly a quarantine facility for Mars sample returns.

100 kW of dynamic power is required to provide the additional power for the habitat, resource nodes, and LTV processing facilities.

The ability to evolve to these levels of capabilities preserves the option to accommodate, at a top level of functionality, the OEXP Mars Evolution case study which requires Space Station Freedom as a part of the overall infrastructure.

## MARS EVOLUTION CASE STUDY
## TRANSPORTATION NODE RESOURCE REQUIREMENTS

| Station Configuration | Current Recommendation |
|---|---|
| Power | |
| Average | 175 kW |
| Peak | NA |
| Crew | 18 |
| Pressurized Modules | |
| US Habitation | 2 |
| US Laboratory | 2 |
| ESA Laboratory | 1 |
| JEM Laboratory | 1 |
| Pocket Laboratory | 3 |
| Resource Nodes | 8 |
| **Transverse Boom** | |
| Dual Keel | Scar for distributed systems |
| Servicing Facility | Scar for all possible locations |
| Power Modules | SD array growth on extensions of boom ends |
| **Payloads** | |
| APAE | TBD |
| Location points for APAE | TBD |
| Tether Payloads | 2 |

## Mars Evolution Time-Phased Space Station Freedom Growth Deltas

The time-phased Space Station Freedom growth augmentations, or growth deltas, are shown. These growth deltas reflect major incremental increases in various resources including power, habitable volume, truss, payload attach points, etc. The growth deltas do not reflect the actual hardware manifesting on a flight-by-flight basis, but instead illustrate major incremental increases in various resources including power, habitable volume, structure, etc. The growth increments are shown in this manner because the time-phasing of the additional Space Station hardware elements are directly related to the amount of transportation support that Space Station receives after assembly complete.

Space Station Freedom Transportation Node Concepts and Analysis

## MARS EVOLUTION CASE STUDY
## TIME-PHASED SPACE STATION FREEDOM GROWTH DELTAS

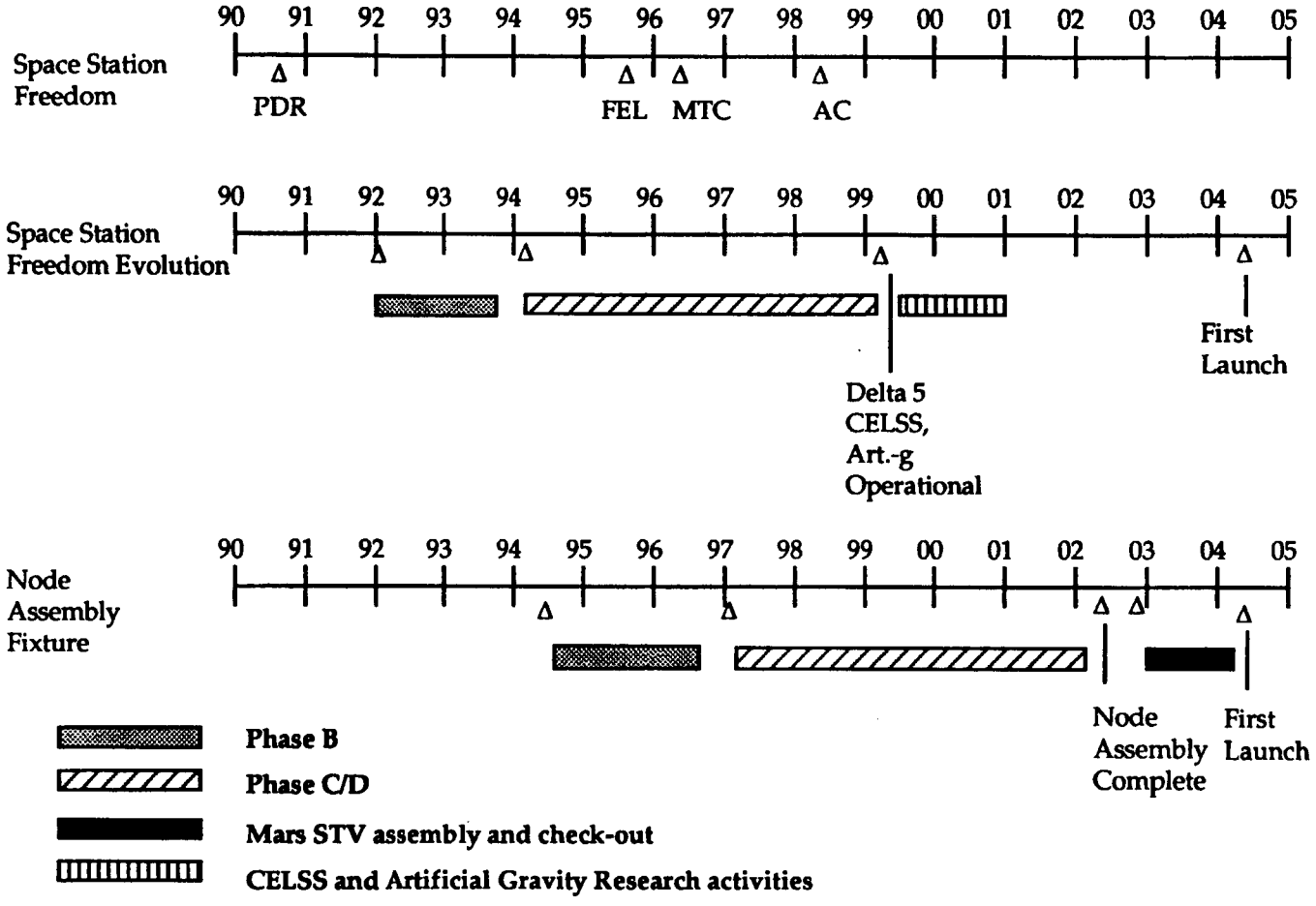
| | |
|---|---|
| Δ1 | (2 - 25 kW) Solar Dynamic Modules; (2) 25 meter Transverse Boom Extensions; Space Based OMV & Space Based OMV accommodations |
| Δ2 | Upper/Lower Keels & Booms |
| Δ3 | (1) Habitat Module; (2) Resource Nodes |
| Δ4 | (2 - 25 kW) Solar Dynamic Modules; Servicing Facility Phase 1 |
| Δ5 | (1) Large Pocket Laboratory (Art-g); (1) Large Pocket Laboratory (CELSS); Servicing Facility Phase 2 |
| Δ6 | Life Sciences Laboratory Module; (2) Resource Nodes |
| Δ7 | Phase 3 Servicing Facility (Completed CSF); |
| Δ8 | (1) Large Pocket Laboratory (Quarantine Facility) |

## Mars Evolution Case Study Programmatic Schedule

Based on the currently proposed Mars Evolution case study mission description a Space Station evolution programmatic schedule has been developed. It is important to note that with an initial manned Mars launch date in 2004 and the fact that Space Station Freedom will not reach assembly complete until 1998, there is probably not sufficient time to grow the Space Station to support life sciences and technology research required to influence the design of the Mars Transfer Vehicle. Additional understanding of the life science program timelines and resource requirements must be established before a final integrated Mars mission schedule can be established.

Space Station Freedom Transportation Node Concepts and Analysis

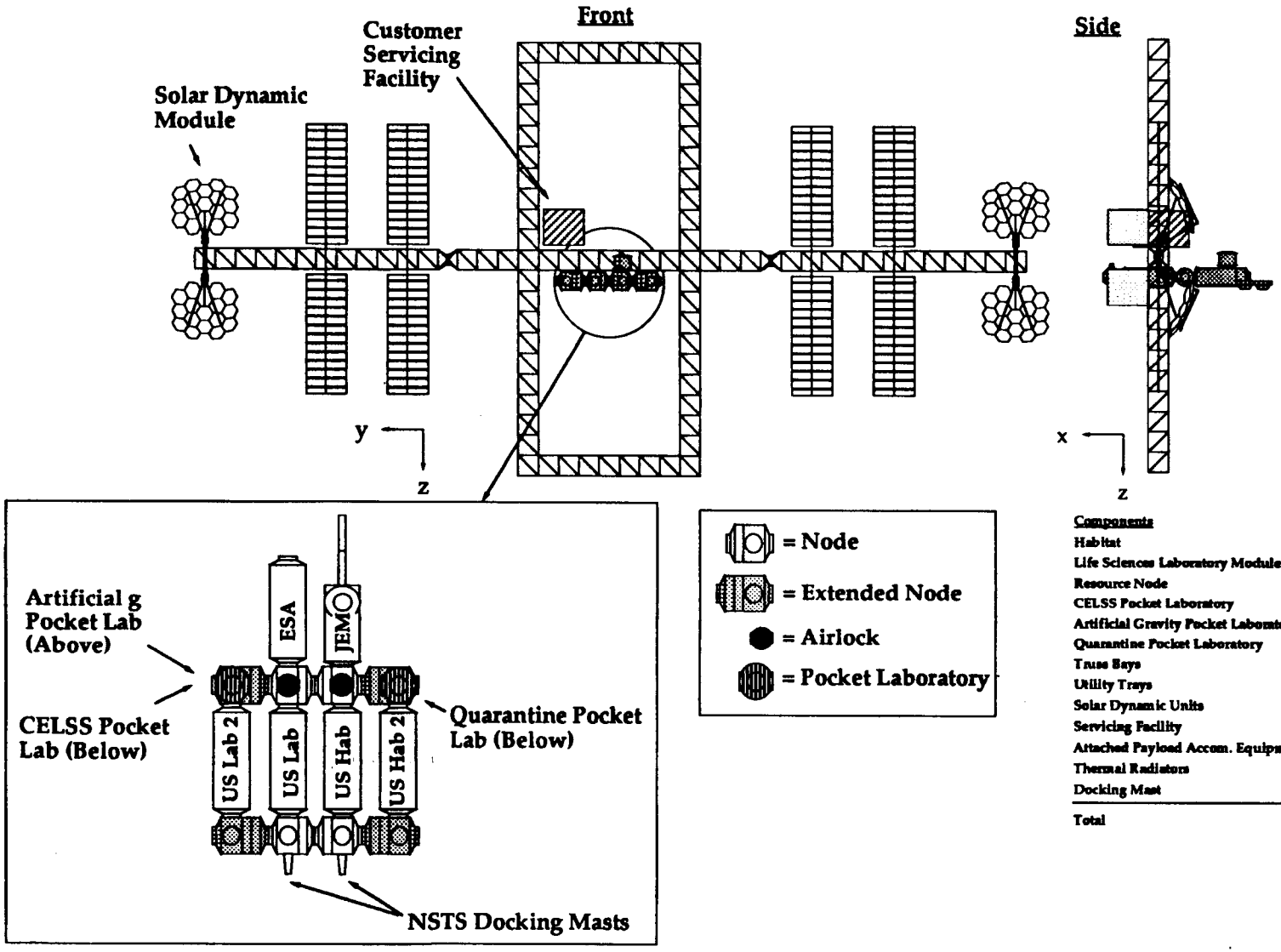
## Mars Evolution Case Study Programmatic Schedule



## Mars Evolution Space Station Growth Configuration (Delta 8)

The recommended Mars Evolution Case Study growth configuration to support life sciences and technology research is pictured. It is important from a Space Station Freedom programmatic point of view that the proper hooks and scars be maintained in the baseline SSF program. Several important SSF scars are the alpha joint (175 kW), Power Management and Distribution (PMAD) system (175 kW), and the Active Thermal Control System (ATCS) (175 kW). Configutationally, it is important that the Reaction Control System has the capability to be relocated on the upper and lower keels, and that the module pattern has sufficient room for growth along the transverse boom. In addition, the radiators must be located such that there is ample clearance with the upper and lower keels.

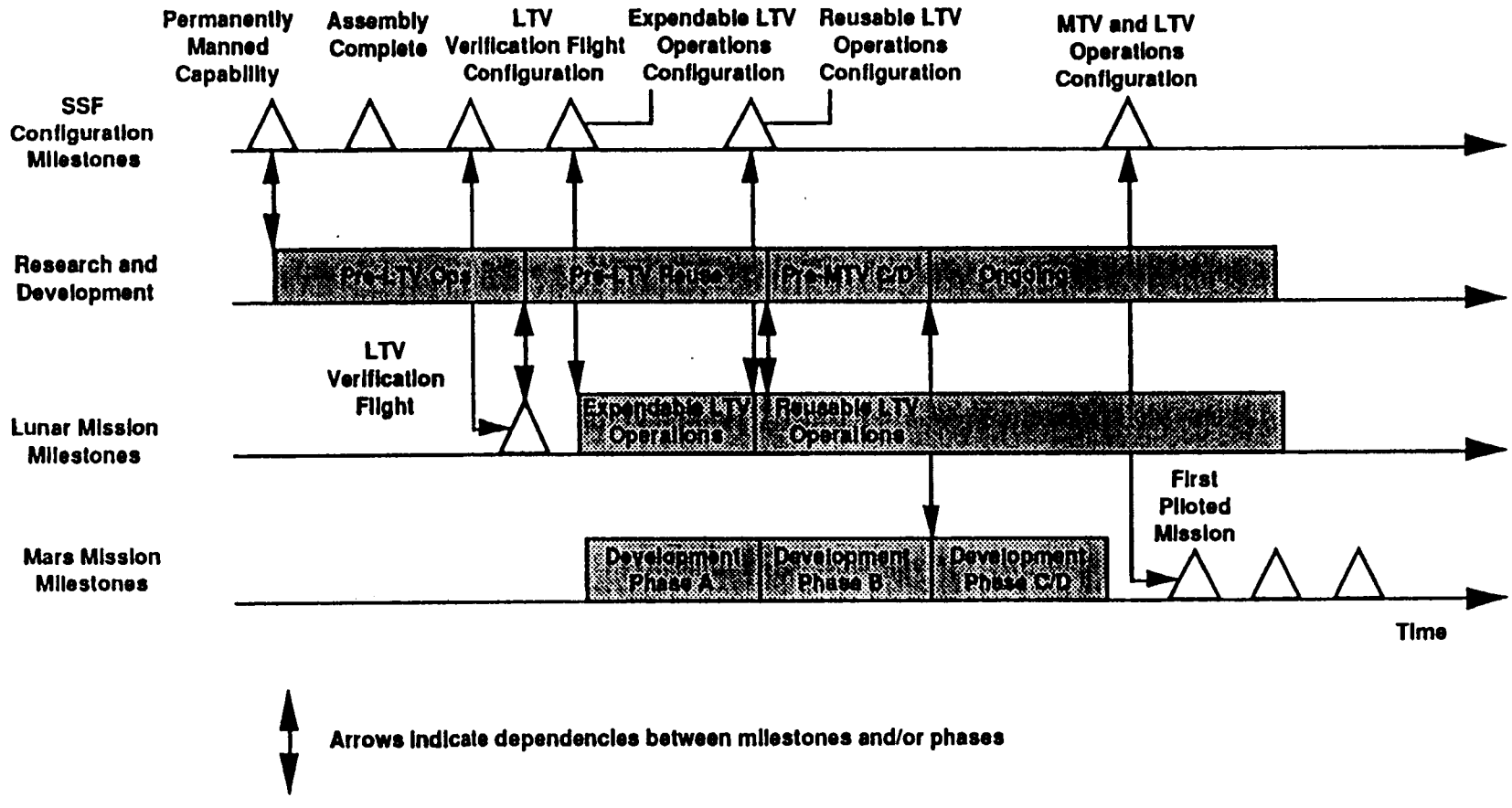
# Mars Evolution Space Station Growth Configuration (Delta 8).



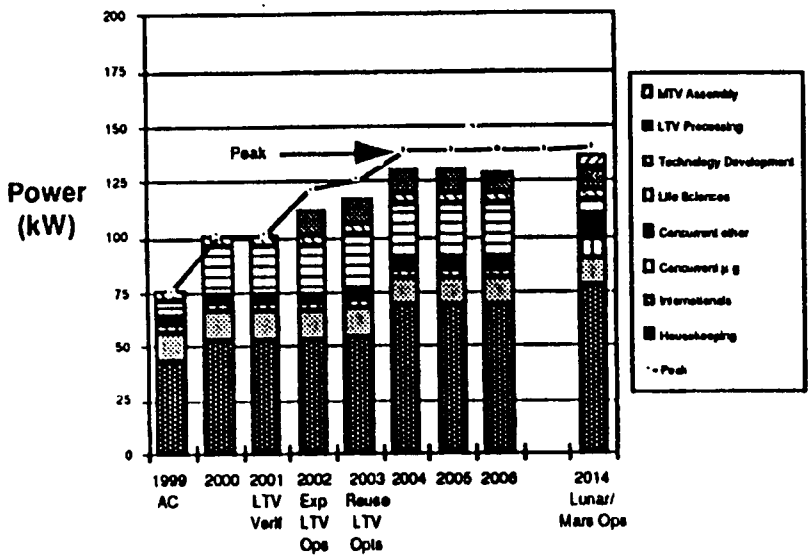

| Components | Number | Mass (kg) |
|---|---|---|
| Habitat | 1 | 23,500 |
| Life Sciences Laboratory Module | 1 | 34,700 |
| Resource Node | 4 | 31,200 |
| CELSS Pocket Laboratory | 1 | 10,250 |
| Artificial Gravity Pocket Laboratory | 1 | 10,250 |
| Quarantine Pocket Laboratory | 1 | 10,250 |
| Truss Bays | 64 | 5,700 |
| Utility Trays | 64 | 11,300 |
| Solar Dynamic Units | 4 | 27,600 |
| Servicing Facility | 1 | 11,500 |
| Attached Payload Accom. Equipment | 4 | 1,450 |
| Thermal Radiators | 2 | 6,300 |
| Docking Mast | 1 | 1,400 |
| Total | | 185,400 |

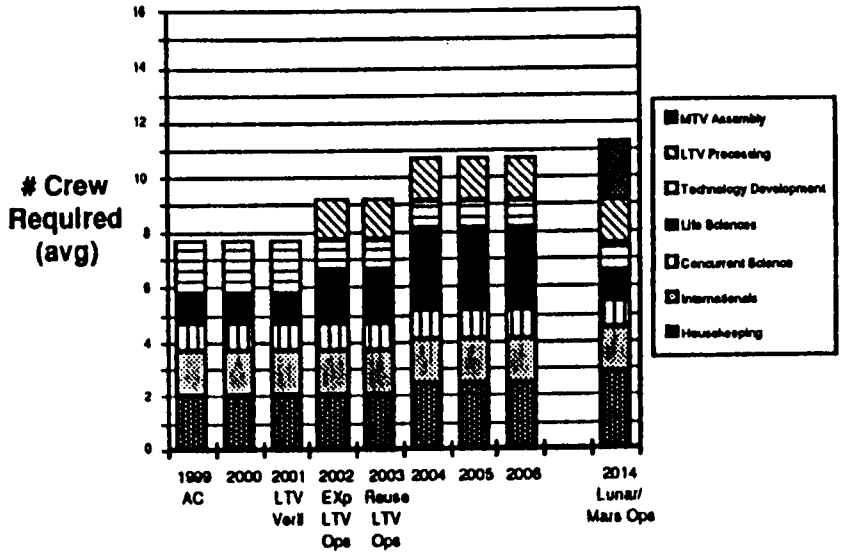
# Lunar/Mars Exploration Initiative Assessment

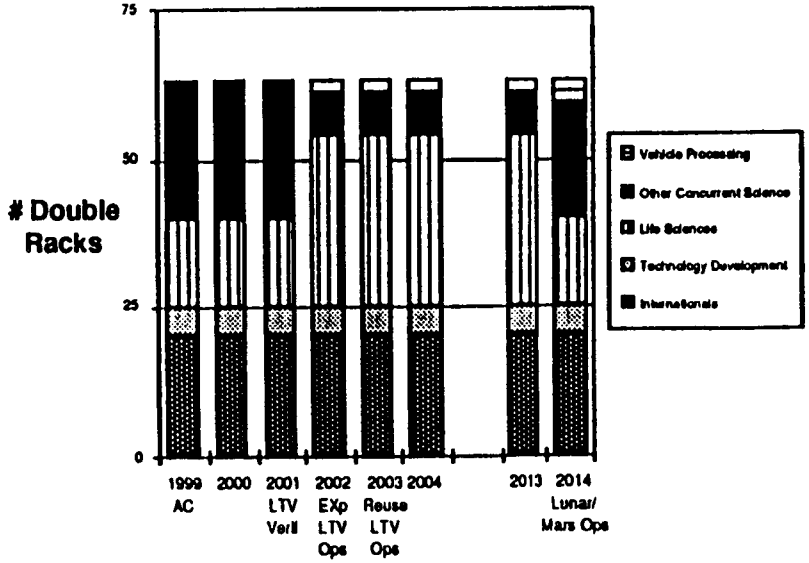
# IMPLEMENTATION AGAINST REQUIREMENTS
## ACCOMMODATION SCHEDULE



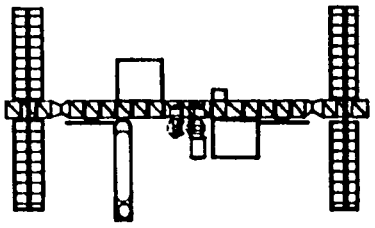
# OPTION 5 - PACED DEPLOYMENT OPTION
## RESOURCE ALLOCATION



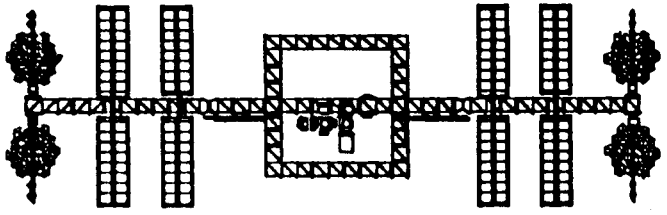



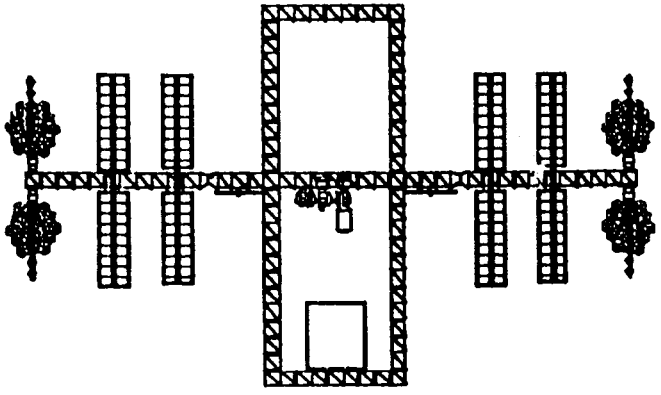
# TRANSPORTATION NODE ANALYSIS
## EXAMPLES OF CONFIGURATIONS ASSESSED



- Minimum augmentation to rephased program PMC
- Large pitch TEA (pitch TEA > 40 degrees)
- Very large angular momentum (control difficulties)
- Operational and physical interferences (module growth blockages, SSF hydrazine thruster plume impingement, etc.)



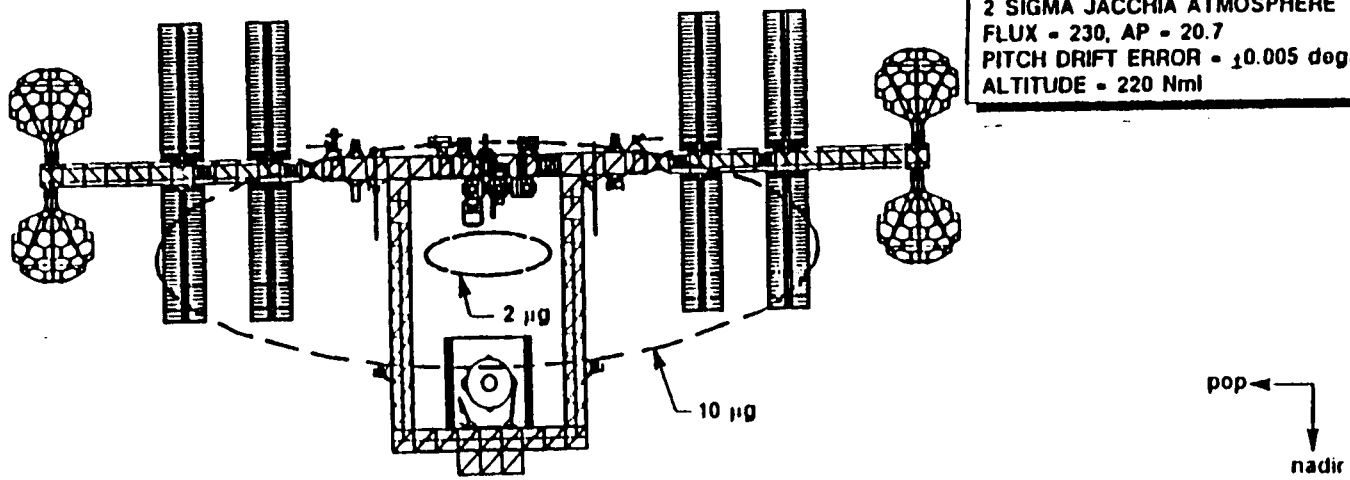
- Minimal augmentation to previous SSF baseline (Phase 1)
- Assembly hangar located behind transverse boom (i.e., offset in the -X direction)
- Large pitch TEA (> 30 degrees)
- Large angular momentum
- Field-of-view blockages (e.g., JEM exposed facility)



- Dual keel selected as Baseline during Phase B of SSFP
- Low pitch TEA (< +5 degrees)
- Stablized gravity gradient (Ixx >> Izz)
- Room for unobstructed vehicle processing and assembly operations
- Increased structure and utility runs

# TRANSPORTATION NODE ANALYSIS
## REUSABLE LTV OPERATIONS CONFIGURATON

2 SIGMA JACCHIA ATMOSPHERE
FLUX = 230, AP = 20.7
PITCH DRIFT ERROR = ±0.005 deg/sec
ALTITUDE = 220 Nmi




Steady State Microgravity Profile

## Mass Properties

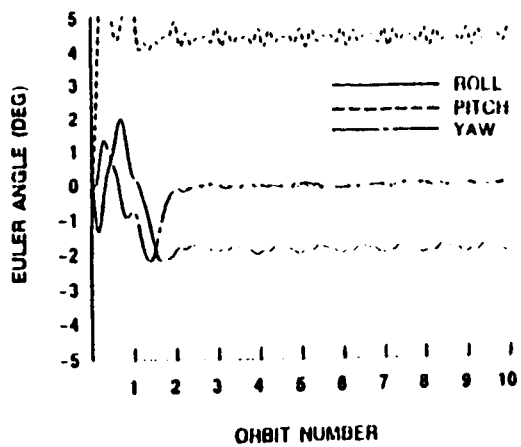
Mass = 488,980 kg

Center of Gravity:
$x_{cg}$ = -1.5 m  $y_{cg}$ = -0.2 m  $z_{cg}$ = 21.2 m

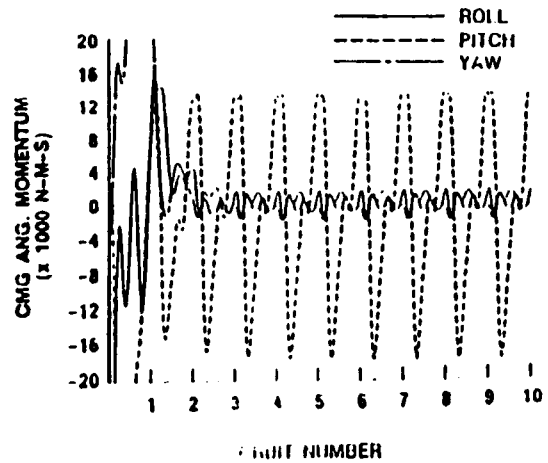
Inertia Matrix (kg-m$^2$):
Ixx = 6.06E8  Iyy = 2.71E8  Izz = 3.97E8
Ixy = -7.05E5  Iyz = 4.10E6  Ixz = -8.03E6

## Control Characteristics

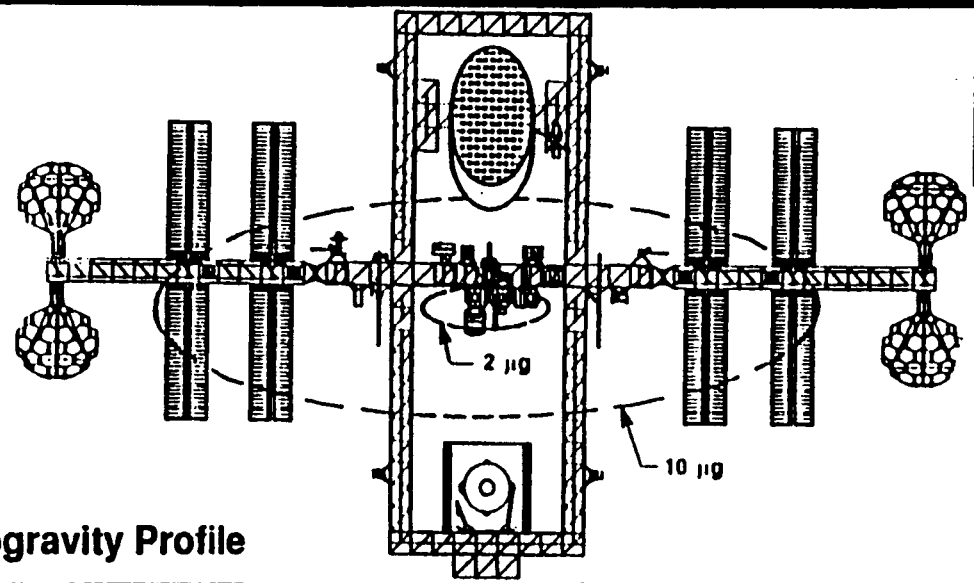
TIME HISTORY OF SSF ATTITUDE




TIME HISTORY OF SSF CONTROL MOMENTUM



# TRANSPORTATION NODE ANALYSIS
## LUNAR AND MARS OPERATIONS CONFIGURATION




2 SIGMA JACCHIA ATMOSPHERE
FLUX = 230, AP = 20.7
PITCH DRIFT ERROR = ±0.005 deg/sec
ALTITUDE = 220 Nmi

pop
nadir

**Steady State Microgravity Profile**

## Mass Properties

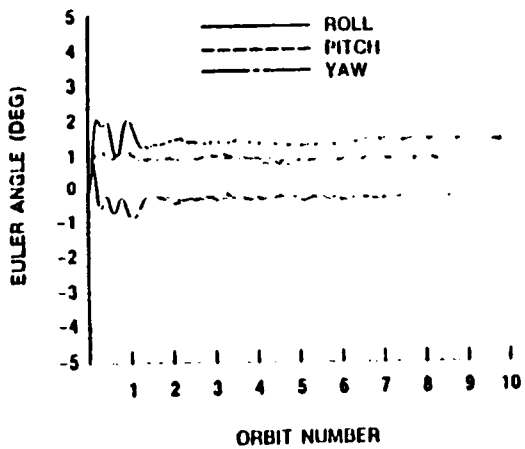
Mass = 644,618 kg

Center of Gravity:
$x_{cg}$ = -1.7 m  $y_{cg}$ = -0.25 m  $z_{cg}$ = 8.60 m

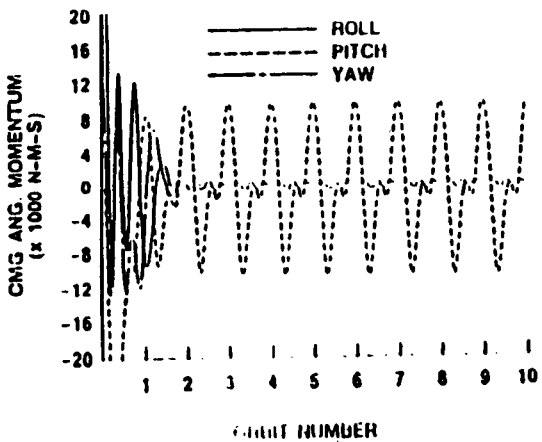
Inertia Matrix (kg-m$^2$):
Ixx = 9.41E8  Iyy = 6.10E8  Izz = 4.10E8
Ixy = -1.00E6  Iyz = 4.97E6  Ixz = -2.30E6

## Control Characteristics

TIME HISTORY OF SSF ATTITUDE

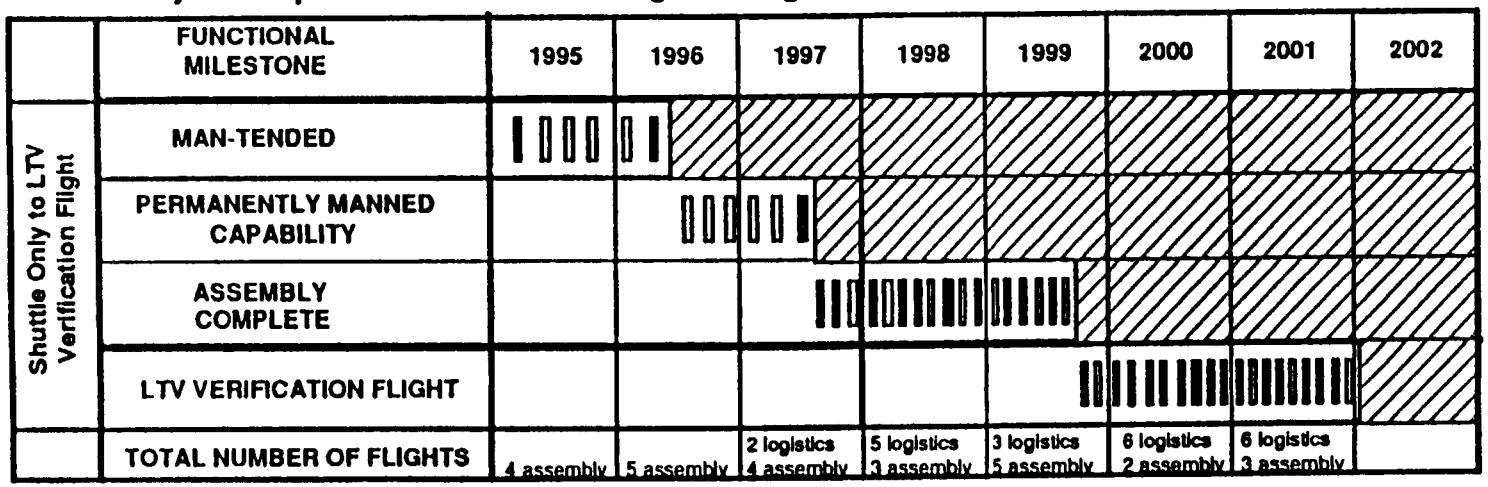



TIME HISTORY OF SSF CONTROL MOMENTUM

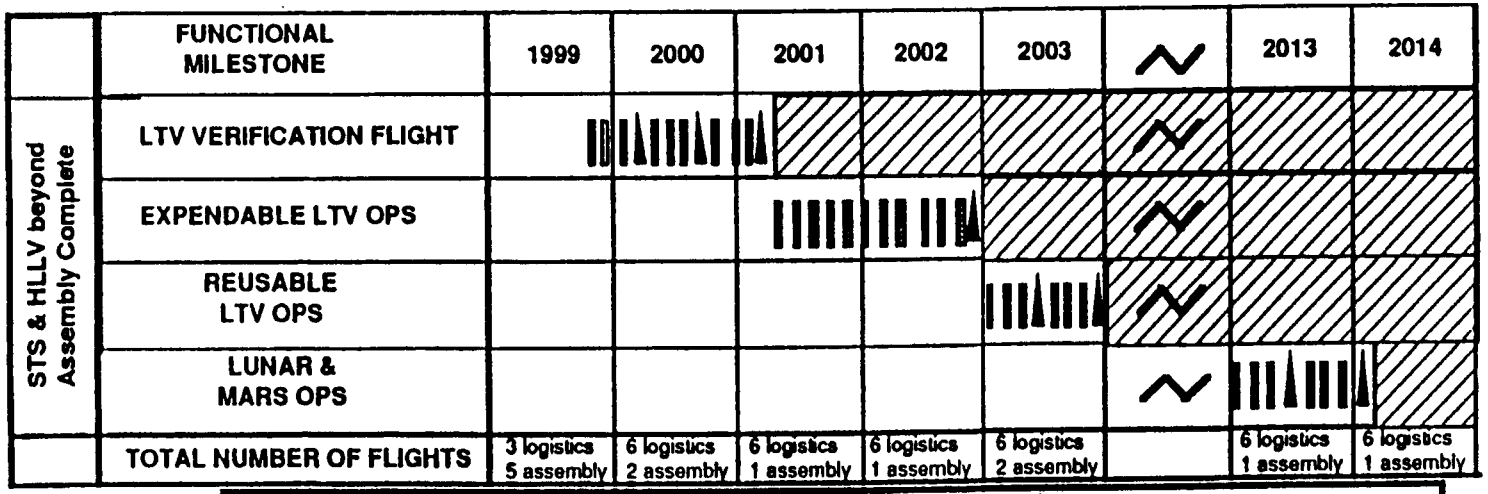


# OPTION 5 - PACED DEPLOYMENT OPTION
## BUILDUP MANIFEST

### Shuttle-only buildup to LTV Verification Flight configuration




### Accelerated buildup beyond Assembly Complete using HLLV



# OPTION 5 - PACED DEPLOYMENT OPTION
## MAJOR ISSUES

- Implementation has potential schedule risk
  - •• Baseline SSF schedule of AC in 1999 is very aggressive
  - •• Use of Shuttle only for buildup to LTV verification flight requires very high flight rates (up to 9 per year)
  - •• Use of HLLV required for buildup to LTV verification flight to provide schedule contingency

# Technology Needs Assessment

## Preliminary Technology Assessment Review

Top level technology needs have been identified and are shown below. In general, these needs were found to be common to both the LEO node function and the R&D growth evolution station with differences between the two primarily in the "magnitude" of the system or the operational function the need supports.

From an Earth orbital node view point, it was found that the technology drivers identified in this study were relatively insensitive to the particular case study under analysis. The following discussion will apply to all of the case studies' technology drivers unless there was some issue unique to a particular case. Generally, the only major differences in the technology drivers for the case studies were in the particular need dates. That is, the technology readiness requirements were keyed to the particular case study's program schedule.

With the exception of the Mars Expedition Case Study, all of the missions analyzed in the report included multiple missions with varying degrees of reusable mission elements. The Heavy Lift Launch Vehicles (HLLVs) assumed in the studies, were not capable of delivering fully assembled Mars space transfer vehicles to LEO, and the large aerocapture systems used extensively on the Mars transfer vehicles exceeded the payload volume envelopes. Therefore, the HLLV's payload mass and volume constraints drove the requirement for an on-orbit assembly function at the node while the need to service the reusable flight hardware drove the requirement for an on-orbit processing capability.

To accommodate on-orbit assembly at the LEO node, the capability to assemble, handle and mate/demate very large, very heavy and complex space vehicles will be required. A high degree of confidence and reliability must be demonstrated and assembly operations must be conducted with minimum risks and minimum IVA/EVA crew involvement. For the planetary space vehicles (aeroshells, spacecraft, space propulsion systems) and any reusable elements/injection stages, the on-orbit technology program must address handling, assembly and mating techniques using large capacity, highly articulated manipulators and telerobotic/teleoperated aids. The success of providing this capability depends upon major technological advances in the areas of Automation and Robotics, Autonomous Rendezvous and Docking, and control of large structures. Most of the issues mentioned have appeared to be adequately covered in the OAST Pathfinder Program but the need dates and funding levels need to be further evaluated.

A commitment to provide an extensive LEO node on-orbit assembly and vehicle processing capability will require considerable future study effort. However, two important factors will undoubtedly influence the decision to provide this capability. These are the specific mission designs, and the performance characteristics of earth-to-orbit (ETO) launch systems.

The on-orbit vehicle processing function, while requiring many of the attributes needed by the orbital assembly function, i.e., handling, mating, manipulating large and massive mission elements in space, must also be capable of integrating, testing, and the subsequent end-to-end checkout of any and all elements of the space vehicle. To accomplish on-orbit what has traditionally been done utilizing ground based facilities will require a whole new set of in-space operational philosophies, procedures and support equipments - especially where manned systems are involved. From a technology needs standpoint, the orbital test programs for this function (which is yet to be addressed in any of the case studies) must focus on the development and implementation of advanced systems capable of performing automated checkout and systems status interrogations on each element as processed, and on the final flight configuration. In addition to

## Preliminary Technology Assessment Review (continued)

the integration and checkout functions, the capability to service, maintain and refurbish all reusable flight hardware elements must be developed.

The successful implementation of the case studies described in OEXP SRD depend on efficiently managing cryogenic fluids in space. From the orbital node viewpoint, the capability to handle, transfer and manage large quantities of cryogenic propellents in space for long periods of time must be developed and demonstrated, on-orbit, before these missions can seriously be considered. The facilities and techniques required to transfer the propellents from tank-to-tank, tank-to-vehicle with minimum boiloff and contamination in and around the LEO node must be available early in the programs.

Autonomous Rendezvous and Docking is another key technology driver in implementing the proposed case study missions. Space based systems must be developed that are capable of autonomous rendezvous and docking with very large, very heavy and passive vehicles such as ELV's, mission vehicles and reusable transfer vehicles and injection stages. The system must be capable of stabilizing and maintaining control of these mission elements for subsequent handoff and transfer to the station, node and/or co-orbiting facilities with a high degree of accuracy. This capability must further be incorporated into an OMV-type system specifically tailored to handle large masses with adequate control authority to deliver and retrieve mission elements to and from staging orbits. This capability is an enabling technology for the lunar and Mars cases where there is extensive use of unmanned cargo/propellant vehicles in the low lunar orbit and Mars orbits.

The introduction of Nuclear Propulsion cargo vehicles will introduce some challenges to LEO node system definition that are more operational than they are technological. The projected orbital operations, which include the Nuclear vehicle assembly, processing, fueling, cargo loading and periodic refurbishment/changeout of its thrusters, must be accomplished with minimum risks to the crew and the LEO node systems. Procedures and techniques must be developed that will insure safe systems operations that will undoubtedly be conducted in a "nuclear safe" orbit and primarily by remote, telerobotic methods.

## ORBITAL NODE TOP LEVEL TECHNOLOGY AREAS/ISSUES

- In-space vehicle processing/refurbishment
  - A&R /telerobotic techniques and aids
  - Automated systems test and check-out
  - Fault tolerant systems
  - In-space servicing/deservicing and check-out of "wet" systems (hypergols)
  - Processing and handling of nuclear stages/power sources
- In-space assembly/construction
  - Assembly of large aeroshells
  - Assembly of large space transfer vehicles
  - Joining of large structural elements (hangers, propellant storage facilities, etc)
  - Automation/telerobotic principles (precision positioning/handling)
- Cryogenic fluid management and transfer
- Autonomous rendezvous and docking

# Summary

# Issues

- o Significant augmentations to SSF are required to support Lunar/Mars Initiative
- o SSF design must allow power growth to 175 kW average with AC/DC distribution
- o Active thermal control system must be capable of providing heat rejection commensurate with 175 kW power generation
- o SSF-based EVA with advanced suits is required for SSF augmentation and vehicle processing
- o Biomedical Monitoring and Countermeasures (BMAC)/Extended Duration Crew Operations (EDCO) is required (beginning at PMC) to reduce STS flights for crew rotation
- o H2/O2 propulsion is required by SSF to reduce logistics requirements and external contamination
- o Allocation of SSF resources including crew, power, pressurized volume, and attached payload accommodation equipment (APAE) must consider other "non-exploration" users/experimenters
- o Impacts on international/congressional commitments must be addressed

# Summary

- o Space Station is capable of evolving to meet requirements of the Lunar/Mars Initiative
  - Augmentation to the SSF program required
  - Requires scar implementation to rephased program
- o Total SSF implementation/cost is relatively insensitive to different options
  - Same augmentation required for range of options considered
  - Lunar/Mars Initiative milestones drive time-phasing of SSF cost
- o Vigorous/early exploration milestones will lead to requirement for accelerated assembly of Space Station Freedom
- o Very high SSF-dedicated STS flight rate or HLLV is required for SSF augmentation to LTV verification flight configuration (in addition to ongoing STS logistics flights)

## SRD Specified Mars Evolution Case Study Space Station Freedom Requirements

- Provide capability to support advanced development systems for Mars base and space transportation.
- Provide capability for housing transient mission crew, support crew, and mission equipment.

| | |
|---|---|
| - Transient mission crew: | Up to 2016 support mission crew of 5<br>Beginning in 2016 and beyond support mission crew of 7 |
| - Mission support crew: | Accommodate a support crew of 6, for up to 15 months, with 6 month tours of duty |
| - Mission equipment: | Up to 2014 accommodate TBD metric tons of cargo<br>Beginning in 2014 and beyond accommodate 10 metric tons of cargo |

- No vehicle accommodation requirements
- Provide isolation of outbound mission crew and quarantine of Mars crews and samples returning from first 2 missions.

# Servicing Capability for the Evolutionary Space Station

## GSFC Work Package 3

## Servicing
## Contract NAS5-30363

George Alcorn/GSFC
(301) 286-2463
Jim Corbo/MDSSC-ES
Deborah Martin/MDSSC-ES
Lenny Levin/MDSSC-ES
(301) 464-7400
7 February 1990

# Introduction

User servicing for Space Station Freedom(SSF) will span an evolutionary period paralleling that of the station's growth plan. This will include a baseline servicing configuration followed by a final growth phase in which all user servicing requirements are satisfied. Although the basic requirements for user servicing are not station configuration dependent, the emphasis placed on different aspects of servicing may change with the eventual SSF growth objectives.

This paper will discuss the servicing requirements and how they will be satisfied by Freedom baseline and growth capabilities. The accommodation of the growth servicing elements will be addressed, including the required hooks and scars to implement these growth servicing capabilities.

# Overview

- User Servicing Definitions
- User Servicing Requirements
- Servicing Architecture Configuration
- User Servicing Capabilities
- Accommodation of Growth Elements
- Space Station Freedom Evolutionary Growth Options
- Servicing Evolutionary Studies
- Conclusions
- "Rephased Baseline" Changes to User Servicing
- "Rephased Baseline" Changes to Space Station Freedom
- "Rephased Baseline" Conclusions
- Acronyms

# User Servicing Definitions

The terms used to describe user servicing have been defined to ensure consistency in their meaning and to limit their scope. The definitions given represent basic servicing activities which may be combined to describe a complete servicing operation. For example, servicing an Orbital Replaceable Unit (ORU) consists of several activities, such as transfer, disassembly, replacement, assembly, and check-out. A detailed description of user servicing definitions and implementation is presented in the Servicing System Implementation Definition Document, SSP 30501. The activities covered by user servicing include those performed in the external, unpressurized areas of the Space Station Freedom (SSF) and are limited to user hardware.

# User Servicing Definitions

| | |
|---|---|
| Assembly - | Payload integration, checkout, assembly, and disassembly |
| Restore - | Inspection, replacement/repair, test, and calibration |
| Storage - | Unpressurized with thermal and contamination protection |
| Transportation - | Retrieve, deploy, and boost to operational orbit |
| Transfer - | Payload, ORU, and free-flyer relocation on the external structure of the SSF |
| Replenishment - | User expended fluids, waste removal, harvesting products and raw product resupply |

# User Servicing Requirements

With the increased capabilities provided by a permanently manned space station and the presence of complex user hardware, it is necessary to plan for the servicing of this hardware. A complete assessment of servicing requirements for planned attached payloads, free-flyers, and co-orbiting platforms has been performed to ensure all user servicing needs will be satisfied by the user servicing system. The availability of user servicing capabilities are planned to parallel the increasing complexity of user hardware. This will ensure adequate growth servicing capabilities will be in place when required by users.

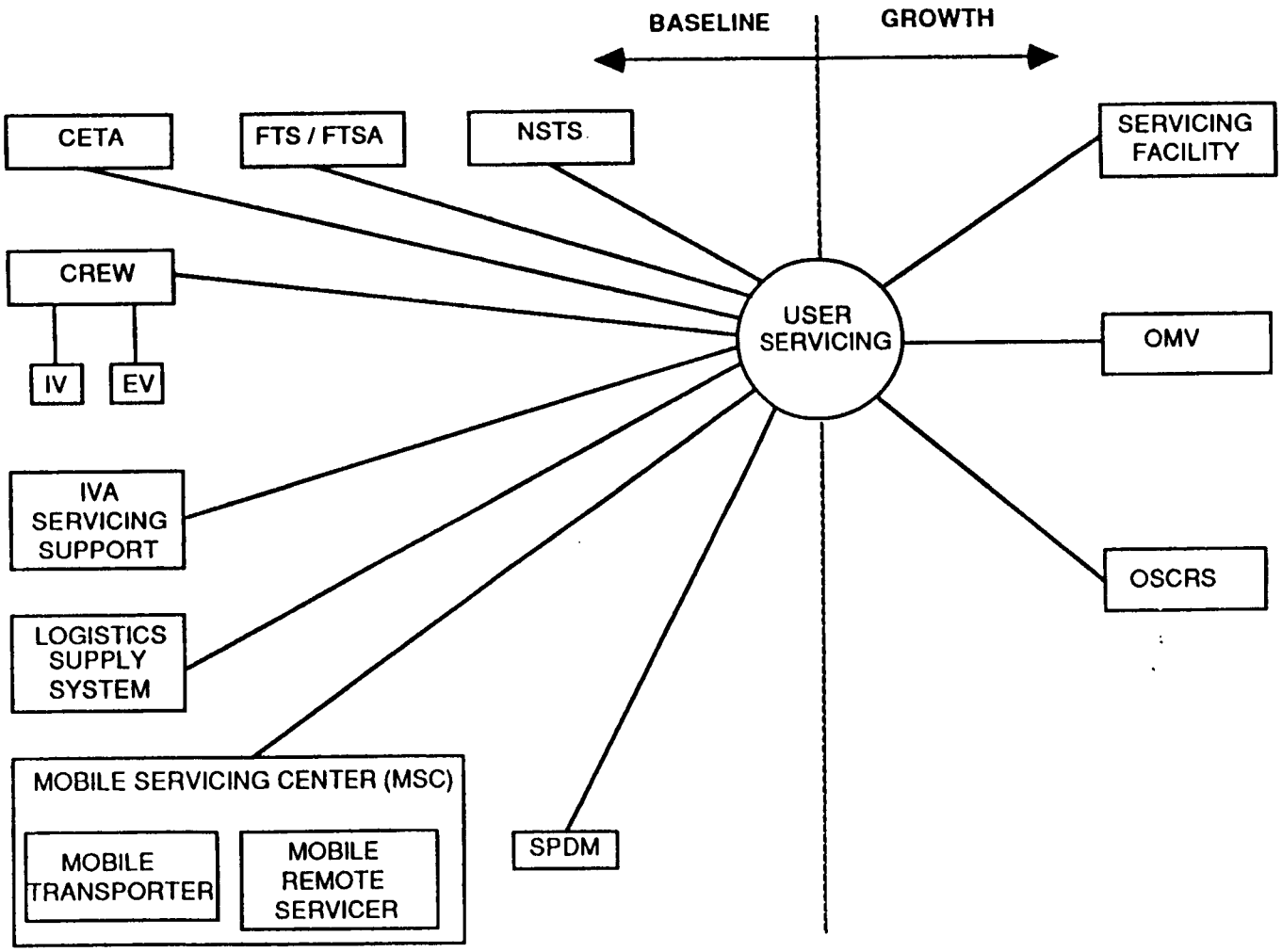
# User Servicing Requirements

- User servicing requirements are derived from the necessity to service user hardware planned for the baseline and growth phases of SSF
- Assessment of user hardware included:
  - Attached Payloads
  - Free Flyers, including the Man Tended Free-Flyer (MTFF/ESA)
  - Co-orbiting Platforms
  - Free-Flyers and Co-orbiting Platforms in-situ servicing
- Assessment of user schedules to ensure availability of servicing capabilities
  - Limited servicing available to early attached payloads
  - Growth of capabilities to support complex servicing of attached payloads, Free-Flyers, and Co-orbiting Platforms

# Servicing Architecture Configuration

The Servicing Architecture depicts the Freedom elements utilized for user servicing. The baseline user servicing system is made up of existing station and NSTS program elements. In addition, the figure illustrates those elements in the baseline and those elements which will be added in the growth phase. SSF elements will be used in conjunction with each other to accomplish a servicing activity.

# Servicing Architecture Configuration



# User Servicing Capabilities

User servicing capabilities are divided into two phases that parallel the evolution of Freedom. In the baseline configuration servicing elements will be shared by many systems on the station. These elements will provide basic servicing capabilities which include the transport and transfer of user hardware, the manipulation of equipment, access to SSF power and data resources, and the ability to monitor and inspect user hardware. During the station growth phase servicing unique elements will be added to complement the baseline elements. The growth elements will provide controlled storage, thermal control, and fluid replenishment, thus completing the servicing system.

# User Servicing Capabilities

- Baseline Servicing Capabilities provides the following
  - Transfer
  - Manipulate Equipment
  - Access to SSF power and data resources
  - Monitor/Inspect
  - Temporary handling site
- Growth Servicing Capabilities add the following
  - Controlled storage
  - Thermal control
  - Fluid replenishment

# Baseline Servicing Capabilities

A matrix was developed to assess Freedom's ability to satisfy required user servicing capabilities. The capabilities listed were derived from user servicing requirements. A check mark was used to indicate where a support element provided a required capability. Since no baseline support elements provide the capability for controlled storage, thermal control, contamination control, and fluid replenishment, SSF provides only limited user servicing. Furthermore, the lack of a transport capability does not provide the ability to service free-flyers and co-orbiting platforms. Therefore, baseline capabilities will only support limited servicing of attached payloads.

# Baseline Servicing Capabilities

- Baseline user servicing capabilities will support limited servicing of attached payloads at their operational site or at a temporary locally adjacent site

| Required User Servicing Capabilities | BASELINE SERVICING ELEMENTS | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | CREW | | LSS* | | |
| | FTS | CETA | IVA | EVA | ULC | MSC | SPDM |
| Transfer | | ✓ | | ✓ | | ✓ | |
| Transport | | | | | | | |
| Manipulate Equipment | ✓ | | | ✓ | | ✓ | ✓ |
| Controlled Storage | | | | | | | |
| Power & Data Resources | | | | | | ✓ | |
| Thermal Control | | | | | | | |
| Contamination Control | | | | | | | |
| Fluid Replenishment | | | | | | | |
| Monitor/Inspect | ✓ | | ✓ | ✓ | | ✓ | ✓ |
| Temporary Handling Site | | ✓ | | | ✓ | ✓ | |

* Internal pressurized storage not included in this document

Note: Transport to the SSF not shown in this table, capability provided by NSTS

# Growth Servicing Elements

Growth of the user servicing system will add SSF elements to support user servicing. These elements are the Customer Servicing Facility (CSF), the Orbital Spacecraft Consumables Resupply System (OSCRS), and the Orbital Maneuvering Vehicle (OMV).

# Growth Servicing Elements

- Customer Servicing Facility (CSF)
- Orbital Maneuvering Vehicle (OMV)
- Orbital Spacecraft Consumables Resupply System (OSCRS)

# Growth Servicing Capabilities

The growth elements were added to the baseline capabilities matrix in order to evaluate the total SSF servicing capabilities. An examination of this matrix illustrates that all required servicing capabilities are provided by one or more of the support elements. Therefore all known user servicing requirements are satisfied by the planned growth user servicing capabilities.

# Growth Servicing Capabilities

- All known user servicing requirements are satisfied by the planned growth user servicing capabilities

| Required User Servicing Capabilities | BASELINE SERVICING ELEMENTS | | | | | | | GROWTH ADDITIONS | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | CREW | | LSS* | | | | | |
| | FTS | CETA | IVA | EVA | ULC | MSC | SPDM | CSF | OMV | OSCRS |
| Transfer | | ✓ | | ✓ | | ✓ | | | | |
| Transport | | | | | | | | | ✓ | |
| Manipulate Equipment | ✓ | | | ✓ | | ✓ | ✓ | ✓ | | |
| Controlled Storage | | | | | | | | ✓ | | |
| Power & Data Resources | | | | | | ✓ | | ✓ | ✓ | |
| Thermal Control | | | | | | | | ✓ | | |
| Contamination Control | | | | | | | | ✓ | | |
| Fluid Replenishment | | | | | | | | ✓ | | ✓ |
| Monitor/Inspect | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| Temporary Handling Site | | ✓ | | | ✓ | ✓ | | ✓ | ✓ | |

* Internal pressurized storage not included in this document

Note: Transport to the SSF not shown in this table, capability provided by NSTS

# Full Servicing Capabilities

The transport capability provided by the addition of the growth element, the OMV, allows free-flyers and co-orbiting platforms to be brought to SSF for servicing. The additional growth elements, the CSF and OSCRS, provide the capabilities for controlled storage, thermal control, contamination control, and fluid replenishment. Therefore, growth capabilities will support complex servicing of attached payloads, free-flyers, and co-orbiting platforms.

# Full Servicing Capabilities

- Accommodates complex Attached Payload servicing
  - Thermal protection and contamination monitoring/control within an enclosed area
  - Complete functional checkout to verify successful completion of servicing activity
  - Fluid removal/resupply capability for user fluids (Cryogens, Gases, etc.)
  - Controlled storage for replacement hardware, tools, and support equipment
  - Dedicated hardware to support complex EVA and robotic servicing tasks

- Accommodates complex Free-Flyer and Co-orbiting Platform servicing
  - Transport between operational orbit and SSF
  - Berthing and holding fixtures to support servicing activity
  - Temporary storage and complete functional checkout
  - Thermal protection, and contamination monitoring and control
  - Power, thermal, data management, and communication interfaces
  - Long term storage of replacement hardware, service tools, and support equipment
  - Fluid removal/resupply ( Hydrazine, cryogens, gases, etc.)
  - Dedicated hardware to support complex EVA and robotic servicing tasks

# Accommodation of Growth Elements

The CSF provides the accommodation for the servicing, handling, and storage of the OMV and for the handling and storage of the OSCRS. The interface to freedom for the OMV and OSCRS is through the CSF. The CSF design results in a single interface between the SSF and all the growth servicing elements.

# Accommodation of Growth Elements

- All growth servicing elements are accommodated within the Customer Servicing Facility (CSF)
- CSF provides storage, servicing, checkout and access for utilization of the Orbital Maneuvering Vehicle and the Orbital Spacecraft Consumables Resupply System

# SSF Hook and Scar Requirements

The table shows the SSF distributed systems that require hooks and scars in order to accommodate the CSF. In addition to the distributed system scars, it is also necessary to reserve a location on the transverse boom to provide maximum operational flexibility in the use of the CSF.

# SSF Hook and Scar Requirements

- CSF interface to the SSF requires scars to the station's distributed systems and hooks into the Operations Management System during baseline
  - A SSF location scar for the CSF ensures the greatest operational flexibility

| SSF Distributed Systems | CSF Requirements | |
|---|---|---|
| | Scar | Hook |
| • Structural and Mechanical | S | H |
| • Electrical Power | S | H |
| • Thermal Control | S | H |
| • Fluid Management | S | H |
| • Data Management | S | H |
| • Communication & Tracking | S | H |
| • Crew Support | | H |

# SSF Evolutionary Growth Options

The final evolutionary path of the Space Station Freedom is yet to be determined. Both the Transportation Node and the Research and Development Station have been studied within the LaRC Evolutionary Working Group activity. Analysis of both designs has led to the conclusion that user servicing is an essential aspect of both evolutionary paths. The Research and Development evolutionary path will result in substantial user participation. This increased user participation will emphasize the requirements for user servicing. The Transportation Node evolutionary path will result in less user participation. However, the availability of Space Transfer Vehicles (STV) will allow greater access to free-flyer and co-orbiting platforms for servicing.

# SSF Evolutionary Growth Options

- Proposed evolutionary paths for SSF will not effect the types of servicing events required by station users
- Evolution is likely to influence the quantity and make-up of user servicing events
- As a result the station evolutionary path will determine the demand on servicing capabilities

# Servicing Evolutionary Studies

In addition to the work done to define the servicing system architecture (GE/TRW) some studies were performed to assess the evolutionary options of the servicing system and any impacts due to SSF evolution. These studies ranged from a CSF Relocation Assessment to an assessment of impacts on the user servicing system due to FTS evolution.

# Servicing Evolutionary Studies

- Servicing Facility Proposed Relocation Assessment
- Hook and Scar Requirements for Growth User Servicing
- OMV, A User Servicing Support Element
- Space Station Freedom User Servicing Capabilities
- Space Transfer Vehicle Accommodations Impact to User Servicing
- Alternate User Servicing Growth Options; Station Keeping
- Space Station Freedom Transportation Node Analysis: Impacts to User Servicing
- Free Flyer Launch and Servicing Schedules
- Servicing Capability for the Evolutionary Space Station
- FTS Capabilities in Support of Growth User Servicing
- FTS Hooks & Scars in Support of Growth User Servicing

# Selected Evolutionary Study Results

Each of these studies yielded conclusions and recommendations relative to their subject matter. Some of the conclusions reached are: do not relocate the CSF to the upper transverse boom; accommodating an STV on SSF will increase contamination potential, decrease the availability of servicing system elements, and limit direct viewing of both CSF proximity operations; evolving to a Transportation Node Space Station may necessitate relocating the CSF and will tie up many of the servicing elements.

# Selected Evolutionary Study Results

- Recommended against CSF relocation to the upper surface of the transverse boom
  - Interference with the radiator panels
  - Limited viewing of OMV/free-flyer proximity operations
- STV Accommodations adversely impact the User Servicing System
  - Increased contamination potential (due to refuelling operations)
  - Decreased availability of Servicing System elements (OMV, FTS, etc.)
  - Interferes with viewing of the CSF and CSF proximity operations
- Evolutionary growth to a Transportation Node affects the User Servicing System
  - STV provides greater range for accessing payloads for servicing
  - Module growth for a Transportation Node requires space used by the CSF
  - Servicing elements utilized for "Transportation" tasks are unavailable for other servicing activities

# Selected Evolutionary Study Results

Additional studies include an evaluation of an alternative option for user servicing system growth and assessing the FTS's capabilities along with the hooks and scars necessary to satisfy user servicing requirements.

The alternative space station growth option is one which may be useful for certain specific cases, such as, hazardous material handling, servicing oversize payloads, and servicing contamination sensitive equipment. The FTS studies concluded that the FTS's capabilities will satisfy growth user servicing requirements, as they are currently defined, however, neither the growth servicing requirements nor the FTS evolutionary capabilities are well defined.

# Selected Evolutionary Study Results

- Alternate Servicing System Growth Options are available for specific activities
  - Hazardous material handling
  - Payloads too large to service in the CSF
  - Reduced contamination potential (both to and from other SSF payloads/equipment)
- Flight Telerobotic Servicer will satisfy growth servicing requirements, as defined
  - Growth servicing requirements require better definition
  - FTS evolutionary capabilities also require better definition

# Conclusions

Regardless of the evolutionary path chosen, SSF will support users in the form of attached payloads, free-flyers, and co-orbiting platforms. These users will continue to require servicing as a part of this support. Therefore, Freedom evolution will not impact the need for a user servicing system.

The integration of existing and growth SSF support elements makes it possible to meet all known user servicing requirements. The design of the Customer Servicing Facility accommodates all the growth servicing elements in one facility. This in turn reduces the interface requirements for the growth servicing elements to a single interface into the SSF.

# Conclusions

- The need for user servicing is independent of station evolution
- All known user servicing requirements are satisfied by the planned growth user servicing capabilities
- The Customer Servicing Facility simplifies Freedom hook and scar requirements for user servicing evolution
  - CSF accommodates all other growth elements
  - This results in a single interface to Freedom for all growth elements

# "Rephased Baseline" Changes to User Servicing

The very existence of the user servicing system in the Space Station Freedom Program is uncertain – the most likely scenario is that it has been eliminated. The "Rephased Baseline" by Langley and the Configuration Budget Review proposed the elimination of user servicing and the deletion of all scarring and servicing accommodations for all phases of the program.

This results in the elimination of the CSF, thereby eliminating the thermal/contamination controlled environment, eliminating SSF accommodations for the OMV, and eliminating unpressurized storage for supplies and spares.

# "Rephased Baseline" Changes to User Servicing

- User servicing existence in SSF Program uncertain
  - GE contract for servicing terminated
  - GE subcontract with TRW for servicing architecture terminated
  - All servicing architecture work deleted from SSF Program
- Configuration Budget Review (CBR) proposed the following:
  - Deletion of all scarring for all phases of the SSF Program
  - Deletion of all servicing accommodations for all phases of SSF
  - Deletion of all provisions for storage and staging accommodations specified in the PDRD
    - CSF eliminated - no thermal/contamination protection from the environment
    - OMV storage eliminated - no Space Station Freedom accommodations for the OMV
    - Supplies and spares storage eliminated

# "Rephased Baseline" Changes to User Servicing

The total available EVA time has been drastically reduced with EVA only available while the shuttle is docked at the SSF. This EVA will be utilized primarily for SSF maintenance and relies upon the shuttle suits - not SS suits. The remaining time may be used for user servicing - but only on a contingency basis.

To accommodate this decrease in available EVA time the CBR has proposed robotics, specifically the FTS, as the primary method for payload servicing. However, recent robotics studies indicate that utilization of robotics to perform many high fidelity tasks takes longer than if performed by EVA. In addition, the payloads are required to be robot-friendly.

# "Rephased Baseline" Changes to User Servicing

- Total SSF EVA hours available drastically reduced
  - Space Station suits no longer planned for EVA
  - EVA for payloads performed on a contingency basis
- CBR proposed robotics (specifically the FTS) as the primary means of changing payloads
  - Payloads should be designed primarily for FTS handling
  - Recent studies indicate that high fidelity tasks, on average, take longer when performed robotically

# "Rephased Baseline" Conclusions

The existence of the user servicing system in the SSF Program may be eliminated, however, the requirements to service user hardware still exist. Relaxed contamination requirements cause a greater need for enclosed environment/contamination protection. The lack of storage space limits the capabilities of the user since it must find a way to accommodate supplies and spares. The lack of storage also precludes docking the OMV on SSF. The impacts of the "rephased baseline" result in a greater dependency on robotics and an elimination of EVA available to satisfy these requirements.

# "Rephased Baseline" Conclusions

- The scope of user servicing in SSF Program uncertain, however the requirements for servicing still exist
- Specific user requirements will not be met due to the impacts from the "rephased baseline"
  - Greater need for enclosed environment/contamination protection
  - Storage will not be available
  - Checkout capabilities will be limited
- Changes suggest utilization of robotics (specifically the FTS) to satisfy some of the major servicing requirements

# Acronyms

| | |
|---|---|
| APAE - | Attached Payload Accommodation Equipment |
| CBR - | Configuration Budget Review |
| CETA - | Crew and Equipment Translational Aid |
| CSF - | Customer Servicing Facility |
| EVA - | Extra-Vehicular Activity of a crew member |
| FTS - | Flight Telerobotics System |
| IVA - | Intra-Vehicular Activity of a crew member |
| MSC - | Mobile Servicing Center |
| MTFF/ESA - | Man Tended Free Flyer / European Space Agency |
| NSTS - | National Space Transportation System |
| OMV - | Orbital Maneuvering Vehicle |
| ORU - | Orbital Replacement Unit |
| OSCRS - | Orbital Spacecraft Consumables Resupply System |
| SPDM - | Special Purpose Dexterous Manipulator |
| SSF - | Space Station Freedom |
| STV - | Space Transfer Vehicle |
| ULC - | Unpressurized Logistics Carrier |

# EVOLUTIONARY SPACE STATION FLUIDS MANAGEMENT

STEVEN M. STEVENSON
ADVANCED SPACE ANALYSIS OFFICE
LEWIS RESEARCH CENTER

MARK W. LIGGETT
GENERAL DYNAMICS
SPACE SYSTEMS DIVISION

## INTRODUCTION

Current NASA planning activities foresee the Space Station as an orbiting facility for supporting the human exploration and mission-to-planet Earth initiatives, staging and servicing commercial and scientific satellites, and conducting a variety of on-board scientific and technology development activities. These activities will involve the accommodation and management of a diverse variety of propellants and other fluids at the Space Station. The impact on and requirements for accommodations of these missions by the evolutionary Space Station infrastructure must be understood, and the proper "hooks and scars" incorporated into the baseline design. A FY88 study, by General Dynamics Space Systems Corporation, has catalogued the projected R&D fluid needs and FY88 Office of Exploration (Code Z) case studies propellant requirements, examined preliminary fluid management concepts, and suggested means of accommodation and impacts to the Space Station. In FY89, an activity will be initiated to examine, more specifically and in-depth, the fluid management aspects of the on-orbit storage and transfer of large quantities of cryogenic propellants using the Space Station as a base of operations for these activities, required Space Station accommodations, and impacts to the Space Station infrastructure.

# INTRODUCTION

- SPACE STATION WILL SERVE AS A STAGING NODE FOR THE MANNED EXPLORATION INITIATIVES; CONSEQUENT HANDLING IMPLICATION OF LARGE QUANTITIES OF CRYOGENIC PROPELLANTS
- ADDITIONAL/ALTERNATIVE SPACE STATION UTILIZATION IMPOSES OTHER FLUIDS REQUIREMENTS
- IMPACT ON AND REQUIREMENTS FOR ACCOMMODATION OF THESE FLUIDS BY THE EVOLUTIONARY SPACE STATION INFRASTRUCTURE MUST BE DETERMINED
- OPTIMUM FLUID MANAGEMENT STRATEGIES TO MINIMIZE ADVERSE IMPACTS TO THE SPACE STATION AND PRODUCTIVITY MUST BE DETERMINED
- ANTICIPATE POTENTIAL SPACE STATION UTILIZATION AND FLUIDS NEEDS
  - IDENTIFY AND INCORPORATE "HOOKS AND SCARS" IN BASELINE PROGRAM
  - IDENTIFY NECESSARY TECHNOLOGIES

## OBJECTIVES

The objectives of this effort were to identify the types and quantities of fluids expected to be associated with Space Station Freedom during its evolutionary phase (growth beyond Phase I), the associated fluid management issues and requirements, concepts for accommodating these fluids at the Space Station, requirements imposed on the Space Station infrastructure (systems, subsystems, operations) and, in particular, the necessary scarring to be included in the baseline Space Station design so as to not preclude the potential future fluid management needs.

# OBJECTIVES OF 1989 EFFORT

- CONDUCT AN INVENTORY OF ALL FLUIDS EXPECTED TO BE ASSOCIATED WITH THE SPACE STATION DURING ITS INITIAL AND EVOLUTIONARY PHASES
- IDENTIFY FLUID MANAGEMENT REQUIREMENTS SUCH AS STORAGE, SUPPLY, TRANSFER, HANDLING, THERMAL, AND SAFETY ISSUES
- DEVELOP OPTIMAL FLUIDS MANAGEMENT STRATEGIES AND CONCEPTS FOR FLUIDS ACCOMMODATION THAT MINIMIZE IMPACTS TO SPACE STATION SYSTEMS AND ITS OPERATIONS
- IDENTIFY "HOOKS AND SCARS" TO BE INCORPORATED IN THE BASELINE DESIGN AND NEEDED FUTURE TECHNOLOGIES

## FLUID CATEGORIES

Five categories of potential fluids usage at the space station were identified. These were:

1. Research payloads including both attached to the space station and free flying. Fluids here include cryogenic helium for scientific instruments nitrogen for attitude control, hydrazine for propulsion, and rare gases for other sensors and instruments.

2. Propellants for unmanned planetary missions potentially utilizing the space station.

3. Space Transfer Vehicle (earth orbital applications) propellant requirements. The propellants are cryogenic hydrogen and oxygen for a space transfer vehicle (STV) to position payloads in geostationary orbit and other earth orbits.

4. Orbital Maneuvering Vehicle (OMV) propellant requirements. The OMV deploys, retrieves, and services payloads and utilizes, nitrogen, hydrazine (as a monopropellant), and hydrazine/nitrogen tetroxide (bi-propellant) for propellants.

5. Cryogenic hydrogen and oxygen and other fluids for the human exploration initiative.

# FLUID CATEGORIES

- RESEARCH AND DEVELOPMENT FLUIDS
- PLANETARY INITIATIVES PROPELLANT
- SPACE TRANSFER VEHICLE (STV) PROPELLANT
- ORBITAL MANEUVERING VEHICLE (OMV) PROPELLANT
- CODE Z MISSIONS PROPELLANT

## U.S. ATTACHED AND FREE-FLYING PAYLOADS

The research payloads for which the fluids requirements were determined consist of attached and free-flying payloads. The research facility names and acronyms, which are used on the next chart, are presented here.

# U.S. ATTACHED AND FREE-FLYING PAYLOADS (R&D FLUIDS)

## ATTACHED

1. ASTROMAG* - ASTROPHYSICS MAGNET FACILITY
2. DXS* - DIFFUSE X-RAY SPECTROMETER
3. LAMAR* - LARGE AREA MODULAR ARRAY
4. STO/SIG* - SOLAR TERRESTRIAL OBSERVATORY/SOLAR INSTRUMENT GROUP
5. STO/PIG* - SOLAR TERRESTRIAL OBSERVATORY/PLASMA INSTRUMENT GROUP

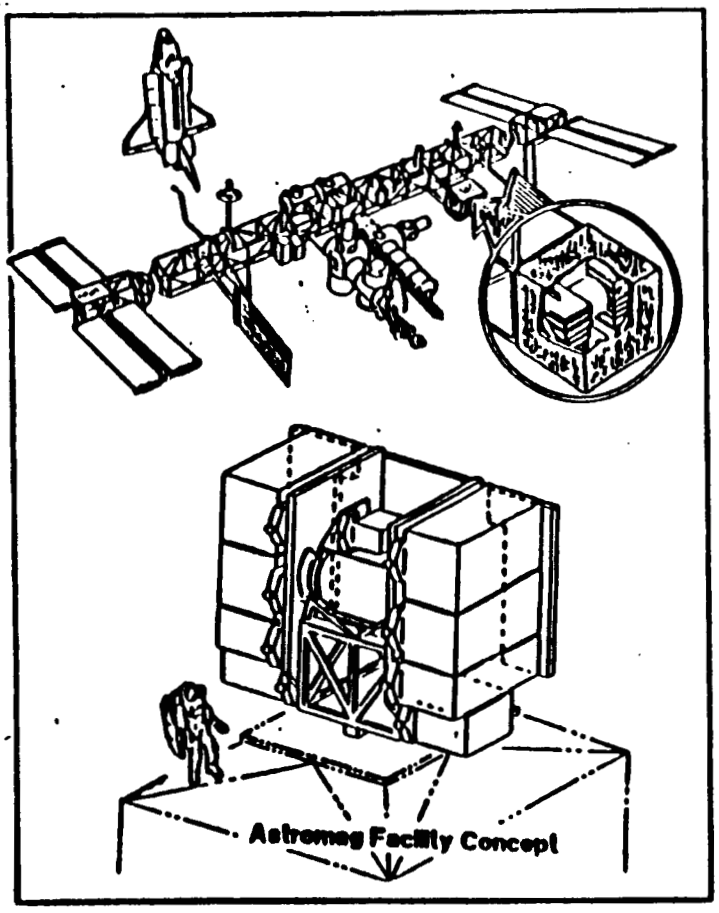
## FREE FLYERS

6. STO/SS - SOLAR TERRESTRIAL/SPACE STATION ATTACHED
7. ASAF - ADVANCED X-RAY ASTROPHYSICS FACILITY
8. GRO - GAMMA RAY OBSERVATORY
9. LDR - LARGE DEPLOYABLE REFLECTOR
10. SBAR - SPACE BASED ANTENNA RANGE
11. SIRTF - SPACE INFRARED TELESCOPE FACILITY
12. 3S - SPACE STATION SPARTAN
13. STO/POP - SOLAR TERRESTRIAL OBSERVATORY/POLAR ORBITING PLATFORM
14. XGP - EXPERIMENTAL GEO PLATFORM

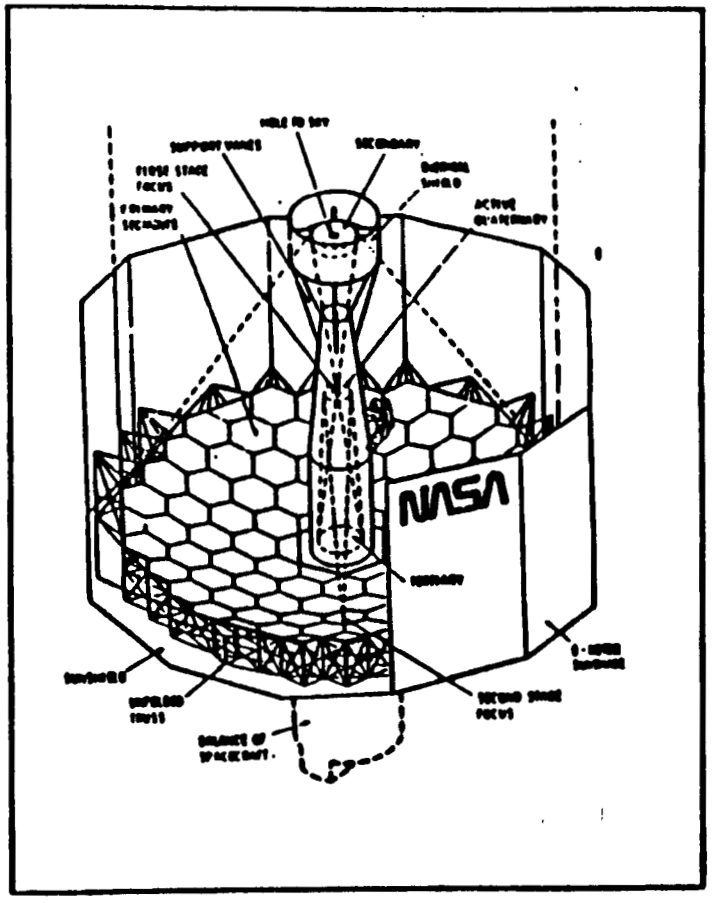
## EXAMPLE SPACE STATION RESEARCH PAYLOADS

Two of the research facilities requring fluids replenishment are the Particle Astrophysics Magnet Facility (ASTROMAG), an attached payload, tne the Large Deployable Reflector (LDR), which is a free-flyer. The ASTROMAG requires superfluid helium replenishment and possibly rare gas mixtures. The LDR also requires superfluid helium.

# EXAMPLE SPACE STATION RESEARCH PAYLOADS




Particle Astrophysics Magnet Facility (ASTROMAG)

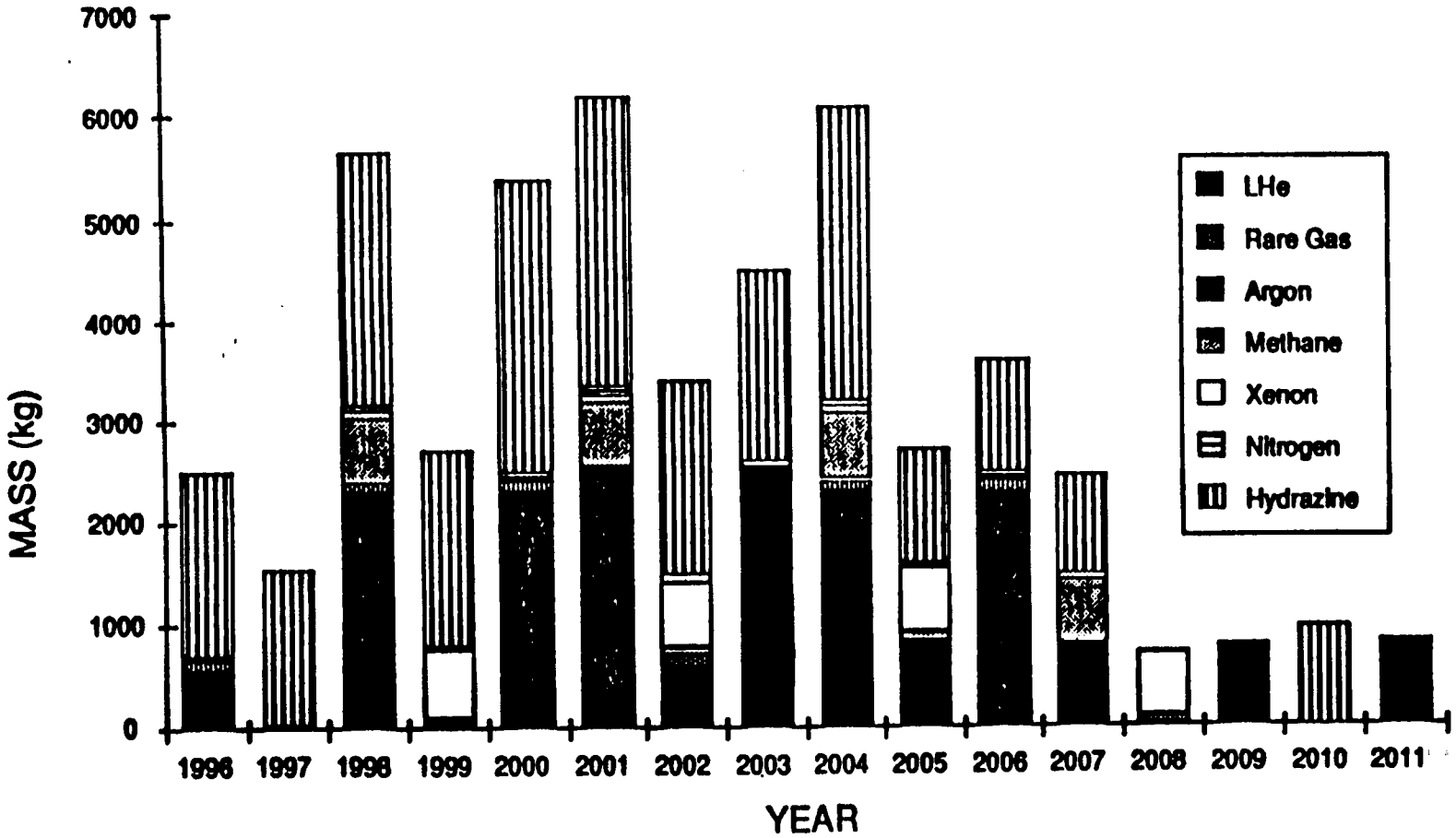



Large Deployable Reflector (LDR)

## U.S. RESEARCH PAYLOAD FLUID REQUIREMENTS COMPOSITION

The individual fluid types and amounts needed during each year to support the U.S. research payloads are graphically summarized on this chart. The international fluids needs, although not shown here, were estimated to be 30% of the U.S. requirements. The greatest demands are for hydrazine and helium, which comprise 49 and 37% of the fluid needs, respectively. The corresponding volume requirements of the fluids and a resupply schedule to meet the demand were also generated. At the time the data was generated, the space station was intended to be operational in 1996, hence the 1996 need date is shown on this and succeeding charts. The data would need to be adjusted for the current operational date.

# *US* EXPERIMENTAL PAYLOAD FLUID REQUIREMENTS COMPOSITION

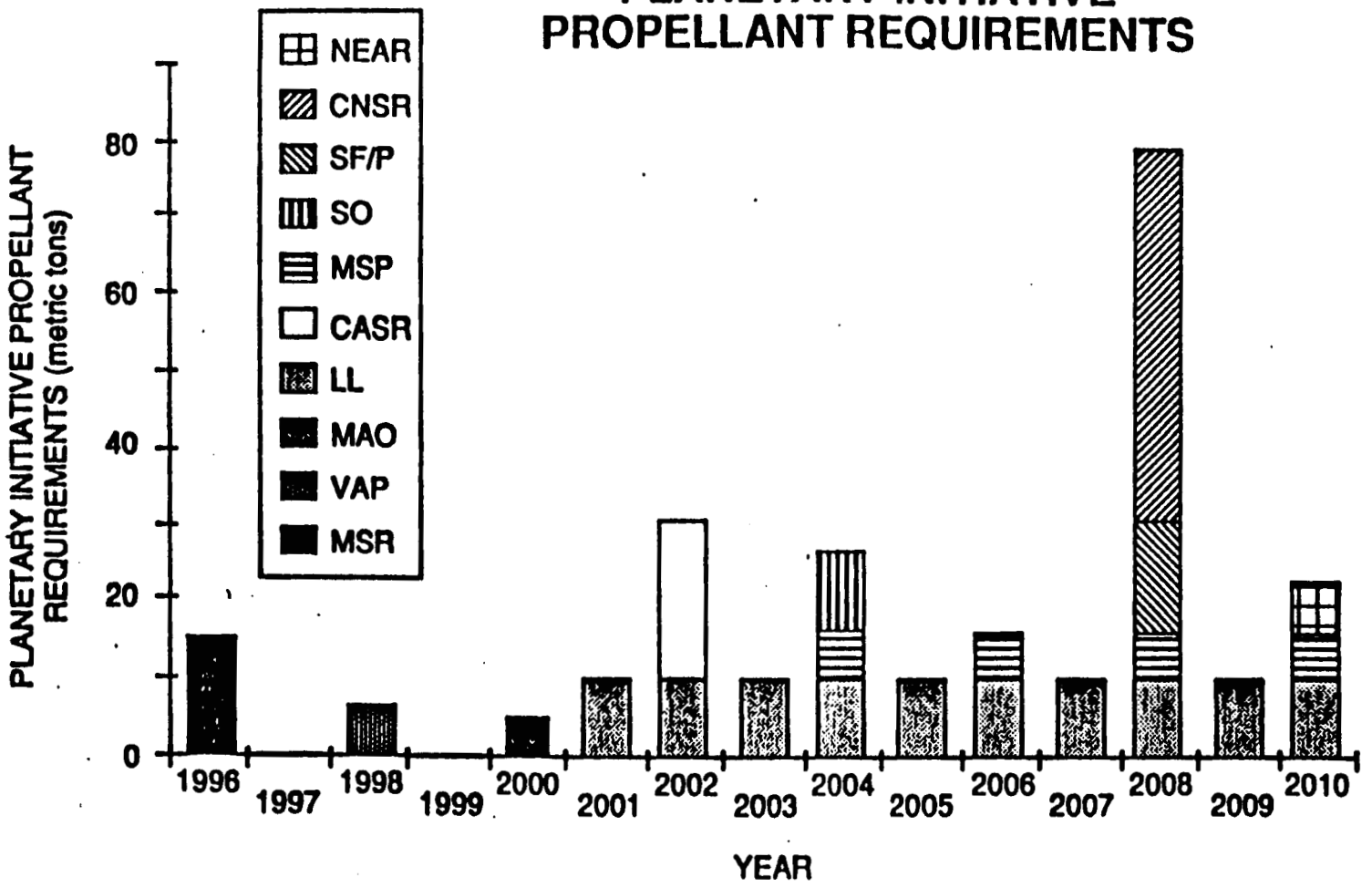


## PLANETARY MISSION PROPELLANT REQUIREMENTS

This chart shows the propellant (hydrogen and oxygen) requirements for the unmanned planetary missions (the third fluids category) that might potentially utilize the space station as a fueling and launch node. The acronyms are defined as follows:

| | |
|---|---|
| NEAR | Near-Earth Asteroid Rendezvous |
| CNSR | Comet Nucleus Sample Return |
| SF/P | Saturn Flyby/Probe |
| SO | Saturn Orbiter |
| MSP | Mars Surface Probe |
| CASR | Comet Atomized Sample Return |
| LL | Lunar Landers |
| MAO | Mars Aeronomy Orbiter |
| VAP | Venus Atmospheric Probe |
| MSR | Mars Sample Return |

# PLANETARY INITIATIVE PROPELLANT REQUIREMENTS



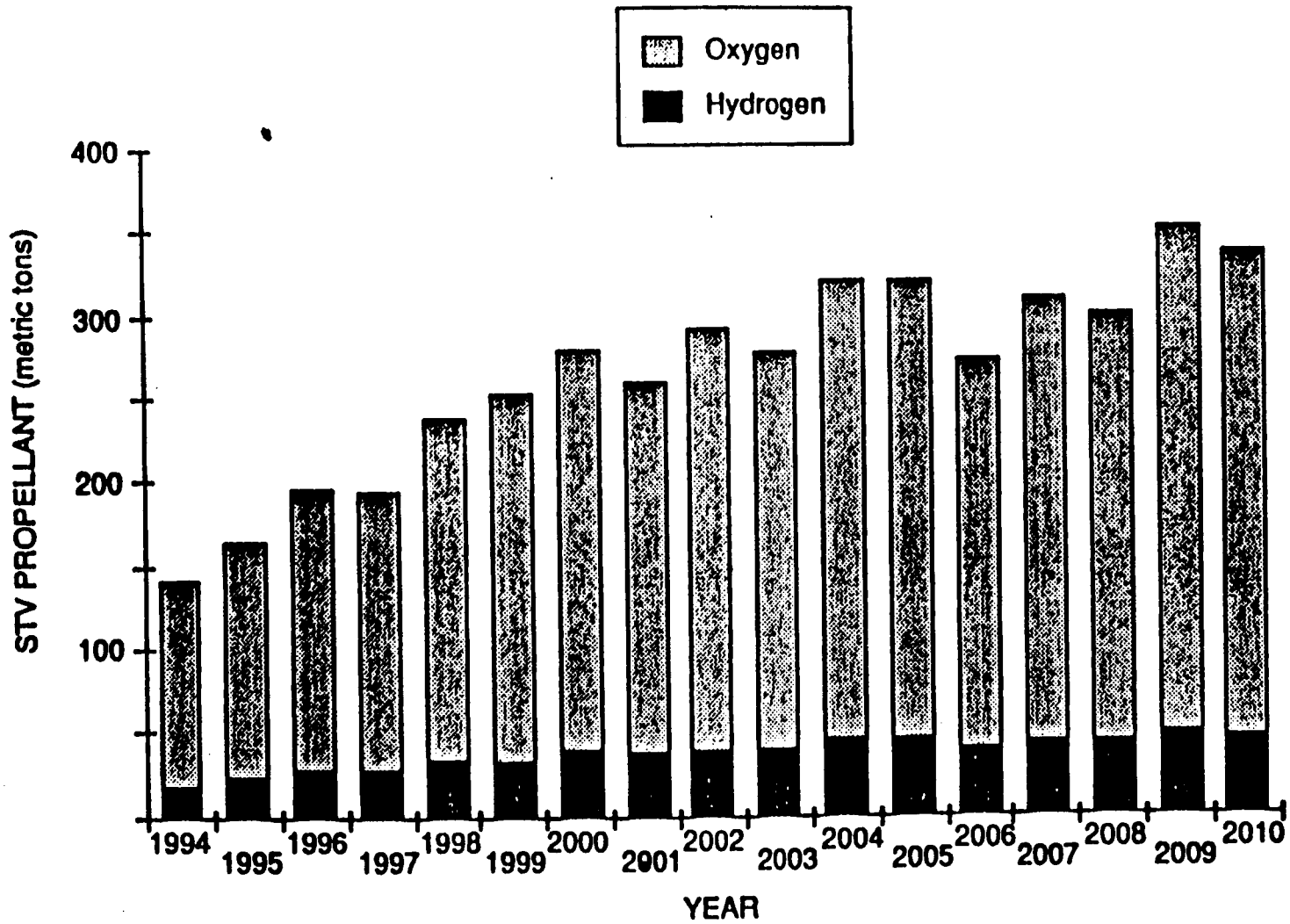

NOTE: This estimate of expendable STV propellant requirements comes from the "Space Station Transportation Interfaces", NASA, JSC, August 1988. It represents the augmented mission program recommended by the Solar System Exploration Committee of the NASA Advisory Council.

## SPACE TRANSFER VEHICLE PROPELLANT REQUIREMENTS

This chart shows the propellant requirements for the space transfer vehicle (STV). The STV will be used to retrieve and deliver payloads from the Space Station to higher energy orbits (e.g., geosynchronous). The propellant requirements for these missions are based upon NASA's Mission Model for the orbital transfer vehicle (OTV) (Revision 8) with all lunar and planetary missions removed. The STV reference configuration is the "synthesized" version. The propellants are liquid oxygen and hydrogen, burned at a 6:1 mass ratio. Although the STV model used in this study is larger than the current STV flight estimates, the addition of DOD missions and Mission-to-Planet-Earth geosynchronous fluid requirements will result in an increase in the STV propellant requirements.

Accounting for the Mission-to-Planet-Earth Polar Orbiting Platform (POP) servicing would require extra propellant storage at the Space Station. However, servicing from the Space Station is not currently planned because polar orbits are most efficiently accessed from the ground (minimum delta V and propellant requirements). Therefore, POP servicing from the Space Station was not considered in this study.

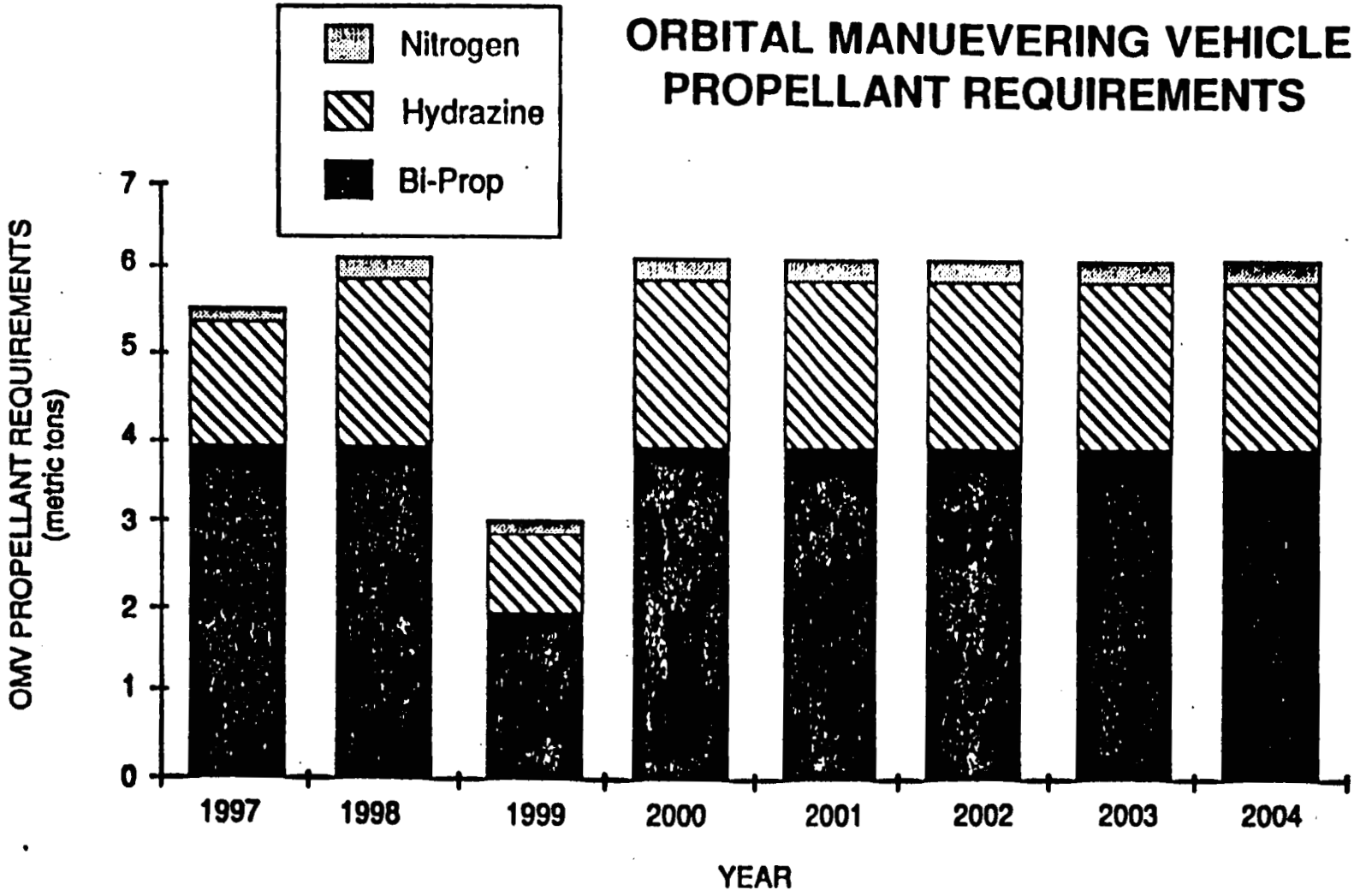
# STV (NON-PLANETARY) PROPELLANT REQUIREMENTS



## ORBITAL MANEUVERING VEHICLE (OMV) PROPELLANT REQUIREMENTS

The fourth fluid category requirements, orbital maneuvering vehicle propellants, are shown here. Even though the OMV is currently designed to be serviced from the Shuttle, basing an OMV at the Space Station is practical, efficient, and "assumed" by a number of studies to exist. Therefore, a Space Station-based OMV concept was assumed for the purposes of this study. The OMV requires hydrazine, bi-prop, and nitrogen. Free-flying experiments also require hydrazine, which also makes hydrazine storage at the SS desirable. The chart shows the amount of OMV propellants required to support the flights identified. Although the number of flights do not extend beyond 2004 and are probably fewer than would be realized, they provide a basis for the study of the impact upon Space Station fluid management requirements. The number of OMV flights will probably be significantly greater when Station operations, logistics using expendable launch vehicles, satellite servicing and proximity transportation is accounted for. Data for the fluid requirements of these types of missions is not currently available.

# ORBITAL MANUEVERING VEHICLE PROPELLANT REQUIREMENTS




NOTE: This estimate of OMV propellant requirements comes from the "Space Station Transportation Interfaces", NASA, JSC, August 1988.

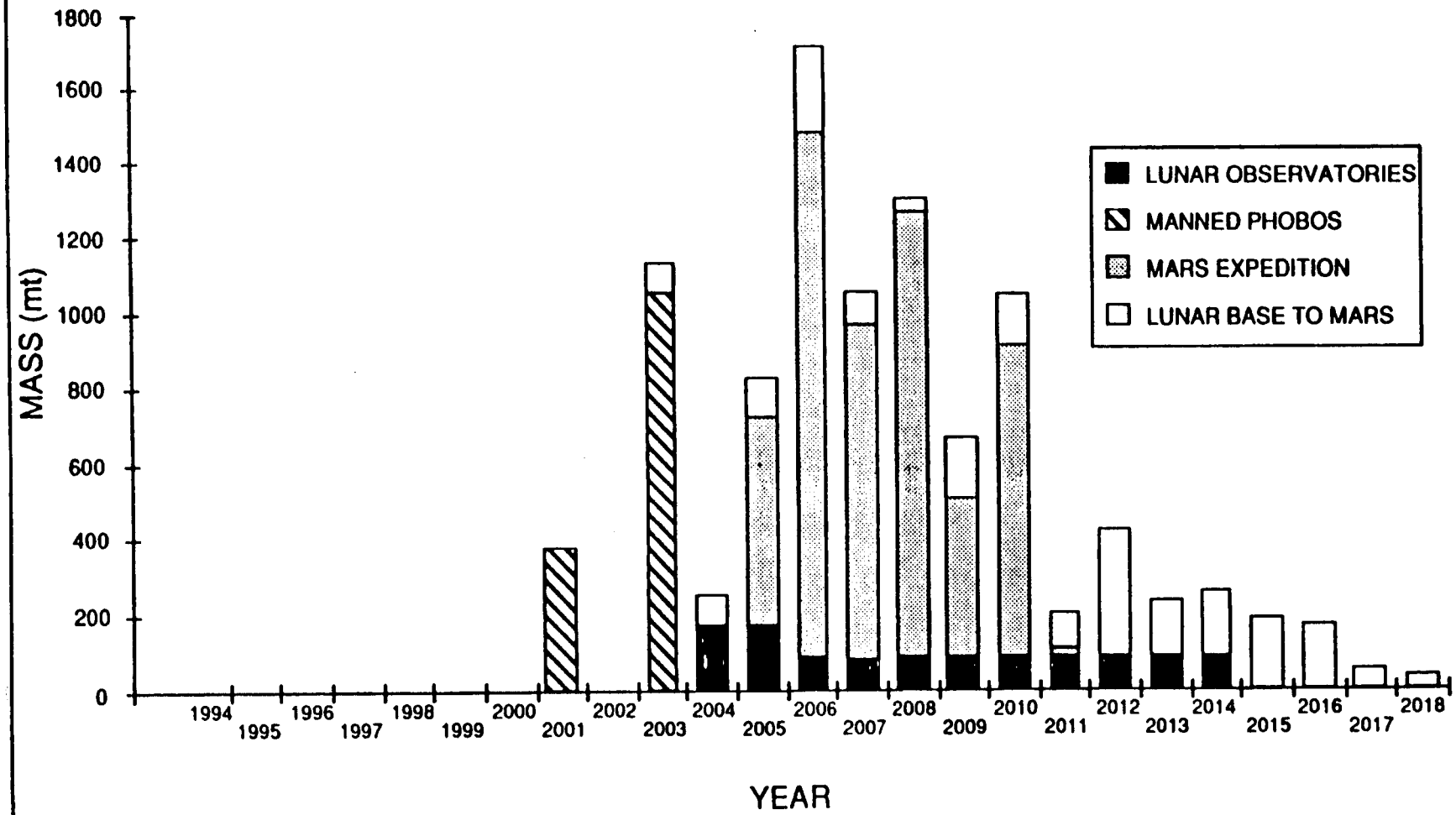
## CODE Z MISSION FLUID REQUIREMENTS

The Office of Exploration (Code Z) case studies are defined in the 1988 Code Z Annual Report (reference 2). This document identifies the propellant requirements for the Human Expedition to Phobos, Human Expeditions to Mars, Lunar Observatories and Lunar Outpost to Early Mars Evolution missions. The Space Station fluid support requirements are separated into four individual schedules, each one based upon a single Code Z missions, since it is very unlikely that two or more Code Z missions will be done concurrently.

The chart illustrates the relative propellant quantity and timephasing requirements of the individual Code Z missions. It is important to note that the propellant amounts for the individual missions within a given bar on the chart are not additive, but must be considered individually. Although some of the fluid requirements for the Code Z missions are needed at locations other than LEO (i.e., lunar vicinity), it is assumed that the fluids will "go through" the Space Station or a co-orbiting depot before reaching their final destination. It is clear from this comparison that Mars Expedition propellant requirements are the greatest of the Code Z mission propellant requirements.

Due to the large quantities involved, it is unlikely that any of the Code Z propellants will be stored at the Space Station (due to operations, safety, logistics, dynamics, and stationkeeping considerations), unless the primary purpose of the SS becomes that of a transportation node.

# CODE Z MISSION FLUID REQUIREMENTS - LEO TO DESTINATION



## RESEARCH FLUIDS CARRIER CONCEPTS

The transport and storage of approximately 470,000 liters (150,000 kg) of R&D fluids (Space Station Users) is required to meet growth model requirements through the year 2010. Carrier design concepts were developed that are representative of the type of tankage which could satisfy the required range of fluid types/quantities, for a scenario which requires the bulk delivery and storage of fluids (which all of the considered options require in growth configurations).

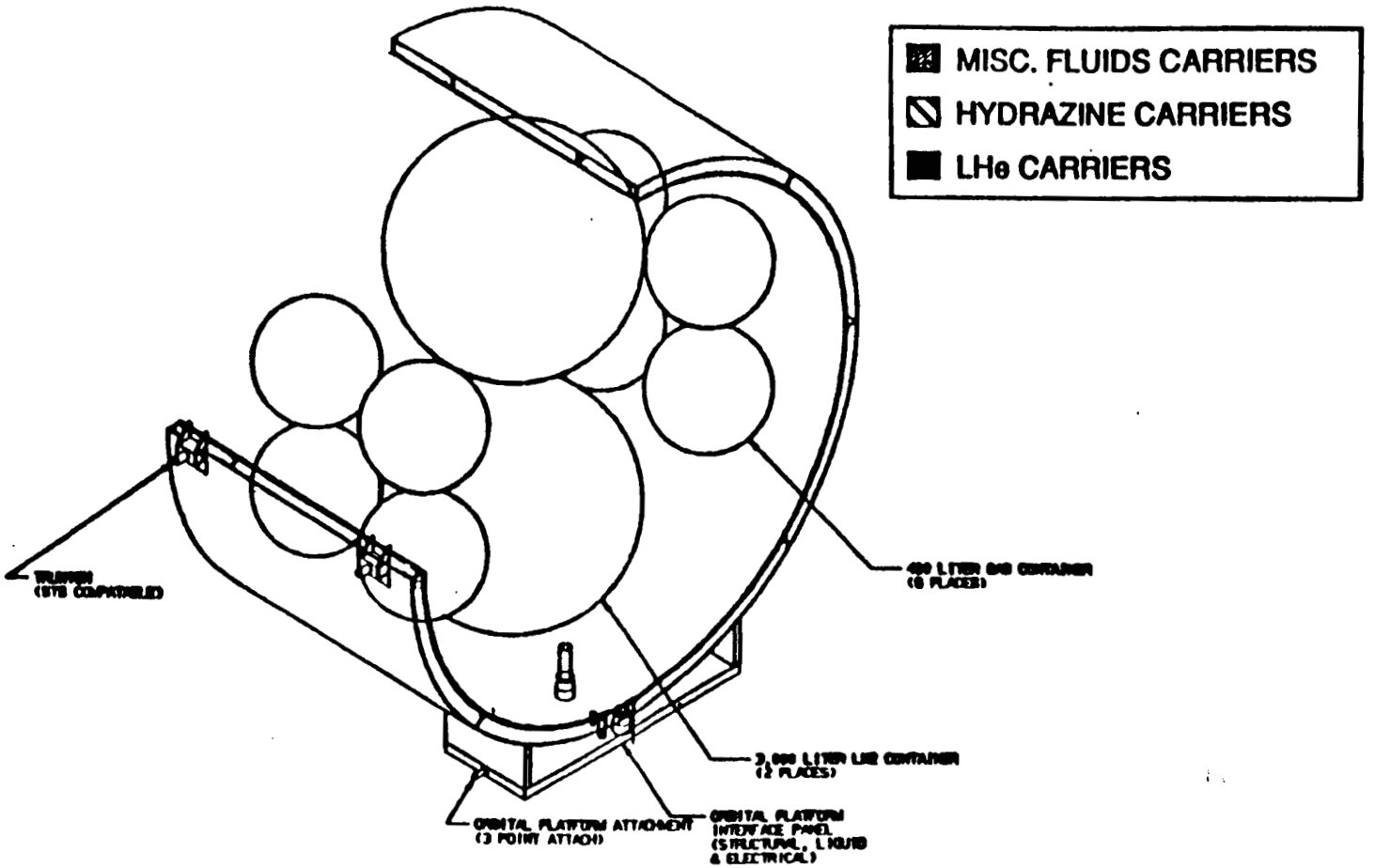
A modular conceptual design, such as the Miscellaneous Fluids Carrier shown on the chart, enables the delivered fluid quantity to be closely tailored to the requirements.

Nitrogen, argon, methane, xenon, and "rare" gas fluid requirements are satisfied by the Miscellaneous Fluids Carrier. This carrier consists of two liquid nitrogen spherical containers each with a capacity of 3,000 liters, and eight high pressure gas containers, each with a capacity of 400 liters.

The requirements for the gases (other than the nitrogen liquid) are so low that three foot diameter containers were selected for commonality and ease of handling and storage, and delivered volume of each is more than sufficient to provide the necessary fluids on orbit during a particular time period.

Since the masses and volumes of liquid helium and hydrazine far overshadow the amounts of the rest of the fluids combined, dedicated carrier concepts were formulated for those fluids, but are not shown here.

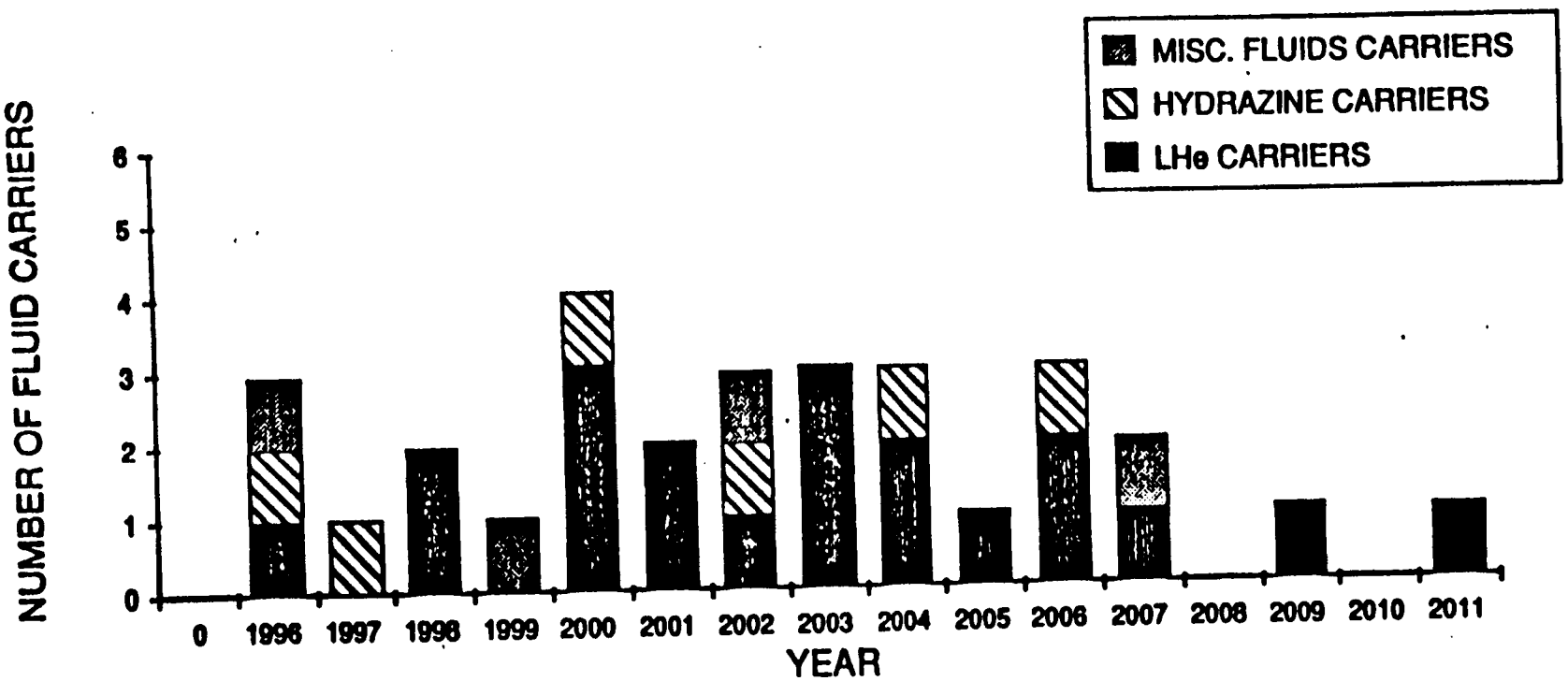
# MISCELLANEOUS FLUIDS CARRIER (2 @ 3,000 LITERS & 8 @ 400 LITERS)



## U.S. AND INTERNATIONAL RESEARCH FLUID CARRIER REQUIREMENTS

A fluids replenishing schedule was developed to match the yearly demand, and then the number of fluids carriers needed per year was determined. Requirements analyses indicate a total launch requirement of a total of 30 fluid carriers through the year 2011, at a rate of 1 to 4 carriers per year. The chart shows the number of fluid carriers required per year for the three different fluid carrier types.

# *US & INTERNATIONAL* EXPERIMENTAL FLUID CARRIER REQUIREMENTS



# GROWTH SS WITH INTEGRATED FLUID MANAGEMENT SUBSYSTEMS

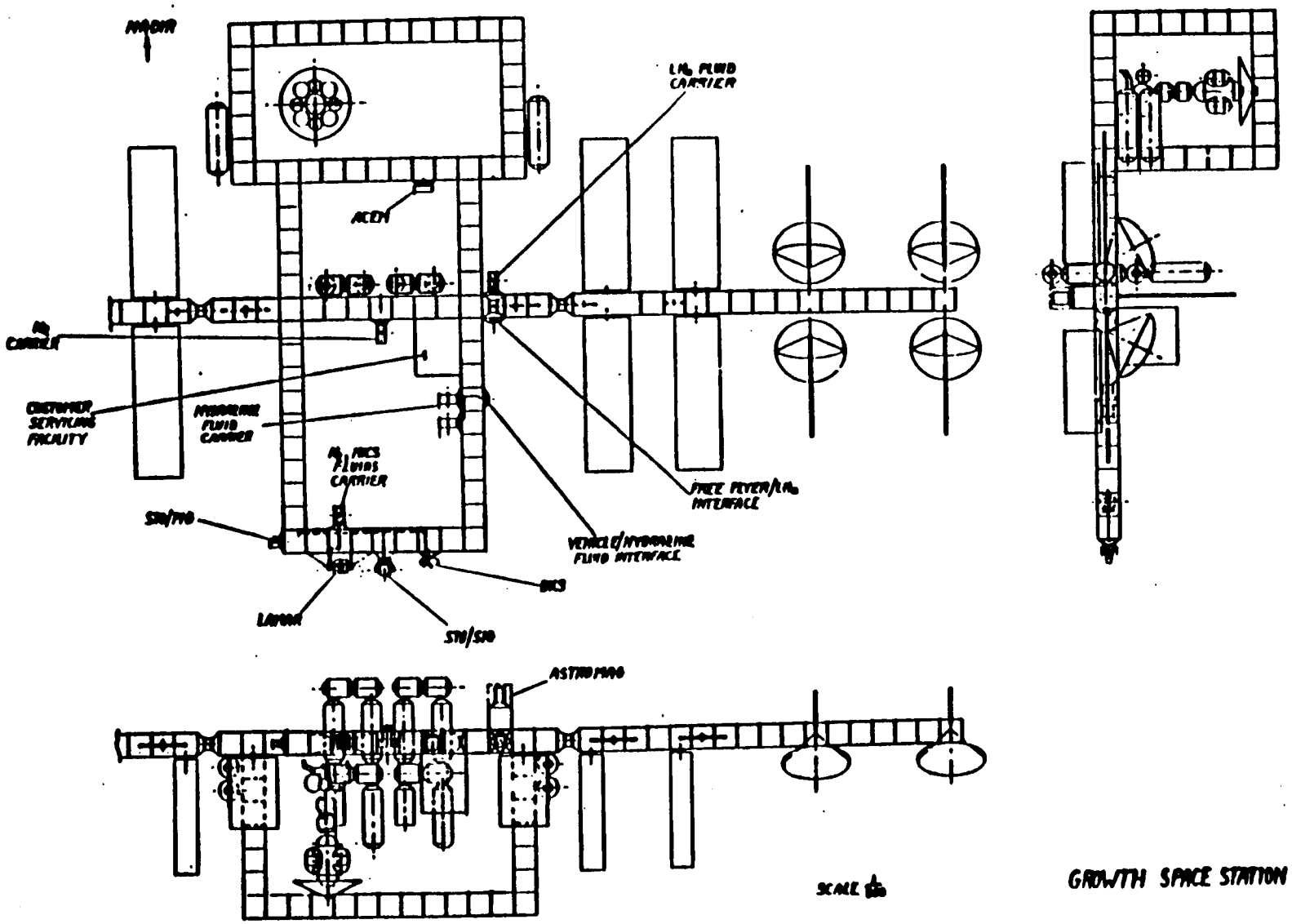
Attached Payloads

- LHe
  - Fluids carrier docked to LHe interface near ASTROMAG
  - Replenishment for each LHe user via "disconnectable" hard plumbed lines
- Gases
  - Hard plumbed lines/Integrated Fluid Susbsystem when justifiable
- Nitrogen
  - Recharge ORUs through disconnect at INS
  - Nitrogen fluid carrier supplements INS capability
  - Experimental Payload connected to INS when justifiable

Free Flying Payloads

- LHe
  - Experiment/vehicle docked at SS, refilled via fluids interface near ASTROMAG
- Hydrazine
  - Experiment/vehicle docked at SS, replenished via fluids interface near CSF (interface hard plumbed to Hydrazine fluids carrier)
- Nitrogen
  - Experiment/vehicle refilled via fluids interface at CSF (interface hard plumbed to the INS)

# GROWTH SS WITH INTEGRATED FLUID MANAGEMENT SUBSYSTEMS

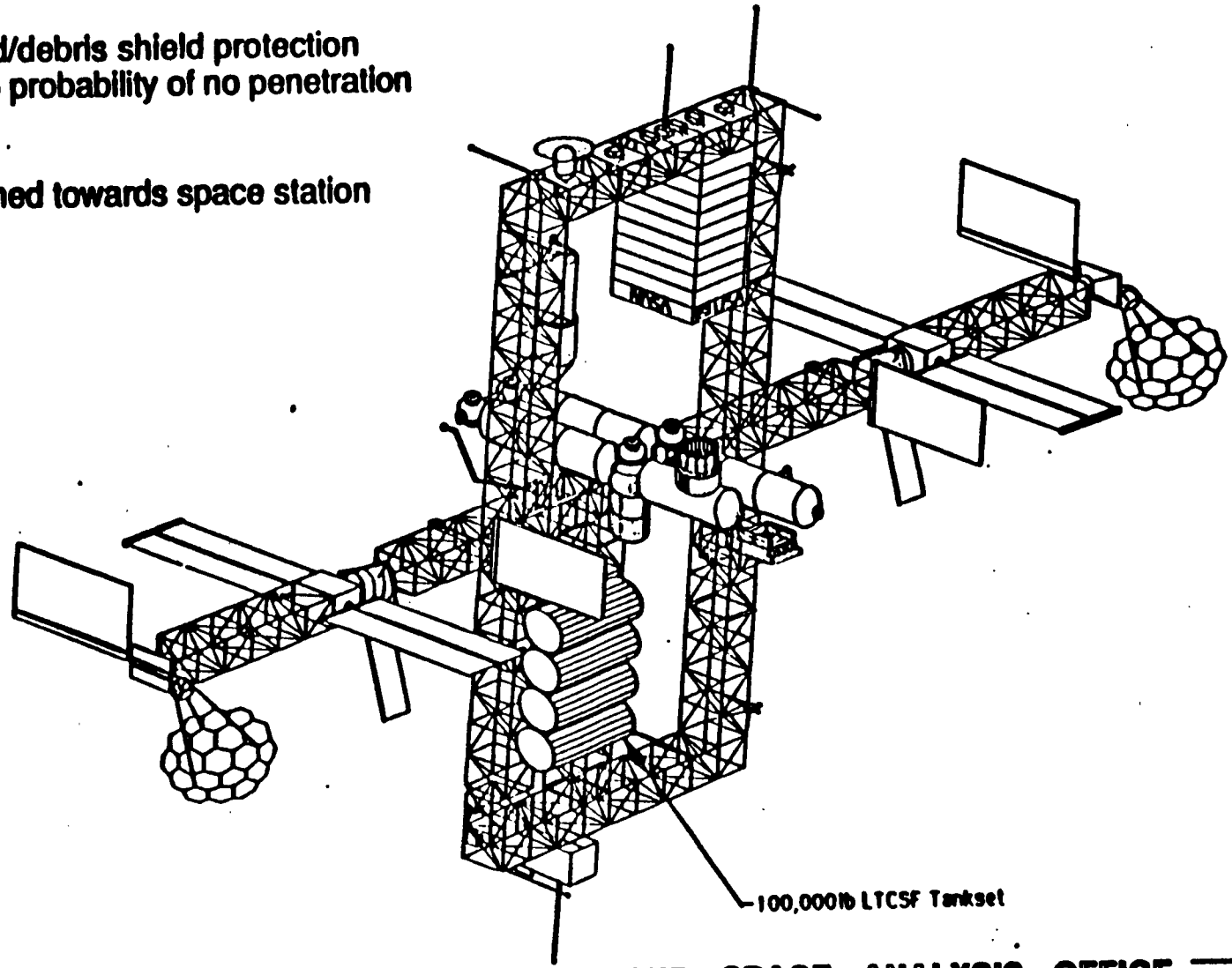


## CRYOGENIC PROPELLANT PROVISIONING APPROACHES

Large amounts of liquid oxygen and liquid hydrogen are required for the space transfer vehicle (STV) and human exploration initiatives. Concepts for managing these propellants include tank facilities attached to the space station and on co-orbiting platforms. General Dynamics, in an earlier contract for Marshall Space Flight Center (reference 3), developed a tankset concept for storing STV propellants. This tankset concept was used as the basic building block for the attached and co-orbiting propellant facilities shown on this and subsequent charts. This chart shows propellant tanks attached to the space station for propellant provisioning for the earth orbital and possibly lunar STV missions.

# STV PROPELLANT ACCOMODATIONS AT SPACE STATION (4 TANKS @ 100KLB EACH)

- Micrometeoroid/debris shield protection to provide .995 probability of no penetration over 10 years
- Protection aligned towards space station velocity vector



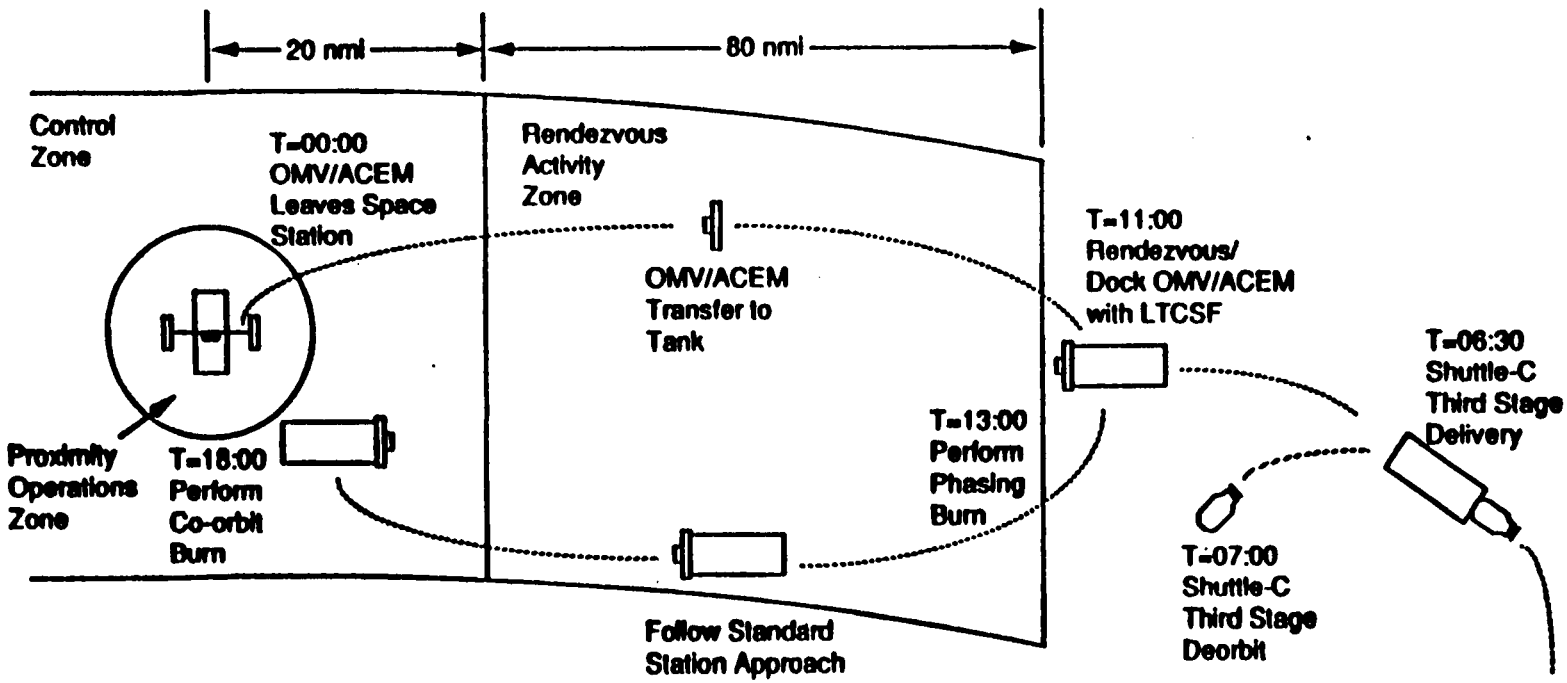
## CRYOGENIC PROPELLANT TANK DELIVERY SCENARIO

A complete scenario of STV refueling and launch was formulated in order to examine the operations/accommodations required of the space station. The scenario included delivery of cryogenic propellants to the space station attached propellant facility, fueling the STV, and deploying and launching the STV.

The scenario for delivery of the tankset to the Station is depicted on this chart. This chart shows the delivery of the tank to the Station rendezvous zone by the Shuttle-Z third stage. The OMV/ACEM assembly travels from the Station, rendezvous and docks with the tankset, and stabilizes it. The OMV performs a burn with its main thrusters for about 20 minutes to initiate the phasing to bring the tank to the Station. Prior to arriving at the proximity zone, the tank is oriented and a burn is performed to co-orbit the tank with the Station. The ACEM cold gas thrusters perform the manuevers to bring the tank within reach of the MRMS.

These tanksets have a total wet (fully fueled) weight of 177k lb. and 245.5k lbs., respectively. These scenarios required that the OMV rendezvous with the tankset and ferry it to the Station. However, the OMV has been designed for a maximum payload weight of 75k lbs., assuming no maneuvering requirements. Bringing the tank to the Station requires positive attitude control throughout the transfer and the use of cold gas during the final approach for contamination reduction. A design solution has been proposed and is more fully described on a succeeding chart.

# CRYOGENIC PROPELLANT TANK DELIVERY SCENARIO TO THE SPACE STATION




ACEM = Attitude Control Enhancement Module

OMV = Orbital Maneuvering Vehicle

NOTE: Times represent the beginning of the identified operation.

## ATTITUDE CONTROL ENHANCEMENT MODULE (ACEM)

In order to increase the OMVs capability with minimum development costs, General Dynamics has developed an Attitude Control Enhancement Module (ACEM) design concept. The ACEM is attached to the front of (and controlled by) the OMV. To minimize the impact to the OMV, the ACEM will have its own batteries, signal processor, and thruster control hardware and software, but it will rely on the OMV for guidance, navigation, and control information. The OMV will relay the commands sent from the ground or Station to the ACEM.

The ACEM will have two deployable S-band omnidirectional antennas capable of extending beyond the diameter of the tanks to allow the OMV to communicate continuously with TDRSS and (or) the Space Station. Two thruster pods, each containing five 110 lb. thrust nitrogen thrusters, will also extend beyond the tank diameter. This will provide three axis control for the tank with sufficient force to allow yawing the tank 180° in about three minutes. The ACEM will carry a total of 1000 lbs. of nitrogen in eight 2.5 ft. tanks. These tanks will be refilled at the Station.

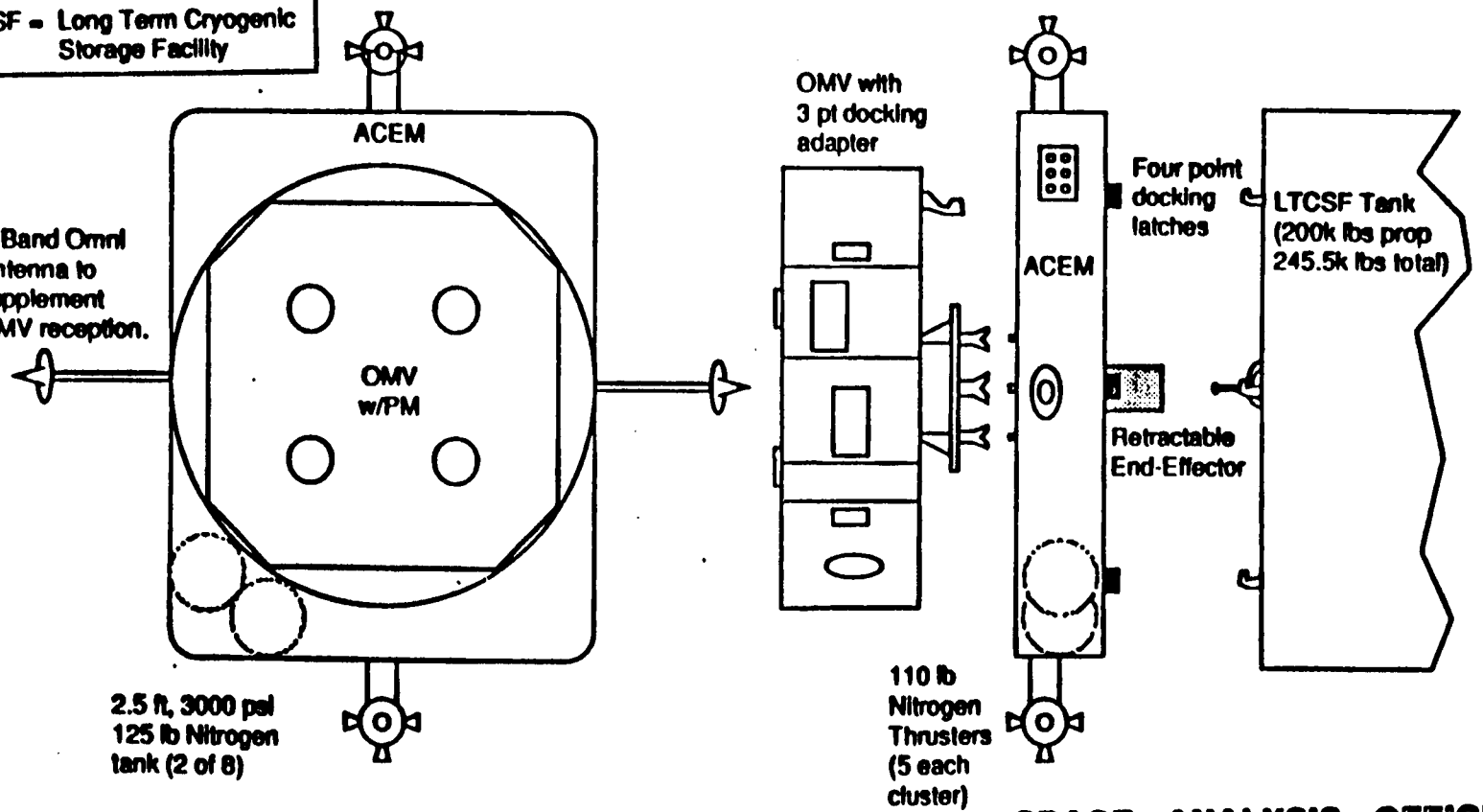
# ATTITUDE CONTROL ENHANCEMENT MODULE (ACEM)

ACEM = Attitude Control Enhancement Module

OMV = Orbital Maneuvering Vehicle

PM = Propulsion Module

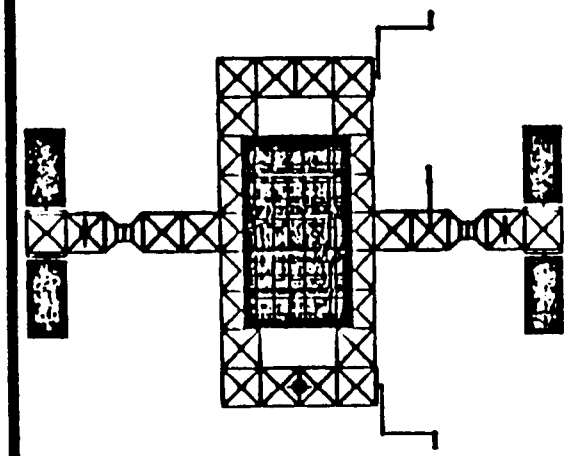
LTCSF = Long Term Cryogenic Storage Facility

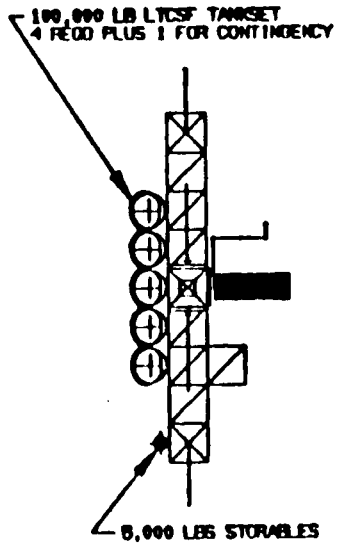


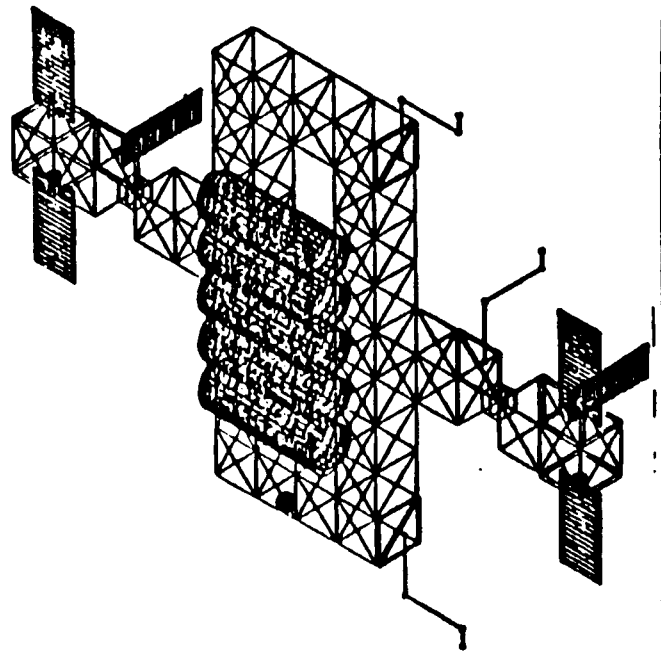
## LUNAR OBSERVATORY MISSION PROPELLANT PROVISIONING

This chart shows an example of a co-orbiting platform for provisioning the propellants for the 1988 Code Z Case Study 3 "Lunar Observatory Mission."

# LUNAR OBSERVATORIES PROPELLANT PROVISIONING; CO-ORBITING PLATFORM





ORBITAL DEPOT FOR LUNAR OBSERVATORIES

FILENAME: 836.WHY.OPP-LUNOBS

## "HOOK AND SCAR" ISSUES

Identifying hard "hook and scar" requirements and providing actual space station design changes for them was beyond the scope of this effort. However, the effort highlighted some areas that should be considered for design enhancements to enable future capabilities in on-orbit fluid management. These included implications for both hardware and software. The chart summarizes these areas.

# "HOOKS AND SCARS"

SPACE STATION DESIGN MUST CONSIDER SCARRING FOR:

- TRUSS STRUCTURE BEAM STRENGTHENING FOR LARGE ATTACHED PROPELLANT TANKS
- DUAL MOBILE REMOTE MANIPULATOR SYSTEMS (MRMS'S)
- SPACE ALLOCATION FOR PROPELLANT TANKS
- LOGISTICS CARRIER INTERFACES MUST BE COMPATIBLE WITH GROWTH SPACE STATION NEEDS
- ATTITUDE CONTROL SYSTEM MUST BE CAPABLE OF GROWTH TO ACCOMMODATE INCREASED MASS OF SPACE STATION WITH ATTACHED PROPELLANT TANKS

SPACE STATION DESIGN MUST CONSIDER SOFTWARE "HOOKS" FOR:

- OPERATION AND COORDINATION OF TWO MRMS'S
- PROVISION FOR INTEGRATED NITROGEN SYSTEM (INS) GROWTH

## HARDWARE DEVELOPMENT REQUIRED FOR SPACE STATION BASED PROPELLANT PROVISIONING

There are several technologies that are required for the realization of cryogenic and storable fluid storage, acquisition, and transfer in the LEO environment. Some of these are:

- Cryogenic and storable fluid disconnects which may be mated by telerobotic operations will be necessary to minimize EVA for fluid carrier delivery and transfer operations.

- Space-qualified refrigeration systems will be needed for propellant storage at the SS, if no venting of oxygen or hydrogen boiloff is allowed, a refrigeration system must be used to condense all boiloff, and return the propellants to storage temperature and pressure.

- Cryogenic valves, pumps, compressors, and capillary liquid acquisition devices for the control of all storage and transfer functions within a propellant storage tankset are not all presently available. Low flow rate Joule-Thompson valves, check valves, low head/flow rate pumps, and high pressure gas compressors designed for low maintenance applications will be needed.

- Mobile remote manipulator system (MRMS) and orbital maneuvering vehicle (OMV) enhancements will need to be developed.

The instrumentation requirements for propellant and other fluid storage tank monitoring and process control are unique due to the lack of substantial gravity. Two-phase flow, mass gauging, and leak detection for microgravity, low pressure environments are not readily available.

# HARDWARE DEVELOPMENT REQUIRED FOR SPACE STATION BASED PROPELLANT PROVISIONING

## HARDWARE

- CRYOGENIC FLUID DISCONNECTS
- SPACE-QUALIFIED CRYOGENIC REFRIGERATION SYSTEM(S)
- LONG-LIFE SPACE QUALIFIED CRYOGENIC VALVES, PUMPS, COMPRESSORS
- MRMS CAPABLE OF HANDLING "LARGE" MASSES (I.E., PROPELLANT TANKAGE)
- GROWTH OMV OR ACEM EQUIVALENT
- MICROGRAVITY LIQUID ACQUISITION SYSTEM

## INSTRUMENTATION

- MICRO-G MASS GAUGING
- MICRO-G TWO-PHASE FLOW INSTRUMENTATION
- LEAK DETECTION TECHNOLOGY FOR MICRO-G, LOW PRESSURE ENVIRONMENT

## CONCLUSIONS AND RECOMMENDATIONS

There are a variety of fluid users which require a variety of fluids and use rates. The storage methods must accommodate fluids ranging from a high pressure gas or supercritical state fluid to a subcooled liquid (and superfluid helium). The cryogenic propellant amounts required for NASA's STV, Planetary, and Code Z missions are enormous in comparison to the other fluid requirements.

In providing the SS attached experiments with required fluids, preliminary comparisons have shown that the best method utilized hard fluid lines between each user and a manifold/ disconnect panel to which each fluid carrier is docked. This capability, however, is not needed at the initial SS (which provides the wide range of fluid use rates/users with fluids via ORU changeout, and bulk LHe replenishing in the case of ASTROMAG) and should only be used for the growth SS if operational and economic benefits are shown to exist.

Reboost settling is not recommended as a baseline mode of operation. Reboost operations of the SS could be scheduled to provide acceleration levels required for "settled" transfer of LH2/LO2 from the SS to an STV propellant tank. However, there are many other issues that need resolution to allow STV propellant provisioning from the SS, such as SS truss structure dynamics, safety, guidance, navigation, and control issues.

The Station must have two Mobile Remote Manipulator Systems (MRMS) and the ACEM for propellant handling operations for the STV at the SS. The two MRMSs must have accommodations for holding full and empty experiment fluid reservoir tanks/bottles, which will also require associated software capabilities.

Propellant needs for the manned planetary Code Z mission models will most likely be provided by co-orbiting propellant platform(s). Although reducing some of the direct impacts to the space station, the station will still have to provide crew accommodations during platform build-up, a shuttle vehicle, and will direct platform operations.

# CONCLUSIONS AND RECOMMENDATIONS

- WIDE VARIETY OF FLUIDS USERS, VARIETY OF FLUIDS AND USE RATES
  - MUST ACCOMMODATE FLUIDS RANGING FROM HIGH PRESSURE GASES TO SUBCOOLED LIQUIDS (E.G., SUPERFLUID HELIUM)
  - HYDRAZINE AND LIQUID HELIUM CONSTITUTE MAJOR PORTION OF ATTACHED AND FREE-FLYING PAYLOAD FLUID REQUIREMENTS
  - LARGE AMOUNTS OF CRYOGENIC HYDROGEN AND OXYGEN PROPELLANTS
- SUGGESTED AN INTEGRATED FLUID SUBSYSTEM ARCHITECTURE FOR PROVISIONING ATTACHED AND FREE-FLYING PAYLOADS
- RECOMMEND TWO MOBILE REMOTE MANIPULATOR SYSTEMS (MRMS)
- ATTITUDE CONTROL ENHANCEMENT MODULE (ACEM) RECOMMENDED TO ENHANCE ORBITAL MANEUVERING VEHICLE (OMV) CAPABILITY
- CREW TRANSPORT VEHICLE (MAN-RATED OMV) FOR TRANSPORT BETWEEN SPACE STATION AND CO-ORBITING PROPELLANT DEPOT

# SPACE STATION EVOLUTION LOGISTICS

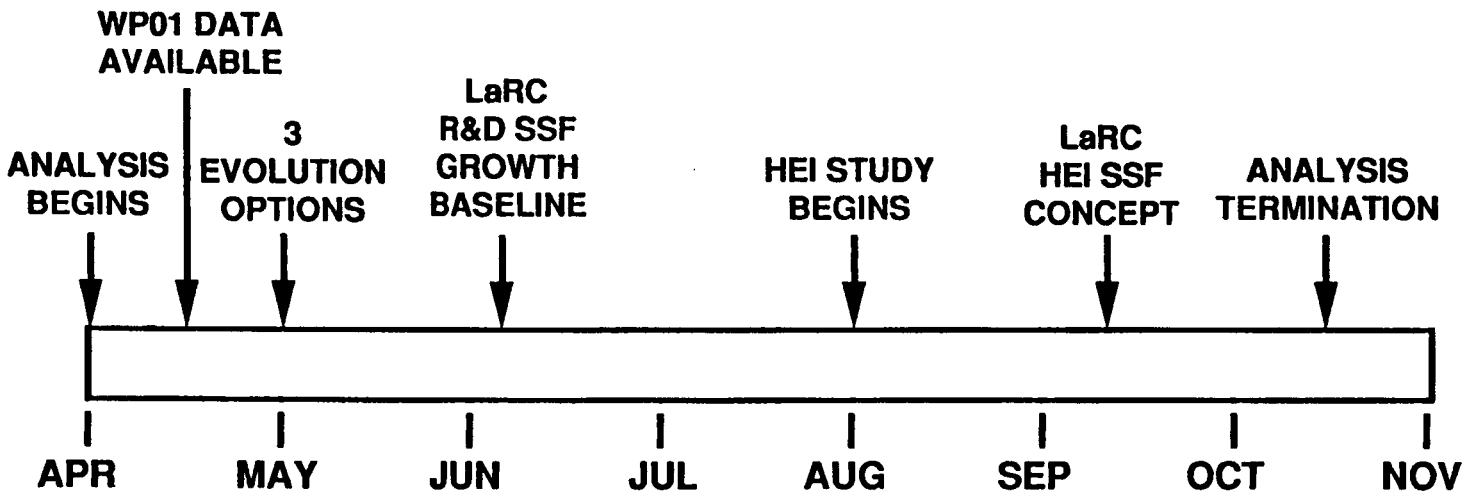
# LUNAR/MARS INITIATIVE CASE

PRESENTED BY:
MICHAEL TUCKER, MSFC

ANALYSIS BY:
MICHAEL TUCKER, MSFC
DAVID THRASHER, BOEING
GORDON DAVIDSON, BOEING

1-321-0-6Da

# LOGISTICS STUDY FY'89 HISTORY



# Objectives

The purpose of this study is to examine the potential logistics requirements for Space Station Freedom growth/evolution, and to provide definition of logistics systems for such growth/evolution as stated in the LS/ME Study Statement of Work, Contract NAS8-50000, Logistics System/Modules Evolution Study, NASA MSFC memorandum KA01, 88-13-071. Logistics requirements and logistics system elements for the initial Space Station were used as a starting point.

In the early part of the study, a small portion of the effort was used to characterize a spectrum of potential SSF growth/evolution possibilities, with the intent of assessing logistics requirements for a few selected SSF concepts. The data characterizing these concepts is included herein. An evolution concept of an R&D SSF & a Lunar/Mars Expedition (data from on-going related studies) began to emerge as a "reference" concept, so the logistics study effort was shifted to focus on this concept.

The ability of the present concepts of the logistics system elements as well as other concepts to accommodate the logistics requirements for the advanced SSF are assessed. The number of required attachment locations on the SSF are identified.

The data provided herein is an initial output from a study that is expected to continue during the next fiscal year. Other studies are in progress which will change the definition of the initial SSF, the growth/evolution SSF, the logistics requirements, and the ETO vehicle concepts. The continuation of this study will assess the implication of such changes.

The implications on the logistics systems of utilizing present and larger (ETO) vehicles than the present space transportation systems is assessed.

"Hooks and Scars" requirements for the initial Space Station, including logistics elements are defined.

# OBJECTIVES

- PROVIDE LIMITED CHARACTERIZATION OF A SET OF REPRESENTATIVE GROWTH/EVOLUTION SSF CONCEPTS.
- DEFINE GROSS LOGISTICS REQUIREMENTS FOR SSF GROWTH/ EVOLUTION OPTIONS.
- DEFINE LOGISTICS ELEMENT CONCEPTS & FLIGHT RATES FOR SSF GROWTH/EVOLUTION OPTIONS AND ETO VEHICLE OPTIONS.
- DEFINE THE NUMBER OF ATTACHMENT LOCATIONS REQUIRED ON THE SSF GROWTH/EVOLUTION OPTIONS.
- IDENTIFY HOOKS AND SCARS REQUIREMENTS ON INITIAL SS TO SUPPORT EVOLUTIONARY LOGISTICS SYSTEMS.

# Scope

The task involves analyzing all elements required for any of the various growth options of Space Station Freedom. Once the uplift has been determined, the elements are broken down into categories that include:

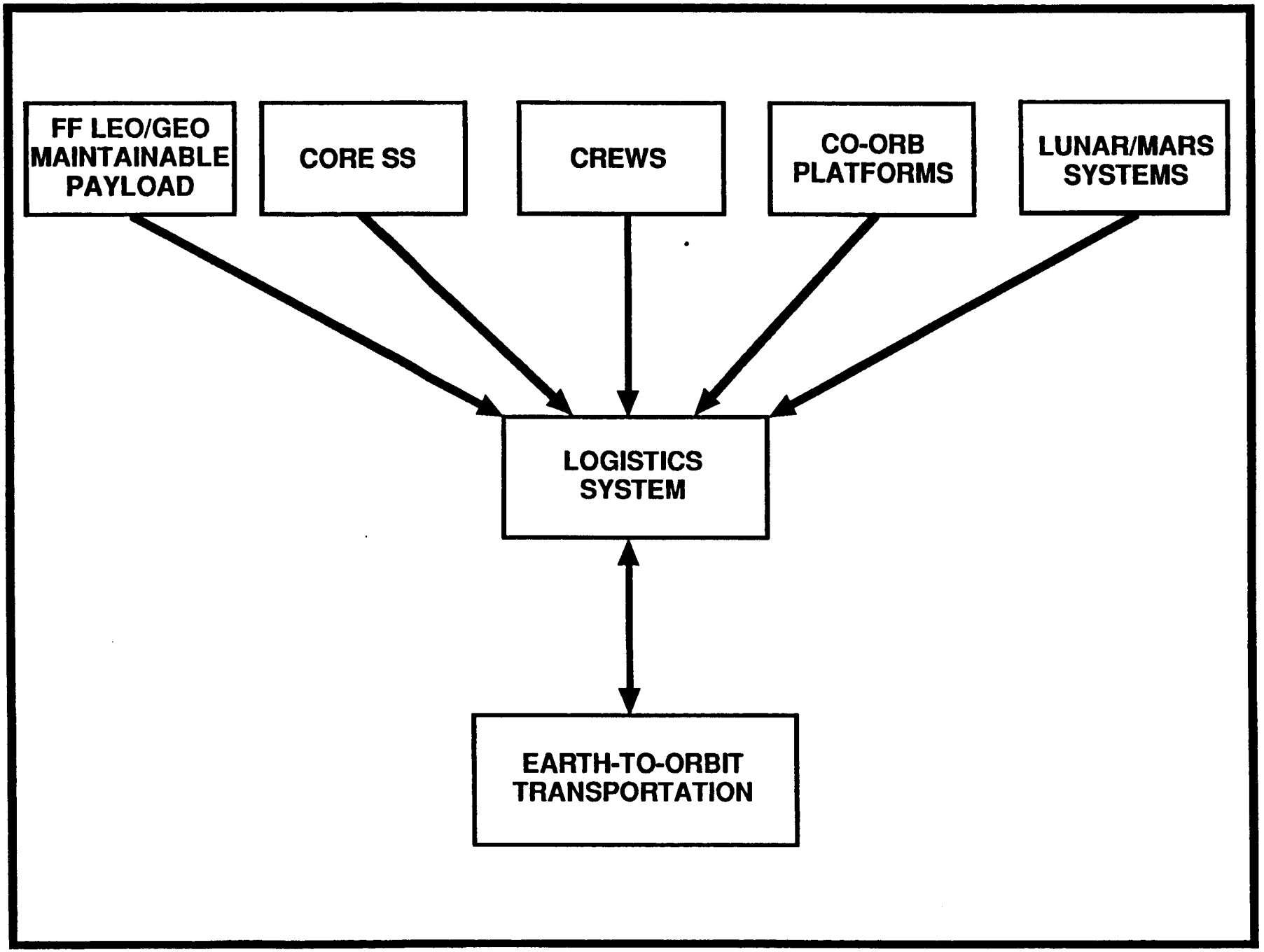
- Space Station Truss and Pressurized Cargo
- Special Equipment
- Lunar Equipment
- Mars Equipment
- Crew Equipment
- Propellant

SSF propellant is resupplied, however Lunar/Mars propellant is not in this study.

Once categories are set, logistics requirements are determined. "ETO" vehicles are then selected to support these logistics requirements.

1-131-0-2Da

# SCOPE



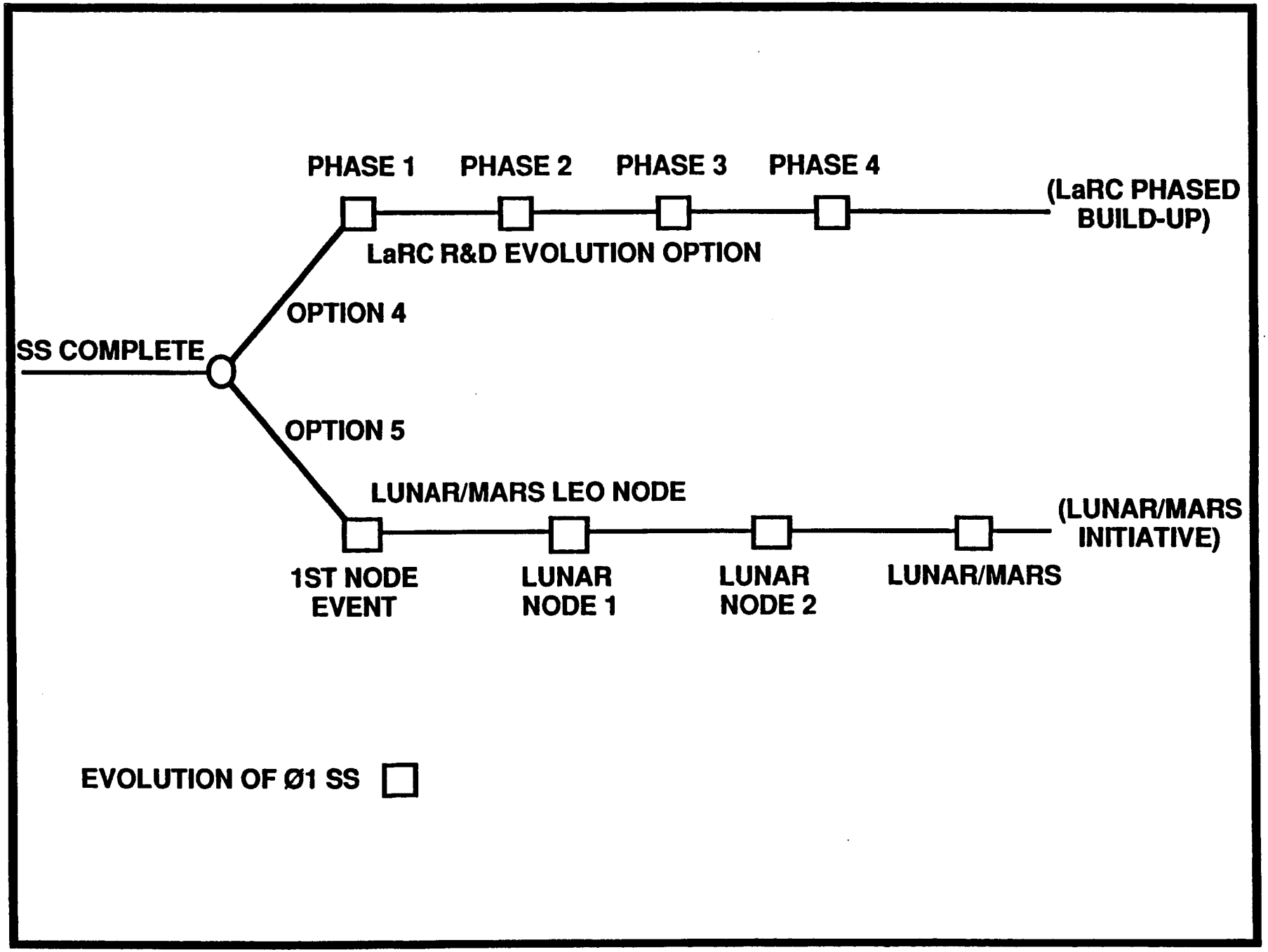
## SSF Evolution Roadmap: 2

Analysis of the logistics requirements for two different SSF growth scenarios has been completed. The first option results in a SSF devoted to research and development and is based on the Phase I SSF. The first growth phase adds power, structure, the space based OMV and accommodations to house a 16-man crew. The second phase adds another 50 KW of power with servicing facilities, space based STV and hangar, a second U. S. Lab Module and a pocket lab. Phase Three adds more power and another Lab and Hab for accommodations to house a 24 man crew. The final changes include two pocket labs and an additional 50 KW of power. The result is an R & D space station with large amounts of available rack space and associated resources for the user community.

The second growth option is designed to satisfy the requirements of the baseline Lunar/Mars Initiative case. This space station's main objective is supplying LEO transportation node for lunar/Mars missions. The build-up consisits of four definable stages which represent an increasing capability for supporting the lunar/Mars manifest. In order to meet the first Node Event, an LTV test flight, and 50 KW of power will be added along with the associated thermal control, space based OMV, lower keel and booms, LTV servicing track with lunar OSE, an airlock and SSEMU's. The Lunar Node adds the LTV Hangar for debris protection, an additional Hab module and additional OSE. Lunar Node 2 adds the Customer Servicing Facility, 50 KW of power, H2O2 propulsion, a pocket lab (to support the addition of the Mars program), upper keels and booms which are added with a second MSC and MT, another Hab Module and the Mars OSE.

1-133-0-2Da

# SSF EVOLUTION ROADMAP: 2



# SSF WP01 Logistics System

Logistics Carriers:

| | Empty Mass (kg) | P/L (kg) |
|---|---|---|
| • Pressurized Logistics Module | 6632 | 13636 |
| • Unpressuried Logistics Carrier | 1091 | 9091 |
| • Hydrazine Subcarrier * | 306 | 1057 |
| • Bipropellant Subcarrier * | 665 | 2313 |
| • Fluids Subcarrier * | 759 | 1063 |
| • Dry Cargo Subcarrier * | 88 | 682 |

* Each hydrazine subcarrier, bipropellant subcarrier, fluids subcarrier, or dry cargo subcarrier require an unpressurized logistics carrier to transport aboard launch vehicle.

1-260-0-5Da

# SSF WP01 LOGISTICS SYSTEM

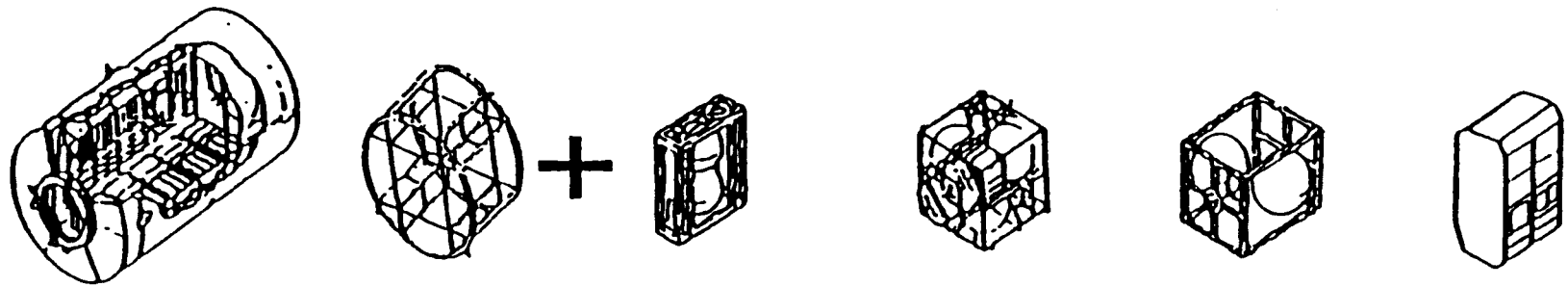
- Baseline Cargo Requirements

| | | Annual Quantity (kgs) Resupply | Return |
|---|---|---|---|
| Crew | Pressurized | 36669 | 33091 |
| Station | Unpressurized | 18700 | 18700 |
| Customers | Fluids | 2909 | 696 |
| | Propellants | 6742 | 0 |
| | | 65020 | 52487 |

- Launch And Landing Resources - STS

  Launch Capability - 17969 kgs to 220 NM
  Landing Capability - 18864 kgs (OV 102 is 3818 kgs less)

- SSF Logistics Elements



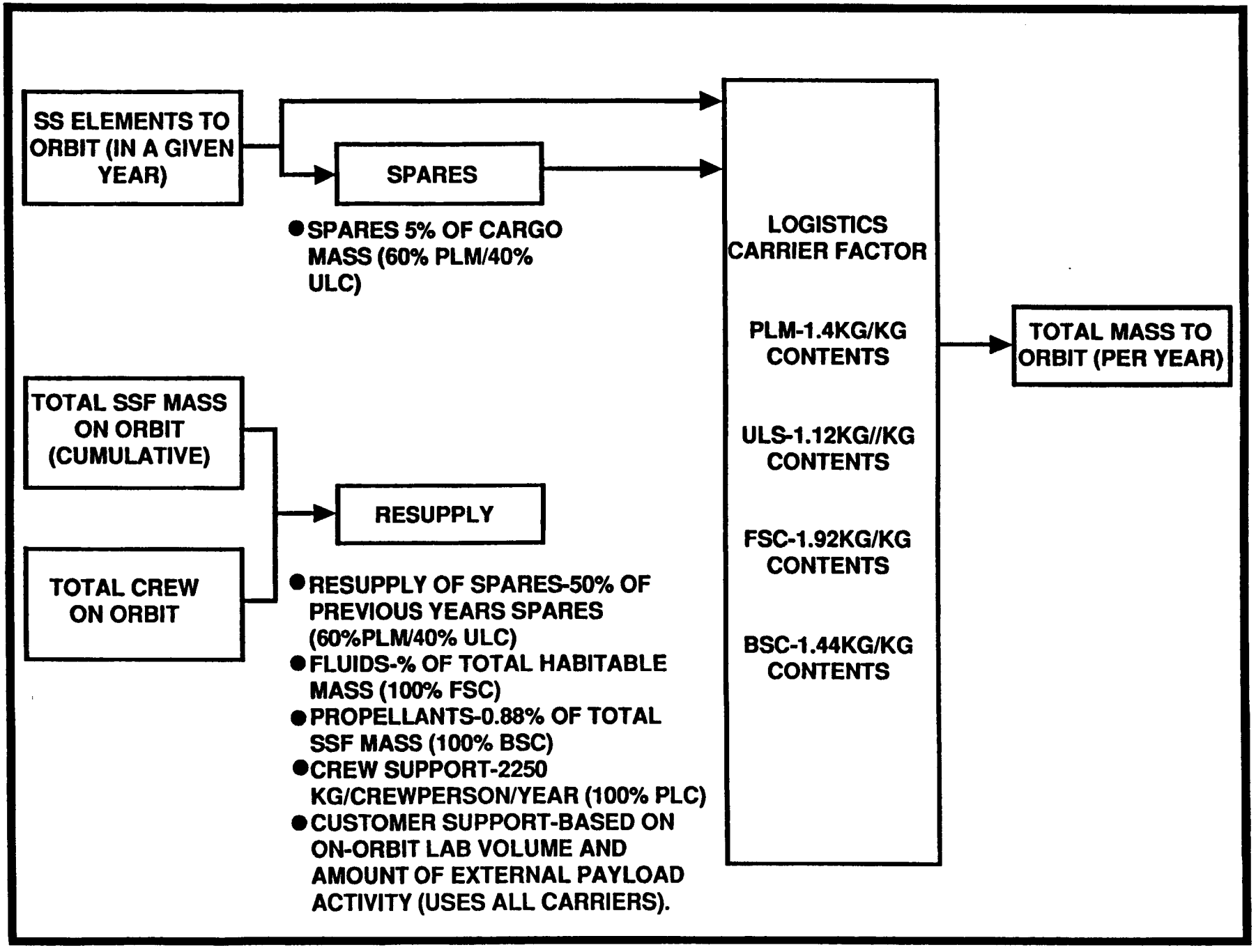
| | Pressurized Logistics Module | Unpressurized Logistics Module | Hydrazine Subcarrier | Bipropellant Subcarrier | Fluids Subcarrier | Dry Cargo Subcarrier |
|---|---|---|---|---|---|---|
| Empty Mass (kgs) | 6632 | 1091 | 306 | 665 | 759 | 88 |
| P/L (kgs) | 13636 | 9091 | 1057 | 2313 | 1063 | 682 |

# Logistics Model

A Microsoft Excel spreadsheet program has been written which compiles a complete set of annual logistics mass to orbit as shown in the chart below. By using the growth breakdown for space station elements initial spares uplift is calculated as 5% of that element mass. For subsequent years, 50% of the initial spares mass is required per year for resupply. Fluids, Propellant & Customer Support resupply are all based on a % of the size of SSF. Crew Support is based on the total number of crewpersons on-orbit. All spares or resupply items are subject to a carrier factor based on the particular carrier they ride on. All of these factors are computed in the spreadsheet program to derive total mass to orbit per year.

1-132-0-2Da

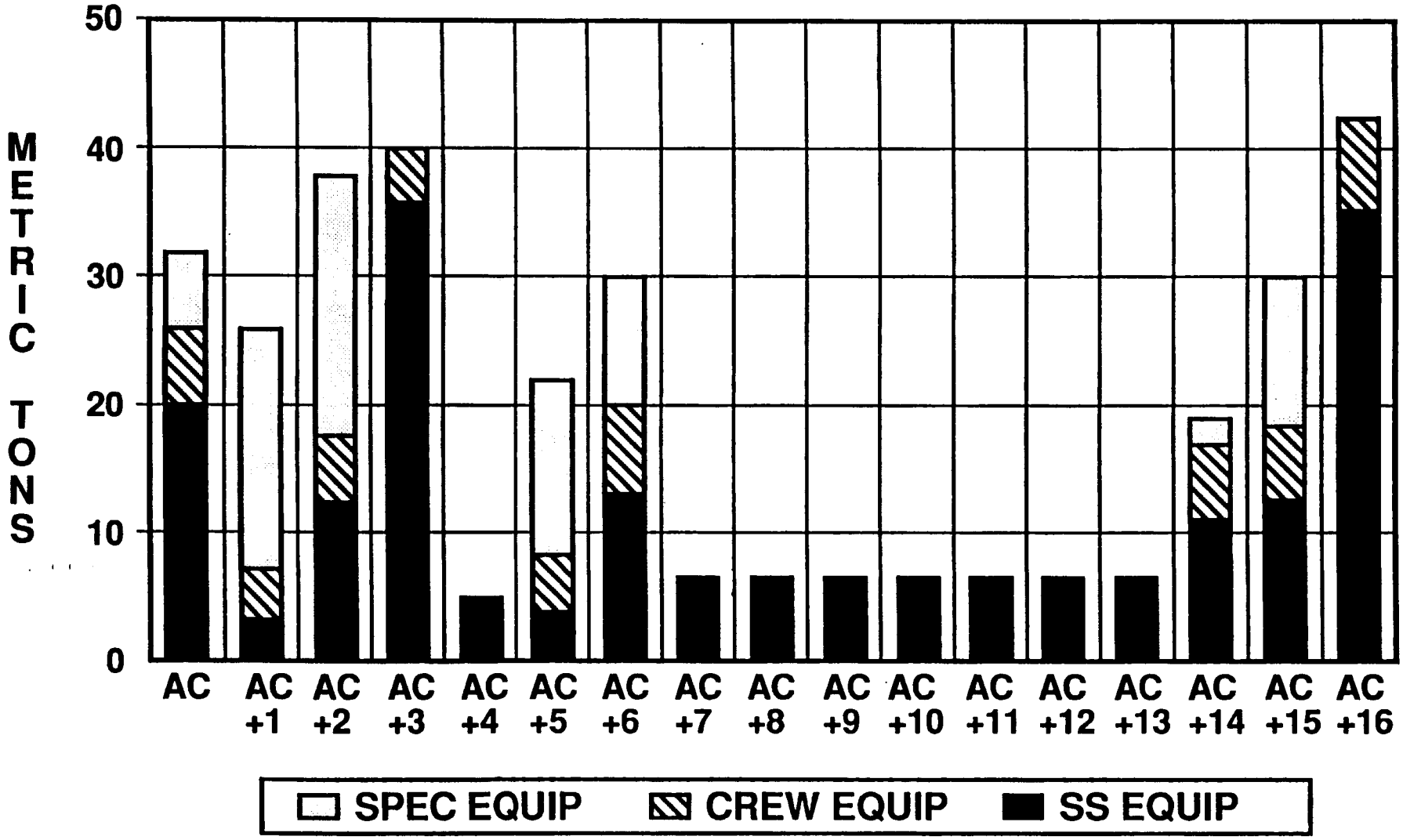
# LOGISTICS MODEL



## Total SS Elements to Orbit
## (Carriers Included)
## (Lunar/Mars Initiative)

The same hardware uplift as in the previous chart but with the inclusion of carrier/ETO interface mass. This factor is calculated as 13% of SS hardware and special equipment. The equipment tare factor is included in payload mass. These calculations are based on WP01 data.

# TOTAL SS ELEMENTS TO ORBIT
# (CARRIERS INCLUDED)
# (LUNAR/MARS INITIATIVE)



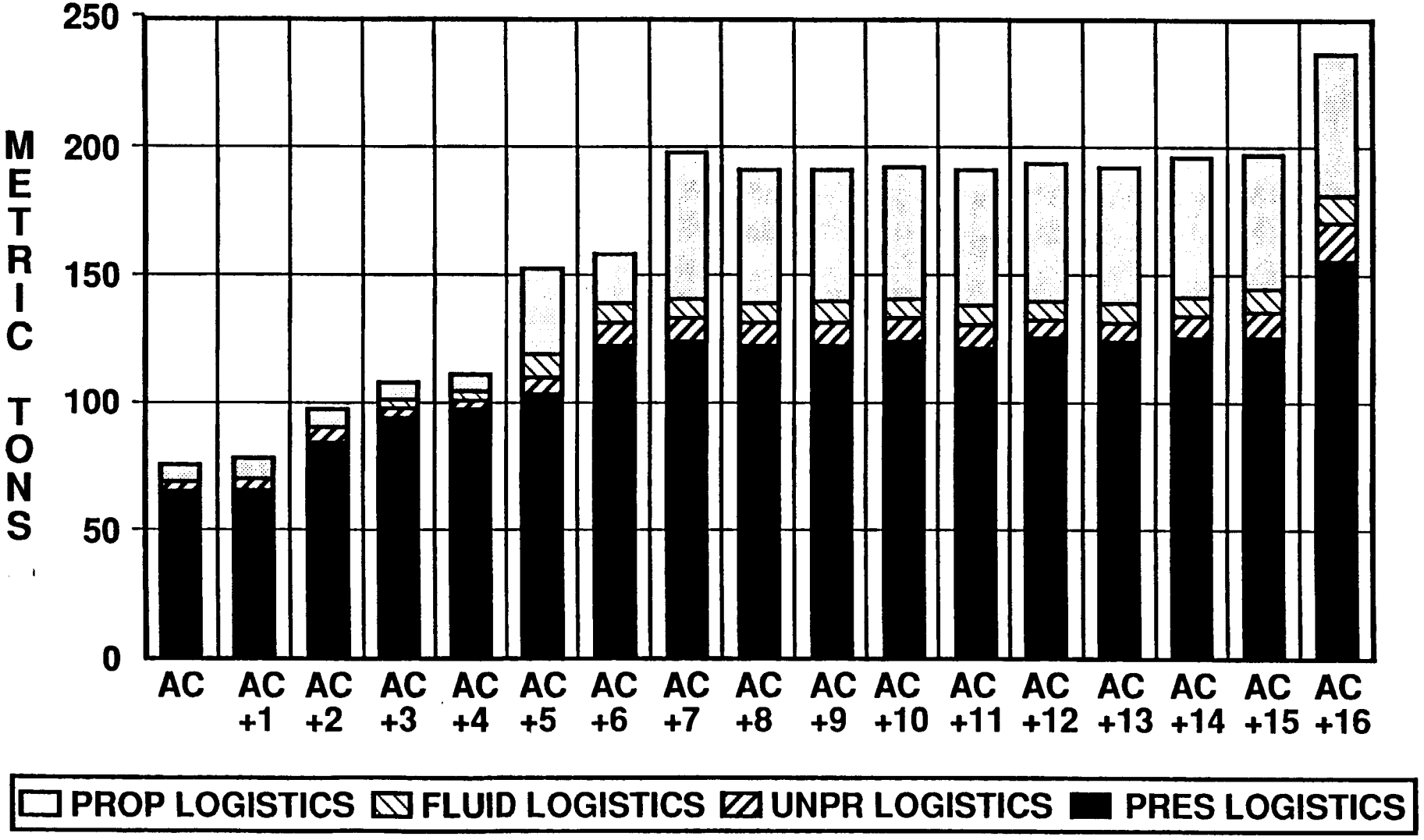
## Total Logistics to Orbit
## (Carriers Included)
## (Lunar/Mars Initiative)

Carrier Factor for Logistics Carriers

| | | |
|---|---|---|
| • Pressurized Carrier | 1.486kg | for each kg of spares or resupply |
| • Unpressurized Carrier | 1.12kg | for each kg of spares or resupply |
| • Fluids Carrier | 1.92kg | for each kg of spares or resupply |
| • Propellant Carrier | 1.442kg | for each kg of spares or resupply |

Carrier factors are imposed on logistics to account for the weight of the carriers required to accommodate them during flight.

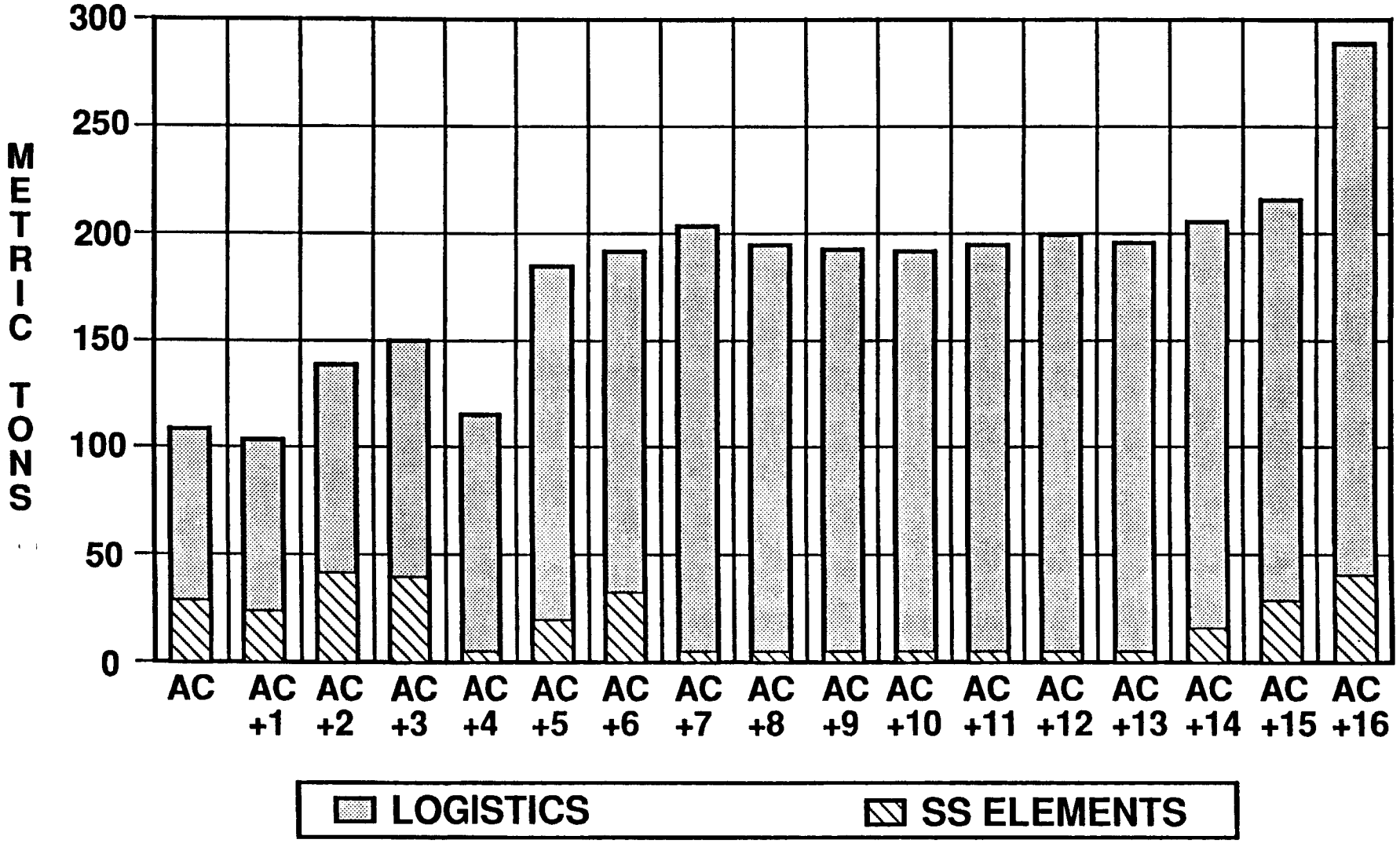
# TOTAL LOGISTICS TO ORBIT
# (CARRIERS INCLUDED)
# (LUNAR/MARS INITIATIVE)



## Total Logistics & SS Elements to Orbit
## (Carriers Included)
## (Lunar/Mars Initiative)

The logistics requirements of the growth SSF combined with hardware mass on a yearly basis with carrier/ETO interface mass. This represents the total SSF requirements for growth.

# TOTAL LOGISTICS & SS ELEMENTS TO ORBIT
# (CARRIERS INCLUDED )
# (LUNAR/MARS INITIATIVE)

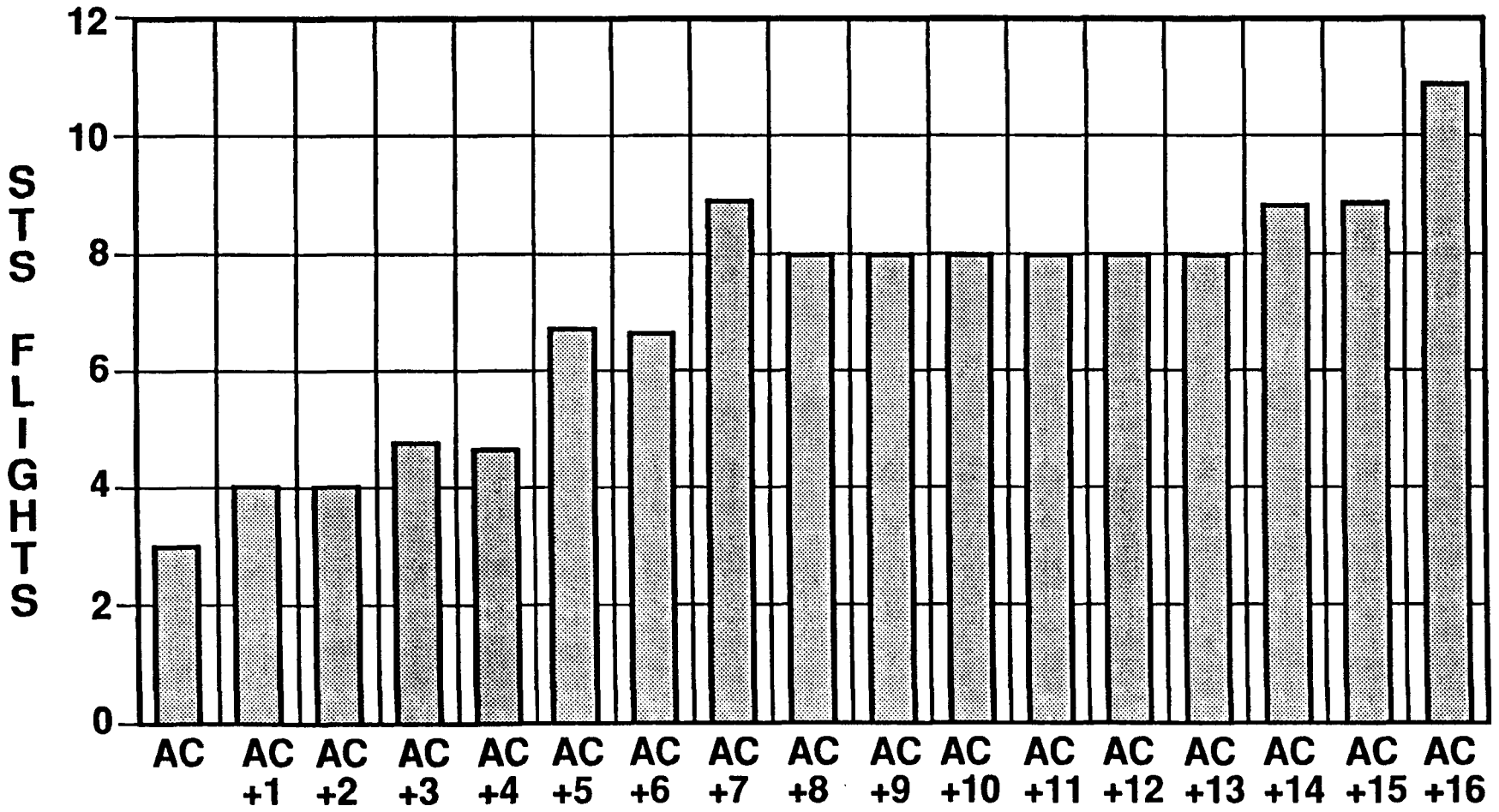


## STS Flights Required for Logistics & Carriers Uplift (Lunar/Mars Initiative)

STS launches required to accommodate logistics uplift to support SSF. Shuttle assumed to be able to accommodate 22,727 kg of cargo per launch.

Chart indicates that the groundruled 8 Shuttle flights per year for logistics is violated in 2004 and after 2011 if only the Shuttle is used for uplift.

# STS FLIGHTS REQUIRED FOR LOGISTICS & CARRIERS UPLIFT (LUNAR/MARS INITIATIVE)

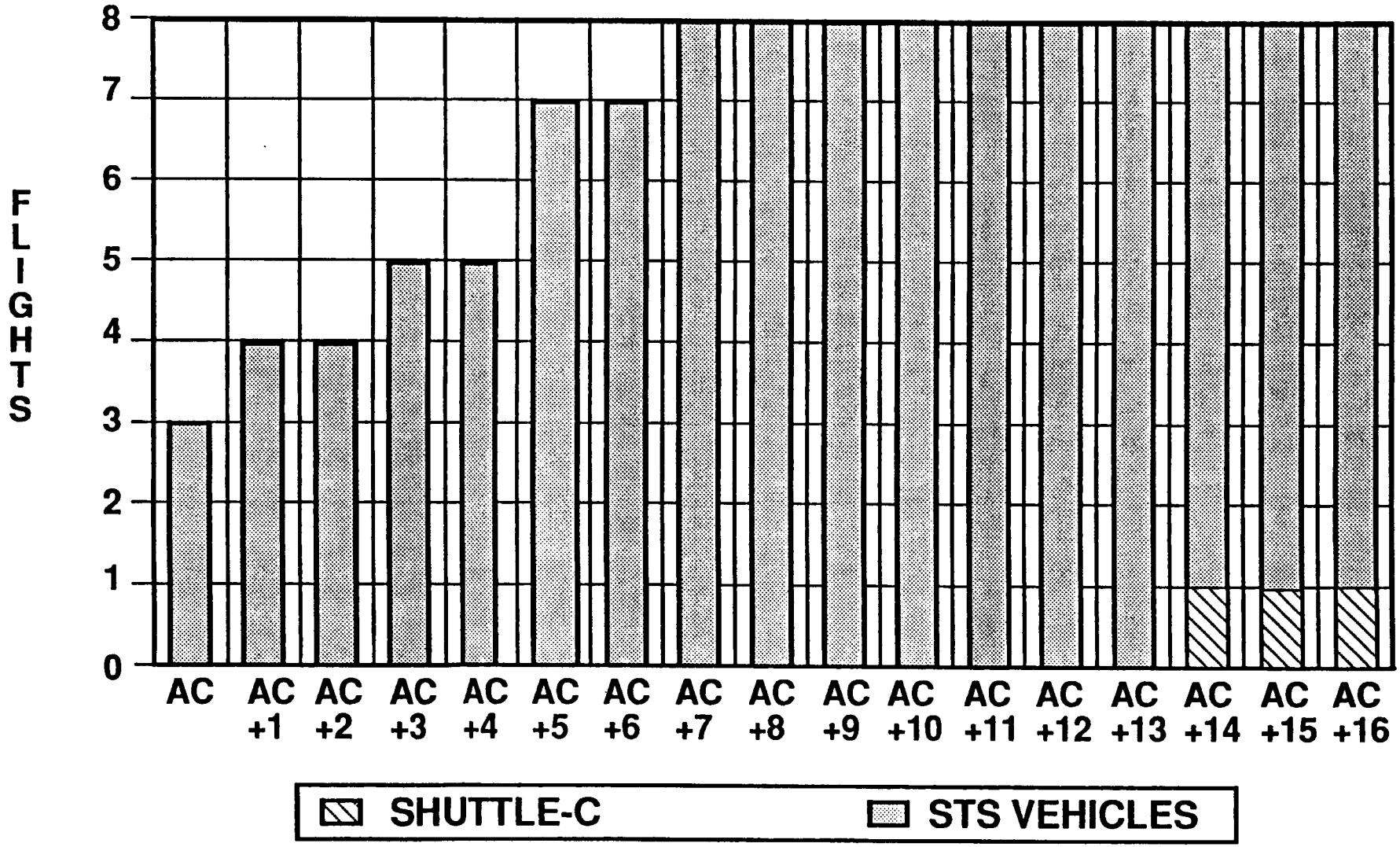


## Total ETO Logistics Flights Required (Lunar/Mars Initiative)

Shuttle and Shuttle-C flights required to accommodate logistics uplift to support SSF. Assumed a maximum of (8) dedicated shuttle missions for logistics and crew rotation. The remainder being launched on Shuttle-C

Shuttle-C has an assumed cargo capacity of 68,127 kg per launch.

# TOTAL ETO LOGISTICS FLIGHTS REQUIRED (LUNAR/MARS INITIATIVE)



# POTENTIAL HOOKS AND SCARS

## HOOKS

- REQUIREMENT FOR A HOOK RELATES PRIMARILY TO REVISIONS IN INVENTORY MANAGEMENT
- ANOTHER NEED IS TO CONTROL TRAFFIC IN PROX-OPS

## SCARS

- GROWTH SSF HAS A POTENTIAL STORAGE PROBLEM TO BE SOLVED BY:
  - ADDITIONAL BERTHING PORTS, OR AT LEAST PARKING POSITIONS
  - "WAREHOUSING" IN A STORAGE FACILITY, AND/OR
  - USE OF LOGISTICS CARRIERS AS ON-ORBIT SEMI-PERMANENT STORAGE
- LONGER UNPRESSURIZED LOGISTICS CARRIERS (ULC's) TO TAKE MAXIMUM ADVANTAGE OF SHUTTLE-C's LONG CARGO COMPARTMENT AND LIFT CAPABILITY
- ENLARGED PROPELLANT AND FLUIDS SUBCARRIERS (BSC & FSC) TO ACCOMMODATE GROWTH
- TETHER ATTACHMENT LOCATION FOR TETHERED REENTRY OF DISPOSABLE WASTE (POTENTIAL)

# CONCLUSIONS/FUTURE WORK

1. CONCLUSIONS FOR THE R & D SSF AND THE LUNAR/MARS INITIATIVE
   - INITIAL SSF LOGISTICS SYSTEM IS INADEQUATE TO SUPPORT GROWTH/EVOLUTION
   - DURING PEAK YEARS FOLLOWING SSF ASSEMBLY COMPLETE THERE ARE INSUFFICIENT NUMBERS OF CARRIERS
   - PROJECTED STS LAUNCH RATE IS INADEQUATE TO SUPPORT GROWTH/EVOLUTION
   - SHUTTLE-C COULD PROVIDE THE ADDITIONAL LIFT TO LEO
   - PARKING LOCATIONS FOR UNPRESSURIZED CARGO IN INADEQUATE

2. FUTURE WORK
   - PERFORM DETAILED ANALYSIS OF NEW CARRIER CONCEPTS FOR GROWTH/EVOLUTION
   - DEVELOP UNPRESSURIZED STOWAGE SYSTEM AT SSF
   - UPDATE AND REFINE LOGISTICS REQUIREMENTS FOR THE GROWTH/EVOLUTION PHASE

3. NEEDS
   - MAINTENANCE PLAN AND STRATEGY FROM CURRENT SSF PROGRAM TO ESTABLISH FIRM SET OF SPARES PERCENTAGES AND RESUPPLY REQUIREMENTS

SPACE STATION EVOLUTION

BEYOND THE BASELINE

# TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE



Uwe Hueter
NASA Marshall Space Flight Center

Doug Comstock
General Dynamics Space Systems Division

South Shore Harbour Resort and Conference Center
League City, Texas

7 February 1990

GDSS-ISTD1-0120N

# MSFC SUPPORTING STUDIES FOR TRANSPORTATION NODE

- Proximity Operations
- Debris Protection
- Orbital Operations
- Station Logistics
- Transfer Vehicle Accomodations

# TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE

## Infrastructure Study - General Dynamics (Contract NAS8-37588)

| | |
|---|---|
| Study Task Manager: | Doug Comstock |
| Concept Development: | Kyle Shepard |
| Operations Analysis: | Brián Emmett |
| Economic Analysis: | Penny Burnstein |
| Technology: | John Maloney |

## TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
Outline

- INTRODUCTION
- REQUIREMENTS
- LUNAR TRANSFER VEHICLE ACCOMMODATIONS
- MARS TRANSFER VEHICLE ACCOMMODATIONS
- CONCLUSIONS

# TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
## Introduction

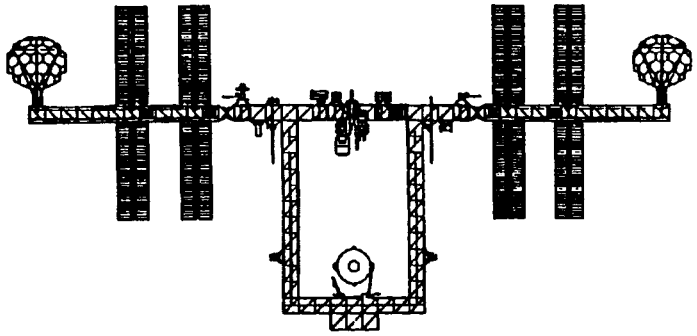
There are three primary objectives of this study. The first is to identify time-phased accommodation capabilities necessary to support the civil space exploration initiatives. These initiatives include the Lunar and Mars missions in the Human Exploration Initiative (HEI). Primary accommodation requirements include integration and assembly of vehicle components and systems on-orbit, and protection of these vehicles from the space environment, particularly debris.

Secondly, this study will develop accommodation concepts, define impacts (hooks and scars) to Space Station Freedom (SSF), identify staging/servicing requirements, and identify required technology advances.

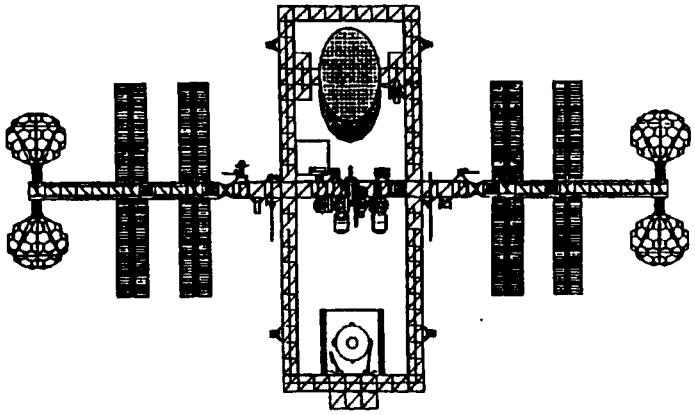
Finally, the majority of the study effort has been devoted to conducting a trade study to evaluate alternative transfer vehicle accommodation concepts. These concepts have ranged from basing all transfer vehicle accommodations for both Lunar and Mars transfer vehicles at SSF, to basing all accommodation capabilities off SSF.

Shown below are two steps in the NASA reference SSF evolution process. The first configuration is to provide lunar transfer vehicle (LTV) accommodation support, and the second is to provide accommodations support for the Mars transfer vehicle (MTV).

# TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
## Introduction



LUNAR TRANSFER VEHICLE ACCOMMODATIONS
SSF Evolution Reference



MARS TRANSFER VEHICLE ACCOMMODATIONS
SSF Evolution Reference

## PRIMARY STUDY OBJECTIVES

- IDENTIFY TIME-PHASED ACCOMMODATION CAPABILITIES NECESSARY TO SUPPORT THE ACCOMPLISHMENT OF CIVIL SPACE EXPLORATION INITIATIVES
- DEVELOP ACCOMMODATION CONCEPTS, DEFINE IMPACTS TO SPACE STATION FREEDOM (HOOKS AND SCARS), IDENTIFY STAGING/SERVICING REQUIREMENTS, AND IDENTIFY REQUIRED TECHNOLOGY ADVANCES
- CONDUCT A TRADE STUDY TO EVALUATE ALTERNATIVE TRANSFER VEHICLE ACCOMMODATION CONCEPTS, PRIMARILY SPACE STATION BASED VERSUS A SEPARATE FREE-FLYING FACILITY

# TRANSFER VEHICLE ACCOMMODATION OPTIONS SUMMARY

There are two primary requirements of on-orbit accommodations facilities. The first is to support a Lunar transfer vehicle (LTV), the second a Mars transfer vehicle (MTV). There is a large difference in size and accommodation requirements for these two vehicles.

In conducting the trade study for basing accommodations at the space station or at a free-flying node, several options were developed. Alternative options were developed as branches to the SSF reference evolution sequence as defined by NASA. The NASA reference has all accommodations at SSF, and the options considered in the trade study for Lunar and Mars vehicles have varying degrees of operations performed away from SSF.

The first branch off of the reference evolution departs from the assembly complete station, to develop free-flying accommodation facilities. The second branch departs from the first node event, and includes an alternative to the all at SSF basing and the free flying tank integrator. The third branch is for Mars accommodations and assumes that SSF has evolved through the reference path to the lunar node 2 configuration. From this configuration, alternatives to basing at SSF are considered including various assembly and integration operations using SSF to a lesser degree, and concepts which are independent of the SSF for assembly and integration.

The alternative (Option 1') to all at SSF basing (Option 1) places the debris protection enclosure below the cross members of the lower keel truss assembly. This option provides easier access to the interior of the debris protection enclosure, and eases some of the operations requirements for assembly of the aerobrake and integration of the propellant tanks at the station.

# TRANSFER VEHICLE ACCOMMODATION OPTIONS SUMMARY

**REFERENCE: Space Station Freedom Evolution Sequence**

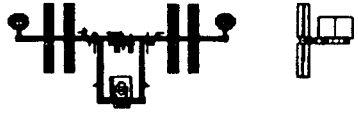
Assembly Complete | First Node Event | Lunar Node 1 | Lunar Node 2 | Mars Node

**Lunar Option 1**
All at SSF

**Mars Option 1**
MTV ass'y at SSF, tank integ. off SSF

**Lunar Option 1'**
All at SSF, DPE below lower keel

**Lunar Option 2**
Vehicle int. at SSF, Tank integration at free-flying facility

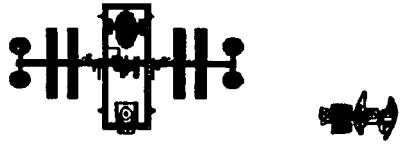


**Lunar Option 3**
All LTV ops at separate man-tended free-flyer

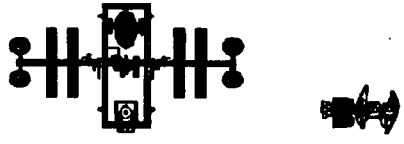
**Lunar Option 4**
All LTV ops at perm. manned free-flyer

**Lunar Option 5**
All ops at perm. manned FF, Tank integration at separate free-flyer

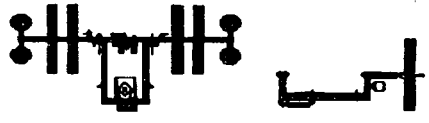
**Mars Option 2**
Component ass'y at SSF, mating & tank integ. off SSF



**Mars Option 3**
Aerobrake Assy. at SSF, aerobrake becomes free-flyer



**Mars Option 4**
All vehicle integration at separate manned FF platform



**Mars Option 5**
Autonomous vehicle assembly at man-tended debris enclosure

GDSS-ISTD1-0100N

## TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
Outline

- INTRODUCTION
- REQUIREMENTS
- LUNAR TRANSFER VEHICLE ACCOMMODATIONS
- MARS TRANSFER VEHICLE ACCOMMODATIONS
- CONCLUSIONS

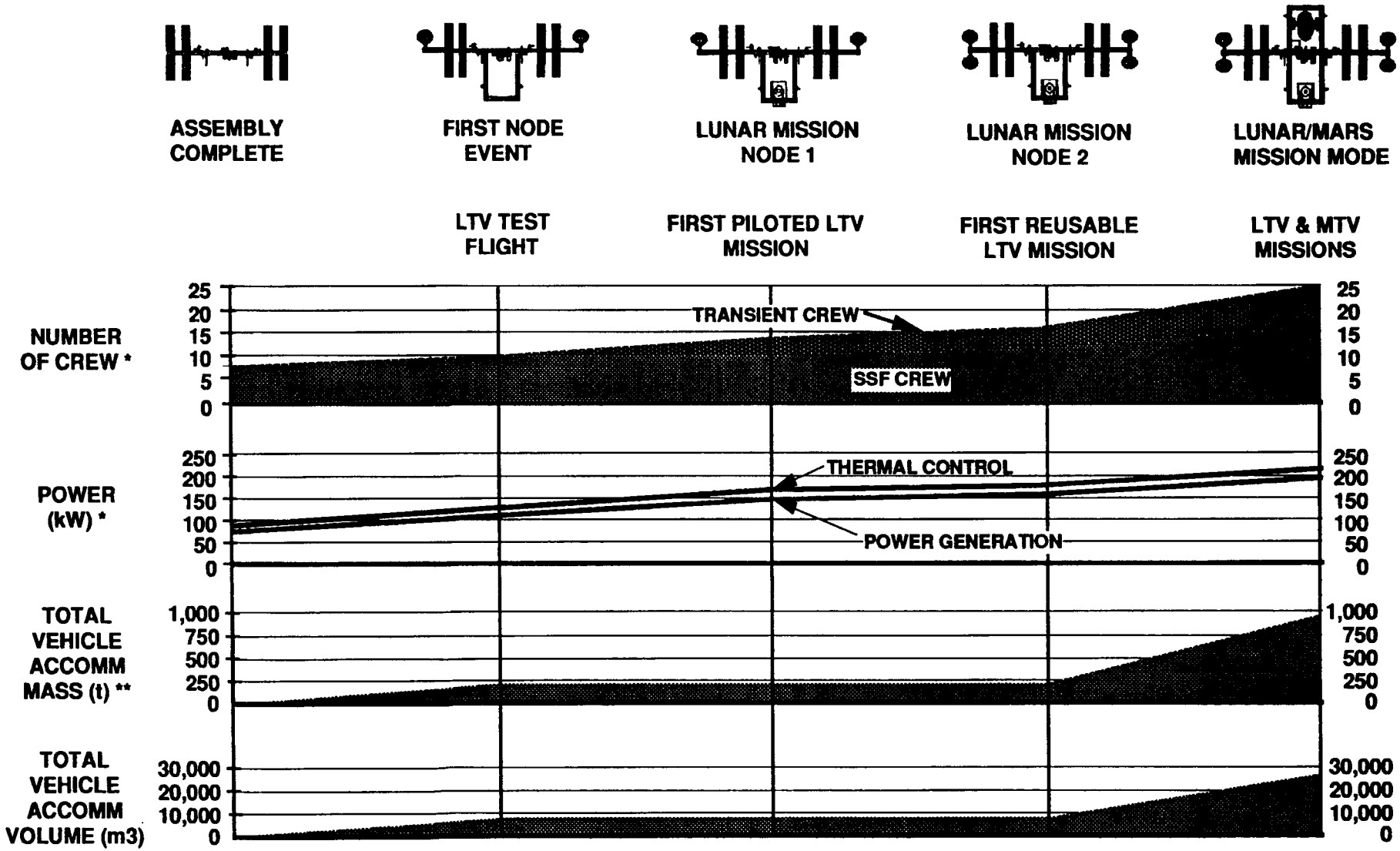
# SPACE STATION FREEDOM EVOLUTION
## Transfer Vehicle Accommodation Support Requirements

Support requirements have been defined for SSF to support evolution to accommodate LTV and MTV operations. These requirements see the number of crew rise from 8 at Assembly Complete (AC) to 25 at completion of the MTV accommodations, 9 of which are transient crew.

Power generation and thermal control requirements increase with the addition of accommodation capabilities at the station, as shown. The mass of the vehicles to be accommodated increases from 0 to 216 metric tonnes for the LTV test flight. Addition of the MTV at 774 metric tonnes brings the total to 990 metric tonnes.

The volume of the vehicles which must be accommodated in the debris protection enclosure begins at 6,300 cubic meters for the LTV. With the addition of the MTV at 20,000 cubic meters, the total increases to 26,300 cubic meters.

# SPACE STATION FREEDOM EVOLUTION
## Transfer Vehicle Accommodation Support Requirements




SOURCE: * NASA, "Report of the 90-day study on Human Exploration of the Moon and Mars", November 1989
** NASA, LaRC SSFO, "Space Station Accommodation of Human Exploration Program Initiative Block II Reference Mission Requirements, Final Implementation", 24 September 1989

GDSS-ISTD1-0111N

# TRANSFER VEHICLE ACCOMMODATIONS
## Incremental Time Phased Requirements

The requirements placed on an orbital transfer vehicle accommodation facility are phased over time, to reflect the maturity of the exploration program and the vehicles involved. There are three steps in the LTV accommodation growth: LTV test flight, a piloted LTV flight and a reusable flight.

The LTV test flight will require the node to support LTV delivery, docking at the node, payload transfer, component assembly, vehicle integration, prelaunch checkout, and launch.

The first piloted LTV flight will require capabilities of the node in addition to those required for the test flight. These capabilities include debris protection, transient crew accommodations, retrieval of the LTV upon return from the moon, and post-mission checkout.

The first reusable LTV flight will require a servicing and maintenance capability, and a long term storage of the LTV at the node between next lunar missions.

MTV accommodations begin several years after LTV accommodations have started. The MTV accommodations are in addition to the accommodations for the LTV. Support for the first MTV mission will require capabilities at the node for MTV delivery, docking at the node, payload transfer, debris protection, component assembly, vehicle integration, transient crew accommodations, prelaunch checkout, and launch of the vehicle.

The MTV carrying the Mars crew returns to the node about four years after initial capabilities for MTV assembly and integration have been in place. Additional capabilities which must available at the node at this time include retrieval of the returning MTV, post-mission checkout, servicing and maintenance of the crew module, and long term storage of the crew module until the next Mars mission.

# TRANSFER VEHICLE ACCOMMODATIONS
## Incremental Time Phased Requirements

**LUNAR TRANSFER VEHICLE**

| LTV Test Flight | First Piloted LTV Flight | First Reusable LTV Flight |
|---|---|---|
| • LTV DELIVERY<br>• DOCKING AT NODE<br>• PAYLOAD TRANSFER<br>• COMPONENT ASSEMBLY<br>• VEHICLE INTEGRATION<br>• PRELAUNCH CHECKOUT<br>• LAUNCH | • DEBRIS PROTECTION<br>• TRANSIENT CREW ACCOMMODATIONS<br>• RETRIEVAL OF LTV<br>• POST-MISSION CHECKOUT | • SERVICING / MAINTENANCE OF LTV<br>• LONG TERM STORAGE OF LTV |

**MARS TRANSFER VEHICLE***

| First MTV Flight | First MTV Return |
|---|---|
| • MTV DELIVERY<br>• DOCKING AT NODE<br>• PAYLOAD TRANSFER<br>• DEBRIS PROTECTION<br>• COMPONENT ASSEMBLY<br>• VEHICLE INTEGRATION<br>• TRANSIENT CREW ACCOMMODATIONS<br>• PRELAUNCH CHECKOUT<br>• LAUNCH | • RETRIEVAL<br>• POST-MISSION CHECKOUT<br>• SERVICING/MAINTENANCE OF CREW MODULE<br>• LONG TERM STORAGE |

* Mars Transfer Vehicle Capabilities are in addition to Lunar Transfer Vehicle Capabilities, which are ongoing in parallel.

# TRANSPORTATION NODE LTV SUPPORT CAPABILITY
## Varying Lunar Surface Stay, Launch Rates & Assembly Times

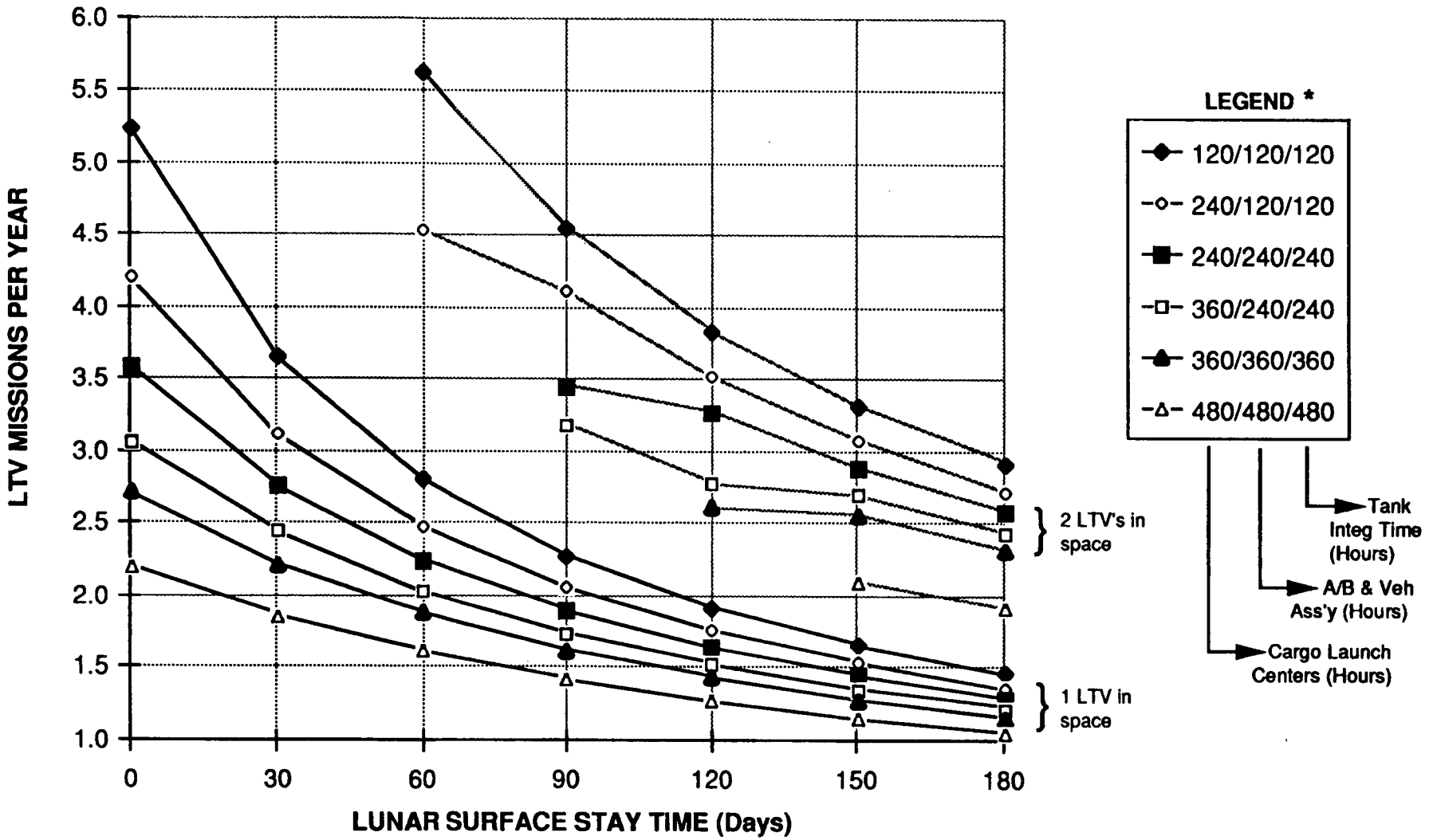
The maximum LTV flight rates that can be supported by a transportation node are shown on this chart as a function of the Lunar surface stay time of the mission, the launch rates of the Earth to orbit (ETO) cargo vehicles, and the duration of the aerobrake and vehicle assembly and the propellant tank integration operations taking place at the node. These capabilities assume that there are on-orbit accommodations for only one LTV at a time.

The shaded lines (upper group) represent the increase in capability when two LTVs are available. One LTV is at the accommodation facility while the other is on a mission. This option is limited by the duration of the mission (Lunar surface stay time). This option considered feasible only if the total time required at the facility is less than the mission duration.

For any of these options, the region above the line indicates a requirement to have multiple accommodations at the node in order to support the LTV flight rate. The region below the curve indicates that the flight rate requirement is satisfied with a single accommodation facility.

LTV flight rate requirements for the current mission options can be supported by a single accommodation facility.

# TRANSPORTATION NODE LTV SUPPORT CAPABILITY
## Varying Lunar Surface Stay, Launch Rates & Assembly Times




ASSUMPTIONS:
- reusable LTV - 5 flights
- Only one LTV at accommodation facility at a time
- LTV stays in LLO during surface stay

* Assuming One 8 Hour Shift/Day

GDSS-ISTD1-0102N

## TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
### Outline

- INTRODUCTION
- REQUIREMENTS
- LUNAR TRANSFER VEHICLE ACCOMMODATIONS
- MARS TRANSFER VEHICLE ACCOMMODATIONS
- CONCLUSIONS

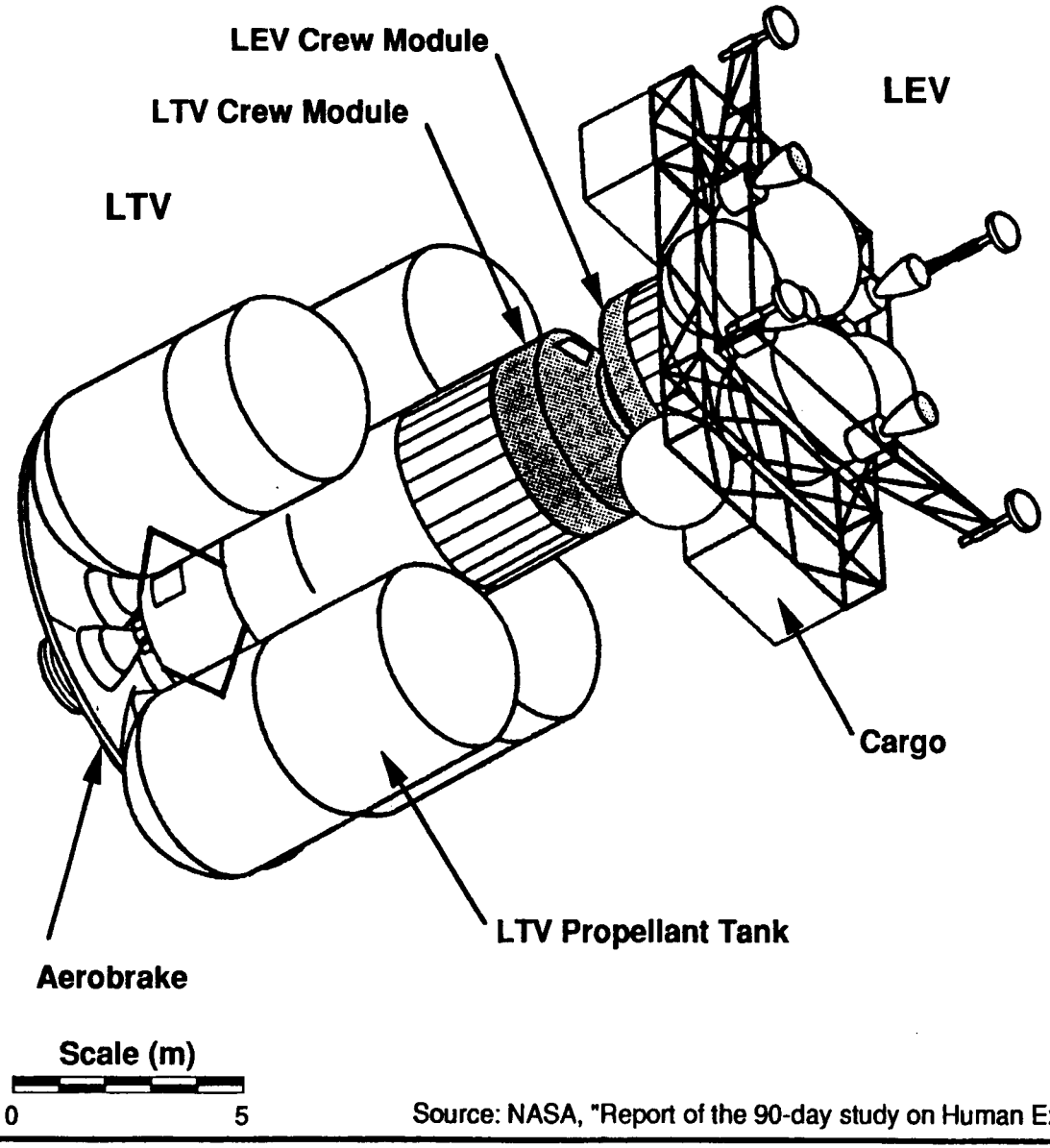
# LUNAR TRANSFER VEHICLE
## Vehicle Description

The baseline Lunar Transfer Vehicle /Lunar Excursion Vehicle (LTV/LEV) design used during this analysis is shown below. This is the all cryogenic aerobraked version capable of delivering 25.6t of cargo to the lunar surface in a reusable mode.

The LTV consists of three major components: a large expendable tankset (4.4m dia x 9.9m long), a smaller expendable tankset (4.4m dia x 6.5m long), and a central core with aerobrake (7.6m dia x 12.2m long). Because the aerobrake is 13.7m in diameter, on-orbit assembly is required. The LEV is delivered in a single piece that packages into 7.6m dia x 6.8m long.

If a piloted mission is required an LTV and LEV crew modules are used. These components are 4m and 2.8m long respectively, and 4.5m in diameter. Mass properties are shown below.

# LUNAR TRANSFER VEHICLE
## Vehicle Description




**TYPICAL DELIVERY SEQUENCE:**
**3 Launches**

1) LTV, LEV & Payload (STS-C')
2) LTV Propellant Tanks (2) (STS-C)
3) LTV Propellant Tanks (2) (STS-C)

**LTV MASS PROPERTIES SUMMARY (t)**

| | |
|---|---|
| LTV | 158.3 |
| CORE | 22.7 |
| Inert | 8.1 |
| Crew Module | 7.6 |
| Propellant | 7.0 |
| PROP TANKS | 135.6 |
| Inert | 5.8 |
| Propellant | 129.8 |
| LEV | 31.8 |
| Inert | 5.8 |
| Crew Module | 3.6 |
| Propellant | 22.4 |
| CARGO | 25.6 |
| TOTAL | 215.7 |

Source: NASA, "Report of the 90-day study on Human Exploration of the Moon and Mars", November 1989

GDSS-ISTD1-0103N

# TYPICAL LUNAR MISSION SCENARIO
## Transportation Node / Infrastructure Element Interfaces

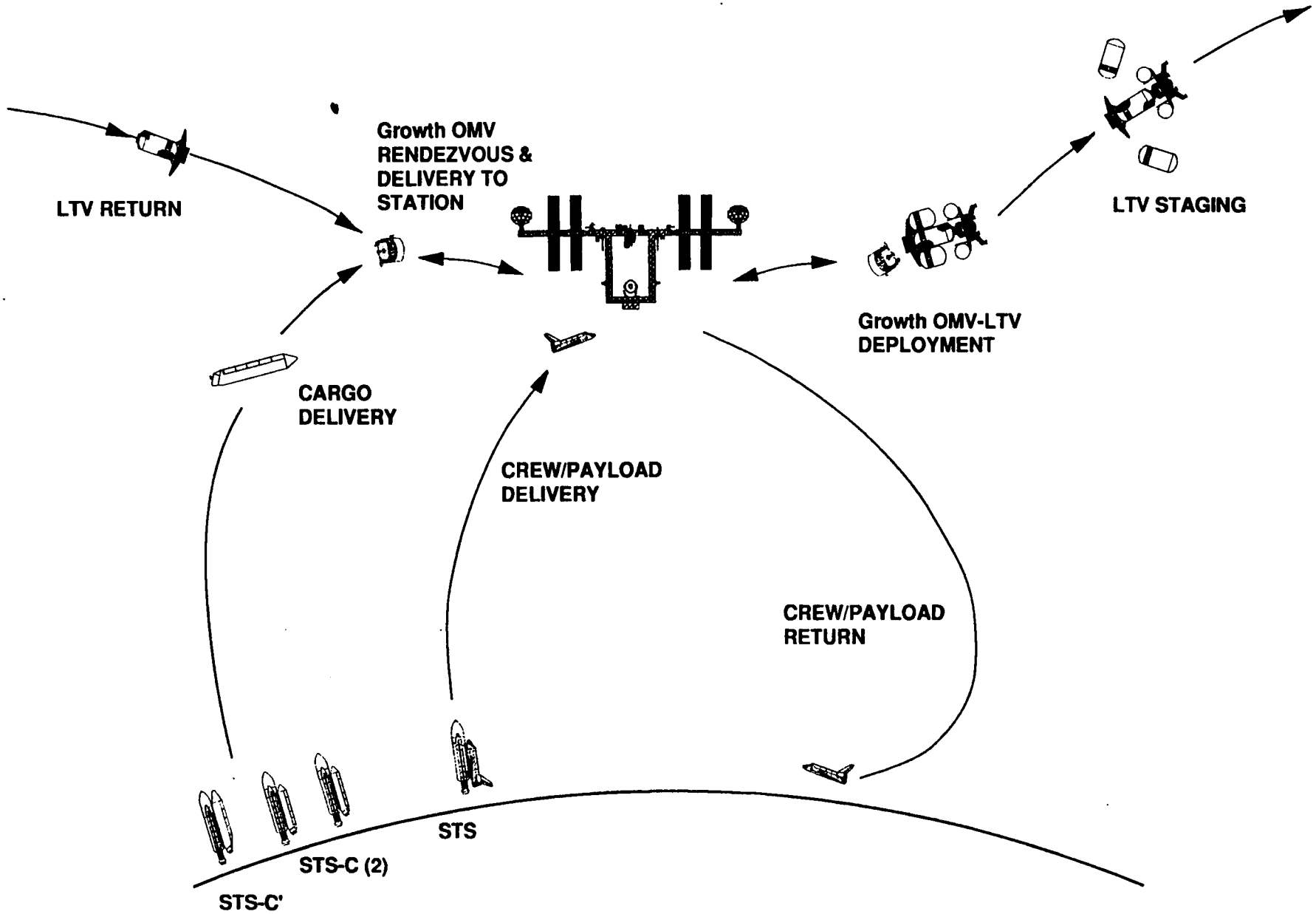
There are several infrastructure elements which must interface with the transportation node in support of a typical lunar mission scenario. These elements include ETO cargo and crew delivery vehicles, vehicles to provide transportation between cargo vehicles or returning spacecraft and the node, and the interface with the LTV for assembly, integration, and maintenance.

ETO cargo vehicles can have a significant impact on the operations at the transportation node. This is a function of the lift capability and the geometric cargo envelope of the vehicle. These factors affect the amount of vehicle assembly that must be done because of element sizing, and the number of elements, particularly propellant tanks that must be delivered and integrated on-orbit. The ETO vehicles considered are the STS-C (used for propellant delivery) with a 71t lift capability and a 4.6m dia payload carrier, and the STS-C' (used for vehicle and aerobrake delivery) with a 61t lift capability and a 7.6m dia payload carrier.

The transfer of cargo between the ETO vehicle and the node is performed by a growth version of the orbital maneuvering vehicle (OMV). The capabilities of the growth OMV are determined by the lift capability of the ETO vehicle, and the size of the cargo it delivers. For the defined cargo vehicles, the growth OMV must have the capability to transfer a 71t payload and see around a 7.6m diameter payload.

Crew delivery and return, and some payload delivery and return are performed by the STS.

# TYPICAL LUNAR MISSION SCENARIO
## Transportation Node / Infrastructure Element Interfaces




GDSS-ISTD1-0104N

# LTV ACCOMMODATIONS OPTIONS

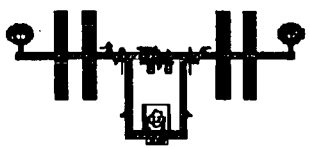
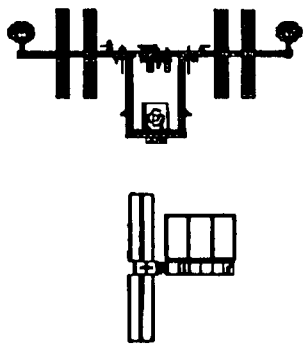
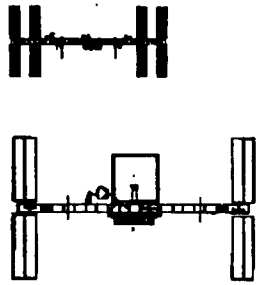
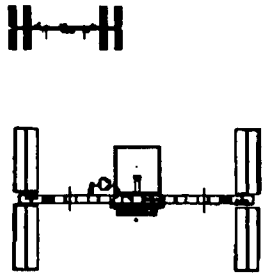
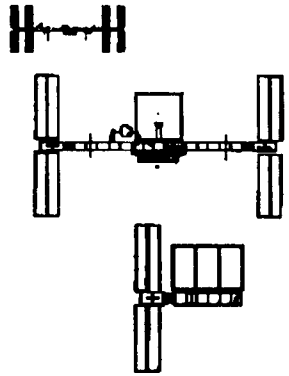
Five primary transportation node concepts have been identified for Lunar Transfer Vehicle (LTV) accommodations. These configurations range from those utilizing an evolved SSF to a node separate from SSF for vehicle integration and assembly.

Options one and two are based on evolving the current SSF into a transportation node. These two options are similiar with the variable being the degree of operational and safety impacts associated with integrating the LTV propellant tanks at SSF.

Option three and four are free flying platform at which vehicle components are assembled and integrated. Scenario 4 is manned and Scenario 3 is man-tended. The LTV is assembled and integrated in a debris protection enclosure at the node. There are no operational impacts to the SSF with the permanently manned option.

Option five is similiar to options three and four with the difference being an additional free flying platform for tank integration.

# LTV ACCOMMODATION OPTIONS

| | OPTION 1 | OPTION 2 | OPTION 3 | OPTION 4 | OPTION 5 |
|---|---|---|---|---|---|
| | ALL ACCOMMODATIONS AT SSF | ACCOMM AT SSF, WITH FREE FLYING PROP INTEG FACILITY | ACCOMM AT MAN-TENDED FREE FLYING PLATFORM | ACCOMM AT PERM MANNED FREE FLYING PLATFORM | PERM MANN FF WITH FREE FLYING PROP INTEG FACILITY |
| CONFIGURATION |  |  |  |  |  |
| DESCRIPTION | All accommodations for option 1 are based at SSF. A drop-keel with a debris protection enclosure (DPE) and additional power modules are the primary additions to the AC station. | Option 2 utilizes a small unmanned free flying node for propellant tank integration. The additions to SSF from Option 1 enable all assembly and integration except for tanks to be done at SSF. | A man-tended free-flying transportation node is used for Option 3. All on-orbit assembly and integration is done at the free-flyer. Crew is delivered from SSF. Hardware for the free-flyer is SSF derived. | A permanently manned free-flying transportation node is used for Option 4. All on-orbit assembly and integration is done at the free-flyer. Hardware for the free-flyer is SSF derived. | Option 5 utilizes a small unmanned free flying node for propellant tank integration. All assembly and integration except for tanks is done at the free-flying node shown in Option 4. |
| MASS PROPERTIES [kg] | Structure..... 4845<br>Power..... 5579<br>DPE..... 4857<br>Habitation..... 0<br>Misc..... 2499<br>Total..... 17770* | Structure..... 6119<br>Power..... 11686<br>DPE..... 9714<br>Habitation..... 0<br>Misc..... 3852<br>Total..... 31371* | Structure..... 5631<br>Power..... 5615<br>DPE..... 4857<br>Habitation..... 24402<br>Misc..... 4363<br>Total..... 44868 | Structure..... 5631<br>Power..... 5615<br>DPE..... 4857<br>Habitation..... 24402<br>Misc..... 4363<br>Total..... 44868 | Structure..... 6905<br>Power..... 11722<br>DPE..... 9714<br>Habitation..... 24402<br>Misc..... 5716<br>Total..... 58559 |

* Mass statements for Options 1 & 2 which use SSF are only the Δ weight above that of SSF at assembly complete, necessary for LTV accommodations

GDSS-ISTD1-0105N

# LTV ACCOMMODATION OPERATIONS SUMMARY
## By Primary Resource Utilization

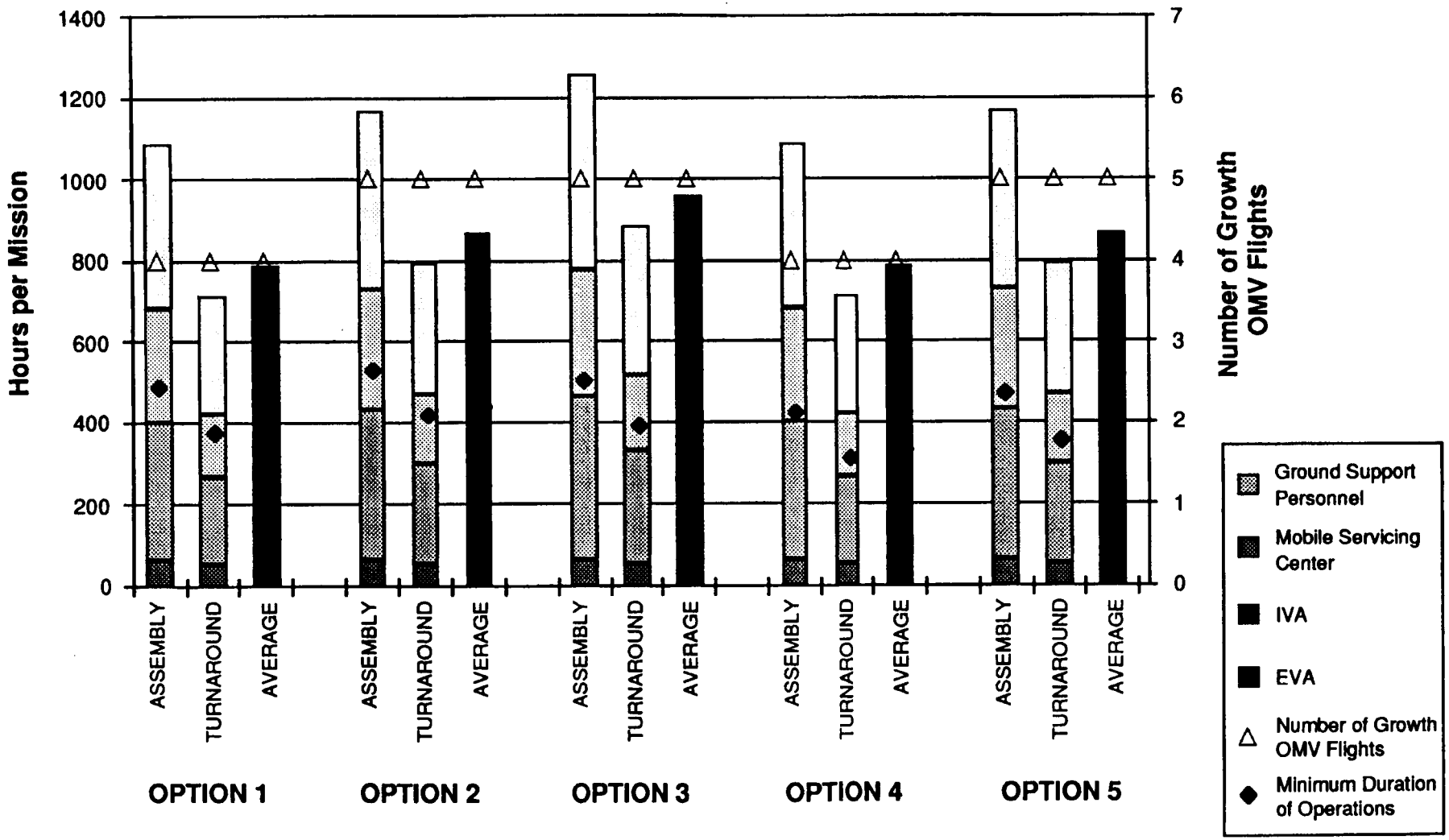
Operational scenarios and timelines for each of the five LTV accommodation options have been generated for comparison purposes. For each LTV scenario in the reusable mode, there is a single assembly and four turnaround missions for a total life of five missions. There are two primary operational sequences required. The first is for assembly of the LTV in preparation for its first of five missions. The second is for turnaround of the vehicle subsequent to its first flight. The average column on the chart below indicates the average of one assembly and four turnaround missions.

There are several resources used for on-orbit operations to support LTV missions, and the utilization of these resources has been identified in our analyses. The primary resources we identify include EVA, IVA, use of the mobile servicing center (MSC), and ground support personnel (GSP). The hours shown on this chart are the cumulative hours for each of these resources over the duration of the assembly or turnaround operations. EVA hours include the time for two EVA astronauts, and the GSP hours include the time for ten personnel.

The line showing minimum duration of operations is the sequential duration of the operations in terms of the estimated time the operations take. It is less than the hours per mission because some tasks take place in parallel. If one eight hour shift per day were assumed, then an operation with a minimum duration of 480 hours would take 60 working days to complete.

The triangles shown on the chart correspond with the axis on the right and indicate the number of growth OMV flights necessary to support the given operations.

# LTV ACCOMMODATION OPERATIONS SUMMARY
## By Primary Resource Utilization




Average hours are for a vehicle life of 5 missions: 1 assembly and 4 turnaround.

GDSS-ISTD1-0112N

# LTV ACCOMMODATION OPERATIONS COSTS
## By Primary Resource Utilization

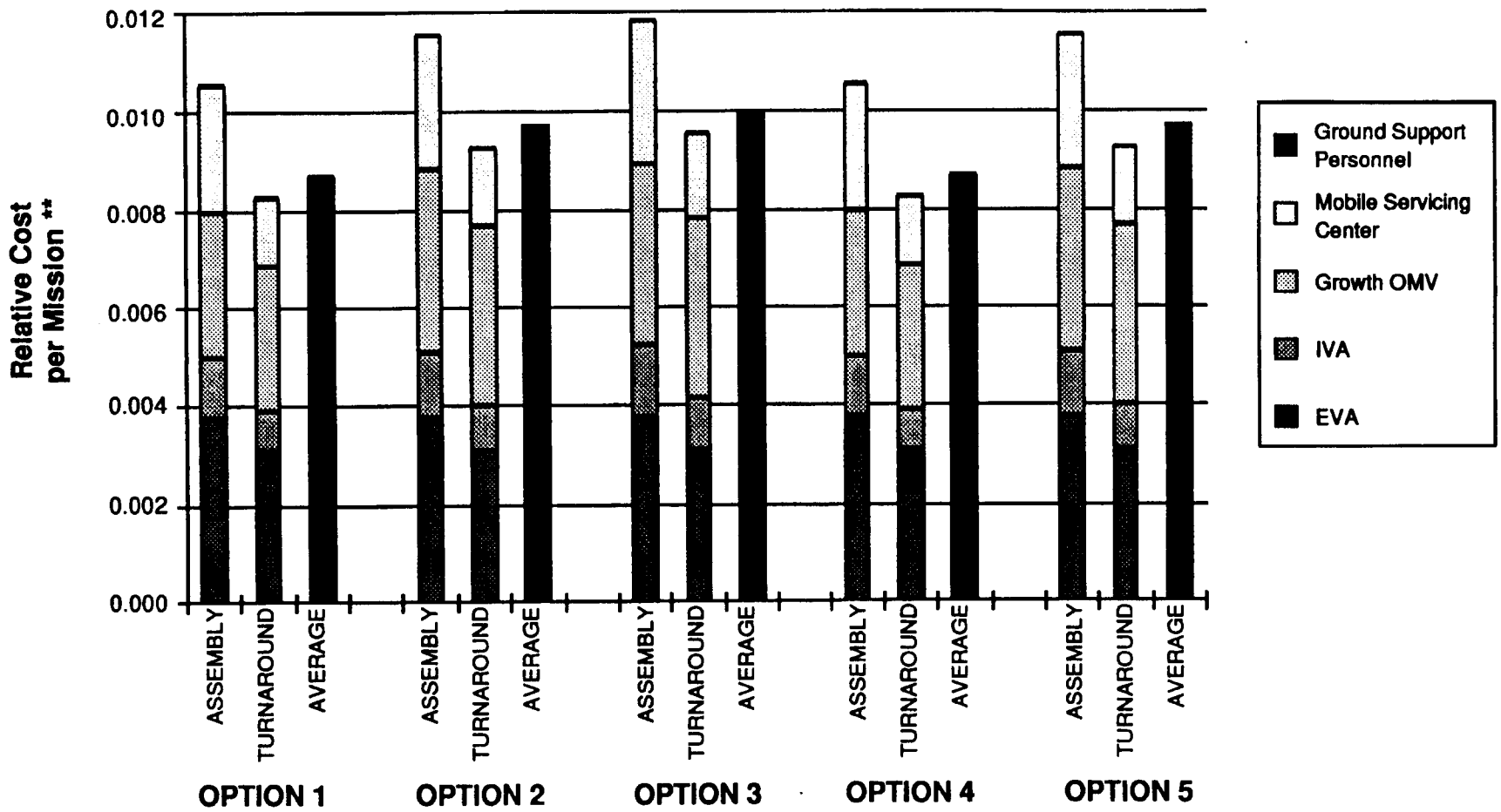
The hours identified in the previous chart have been multiplied by estimates of the costs of each of the respective resources to generate cost estimates of each of the LTV accommodation options.

EVA costs estimates per hour for two EVA astronauts have been applied for each hour shown on the previous chart. IVA costs estimate per hour for a single IVA astronaut have been similarly applied. Costs for each flight of the growth OMV have been included. The MSC costs estimates per hour have been included, as well as GSP costs per hour which include 10 personnel.

The costs shown on this chart are estimates for comparison purposes and do not include many other costs which would be associated with on-orbit accommodations for transfer vehicles. These costs are maintenance and repair of the facility, logistics resupply, and additional GSP which are necessary for regular operation and monitoring of on-orbit assets.

This analysis was intended to be comparative between the options being considered and not an estimate of the total actual costs associated with on-orbit operations.

# LTV ACCOMMODATION OPERATIONS COSTS
## By Primary Resource Utilization




* Average costs are for a vehicle life of 5 missions: 1 assembly and 4 turnaround.
** Relative costs are shown for comparison purposes only.

GDSS-ISTD1-0114N

# LTV ACCOMMODATION OPTIONS EVALUATION

There are several criteria which should be used in the evaluation of alternative LTV accommodation options. These include the relative cost of the alternatives (DDT&E, production, and operations), the schedule and technical risk associated with each option, the complexity of operations, the impact to the LTV design of each option, the degree of on-orbit safety, and the impacts to SSF in terms of disturbances to on-going science activities as well as software hooks and hardware scars necessary for evolution and growth.

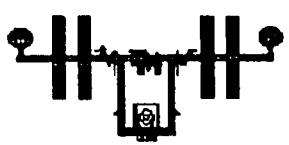
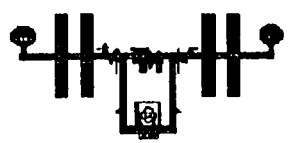
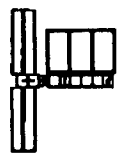
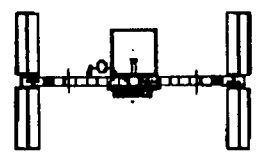
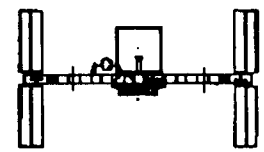
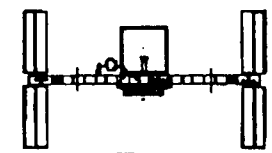
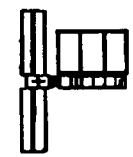
All relative cost estimates are in constant year dollars. The relative DDT&E and production costs include the NASA provided wraparound factors and the operations costs exclude the NASA provided wraparound factors.

Each of the options being considered has been evaluated against each of these criteria and assigned a relative ranking of high, medium, or low. The ***most*** favorable option(s) for each criteria has been highlighted. For all criteria, the low ranked options are most favorable.

Options 1, 3 & 4 are all good options which can meet the requirements and have good rankings for most of the criteria. The costs associated with DDT&E and production of Option 1 are somewhat higher than those of Options 3 & 4, and this is primarily because they include the development of solar dynamic power modules. The free-flying concepts were designed with low acquisition cost in mind and thus incorporated solar panels rather than solar dynamics. The major drawback of Option 1 is the relatively high impact it has on SSF, particularly on the scientific activities at the station. Additionally, if the IOC is moved prior to 2004 the schedule risks become severe for Option 1. The primary disadvantage of Options 3 & 4 are the additional schedule risks and operational considerations of multiple platforms in orbit.

Options 2 and 5 did not satisfy the evaluation criteria nearly as well as the other options and are not considered good options.

# LTV ACCOMMODATION OPTIONS EVALUATION

| | OPTION 1 | OPTION 2 | OPTION 3 | OPTION 4 | OPTION 5 |
|---|---|---|---|---|---|
| | ALL ACCOMMODATIONS AT SSF | ACCOMM AT SSF, WITH FREE FLYING PROP INTEG FACILITY | ACOMM AT MAN-TENDED FREE FLYING PLATFORM | ACCOMM AT PERM MANNED FREE FLYING PLATFORM | PERM MANN FF WITH FREE FLYING PROP INTEG FACILITY |
| CONFIG-URATIONS |  |   |  |  |   |
| RELATIVE DDT&E COST** | MED 0.61* | HIGH 0.89* | LOW 0.52 | LOW 0.52 | HIGH 0.80 |
| REL PRODUC-TION COST** | LOW 0.22* | HIGH 0.39* | LOW 0.24 | LOW 0.24 | HIGH 0.41 |
| RELATIVE LTV OPS COST** | LOW 0.17 | MED 0.20 | MED 0.20 | LOW 0.17 | MED 0.20 |
| SCHED RISK (2004 IOC) | LOW Sufficient time for modifications | MED Additional platform development | MED Development of separate platform | MED Development of separate platform | MED Multiple platform developments |
| TECHNICAL RISK | LOW SSF h/w with new DPE & Sol Dyn | MED SSF common, but automated ops | LOW SSF common elements | LOW SSF common elements | MED SSF common, but automated ops |
| OPERATIONS COMPLEXITY | LOW All ops at SSF, with supervision | MED Tank integ requires automated ops | MED All ops at node, but man-tended | MED All ops at node, but multiple platforms | MED Tank integ requires automated ops |
| LTV DESIGN IMPACTS | LOW Impacts driven by assembly ops | MED Interface with multiple nodes | LOW Impacts driven by assembly ops | LOW Impacts driven by assembly ops | MED Interface with multiple nodes |
| SAFETY CONCERNS | MED All ops at SSF, some hazaradous | LOW Hazardous ops done off SSF | MED Hazardous ops, crew prox to SSF | MED All ops at node, some hazardous | LOW Hazardous ops done at tank integ |
| SSF IMPACTS/ Hooks & Scars | HIGH Hooks & Scars, and μ-G environ | HIGH Hooks & Scars, and μ-G environ | LOW Minimal impact on SSF - only crew | LOW No impact on SSF | LOW No impact on SSF |
| | Good Option | | Good Option | Good Option | |

* Options 1&2 costs include Solar Dynamics, which the other options do not.
** Cost estimates are preliminary and are relative values for comparison only. Ops Costs are at a flight rate of 1 per year over 20 years.

GDSS-ISTD1-0113-R

# LTV ASSEMBLY SEQUENCE (1 of 3)

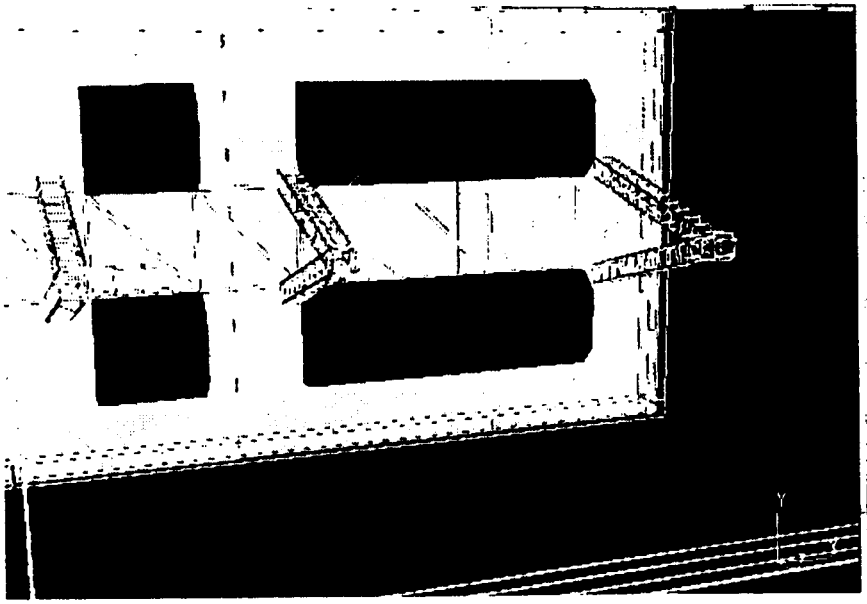
A computer model of SSF evolved to accommodate LTV operations was developed on GEOMOD to aid in visualizing and understanding the assembly operations and requirements. A model of the LTV was also developed, to be used with the accommodation concept.

The chart below is the first of three which identify the LTV assembly sequence inside the debris protection enclosure (DPE). The first four steps involved in the assembly buildup the aerobrake and the core module of the LTV.

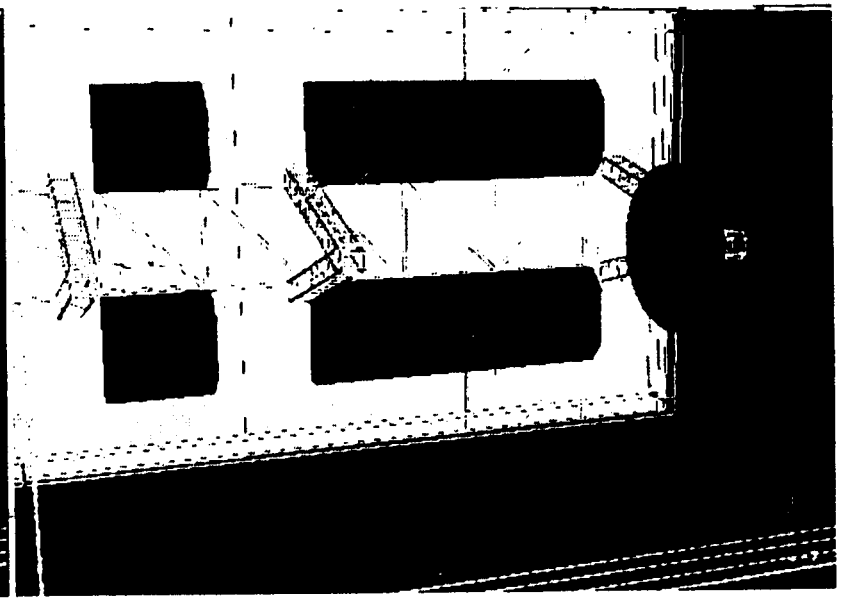
The first step shows the empty enclosure in a dormant mode prior to the delivery of any LTV components. The three raised trusswork elements are the LTV mounting and support fixtures. The fixtures on either end are fitted with a rotary berthing fixture (RBF) which provides the mechanical, electrical and fluid interfaces between the accommodation facility and the vehicle. The dark elements in the empty enclosure are the storage facilities for accommodation equipment and ORU's.

Step 2 shows the position of the core segment of the aerobrake as it is mounted with the RBF. The remainder of the aerobrake is shown mounted to the core aerobrake segment in Step 3. The P/A module and core structure of the LTV are shown mounted to the assembled aerobrake in Step 4 of the assembly process.

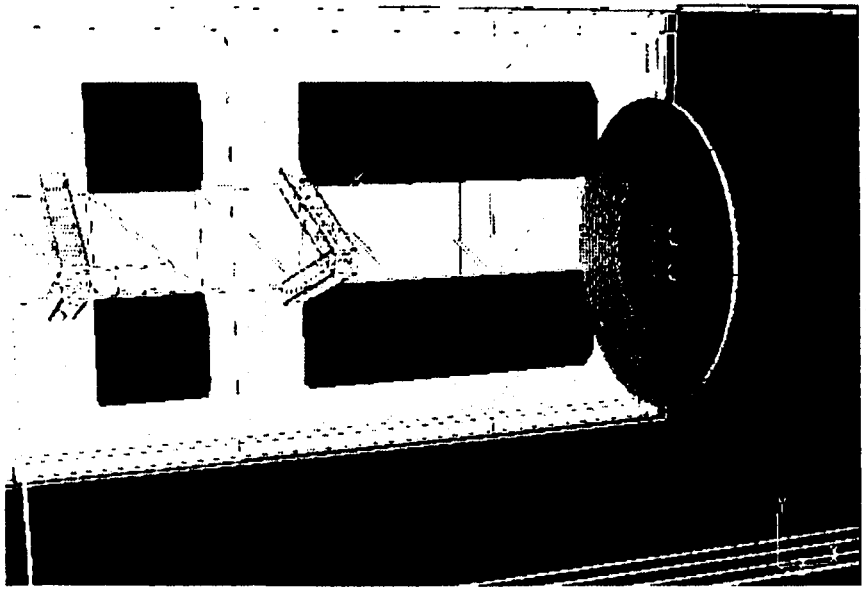
# LTV ASSEMBLY SEQUENCE (1 of 3)



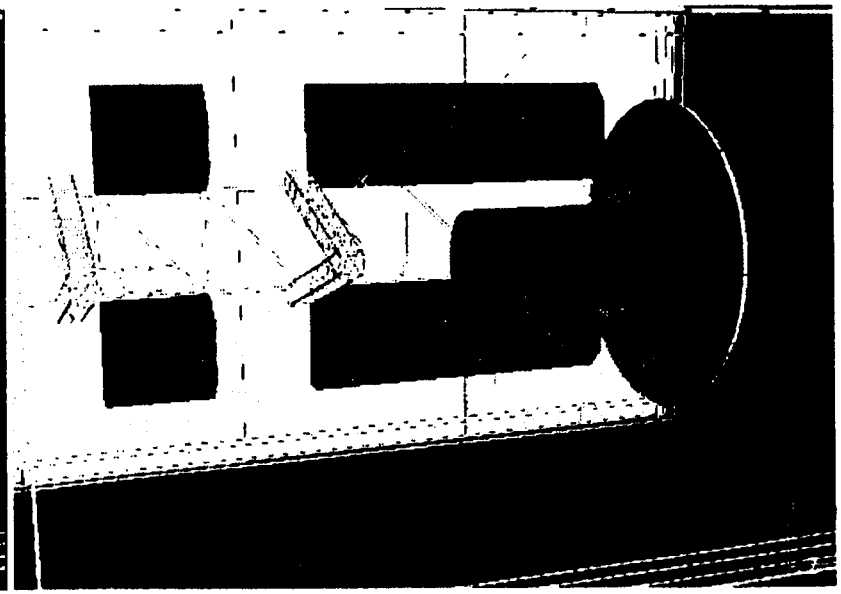
STEP 1: EMPTY ENCLOSURE



STEP 2: AEROBRAKE CORE



STEP 3: AEROBRAKE SEGMENTS



STEP 4: P/A MODULE & CORE STRUCTURE

GDSS-ISTD1-0129N

# LTV ASSEMBLY SEQUENCE (2 of 3)

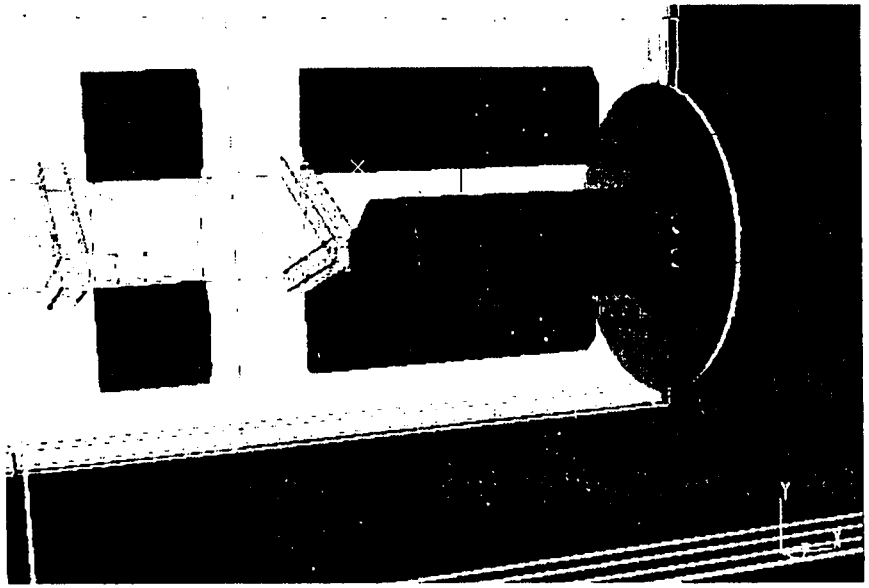
A computer model of SSF evolved to accommodate LTV operations was developed on GEOMOD to aid in visualizing and understanding the assembly operations and requirements. A model of the LTV was also developed, to be used with the accommodation concept.

The chart below is the second of three which identify the LTV assembly sequence inside the debris protection enclosure (DPE). This set of steps (5 through 8) identifies the integration of the crew modules and the LEV along with the payload that is to go to the moon.

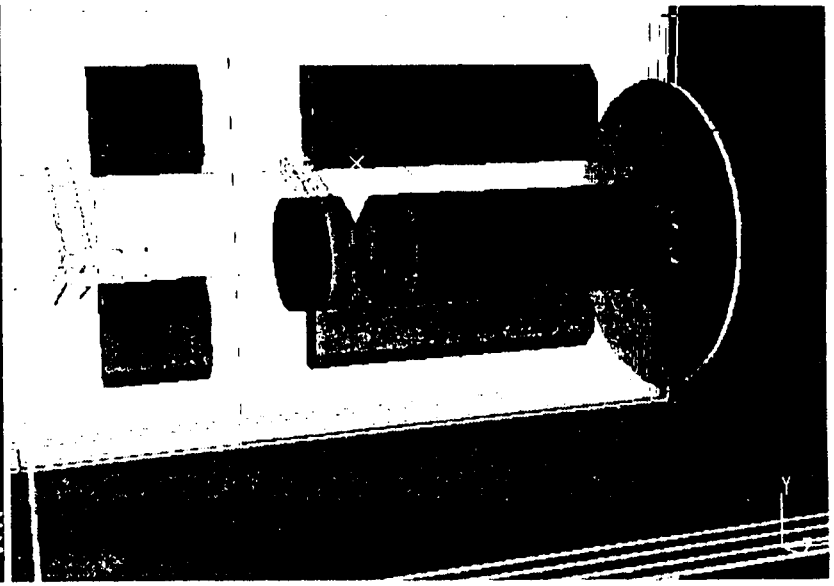
Step 5 of the assembly process integrates the LTV crew module with the core segment and aerobrake. The LTV crew module mounts to the center support in the DPE.

The LEV crew module is mated with the LTV crew module in Step 6, and the LEV is integrated with the rest of the LTV in Step 7. Payload to be delivered to the lunar surface by the LEV is integrated with that vehicle in Step 8 of the process.

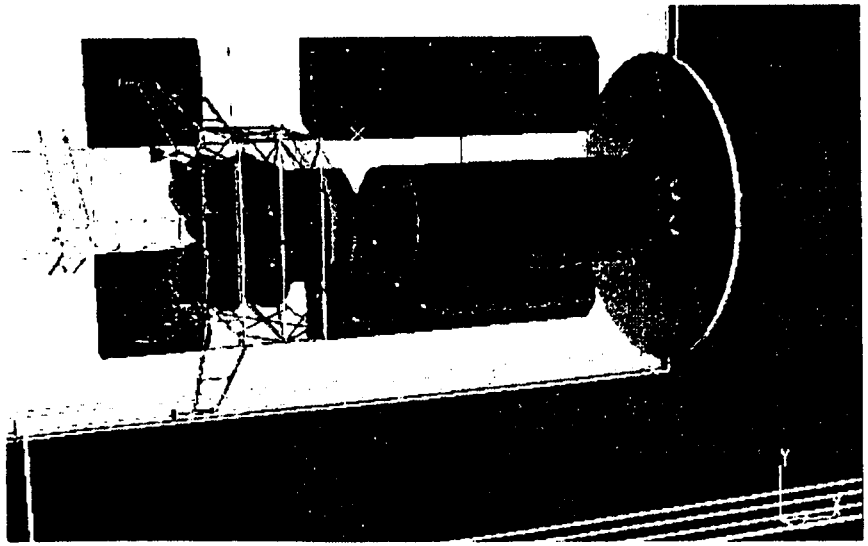
# LTV ASSEMBLY SEQUENCE (2 of 3)



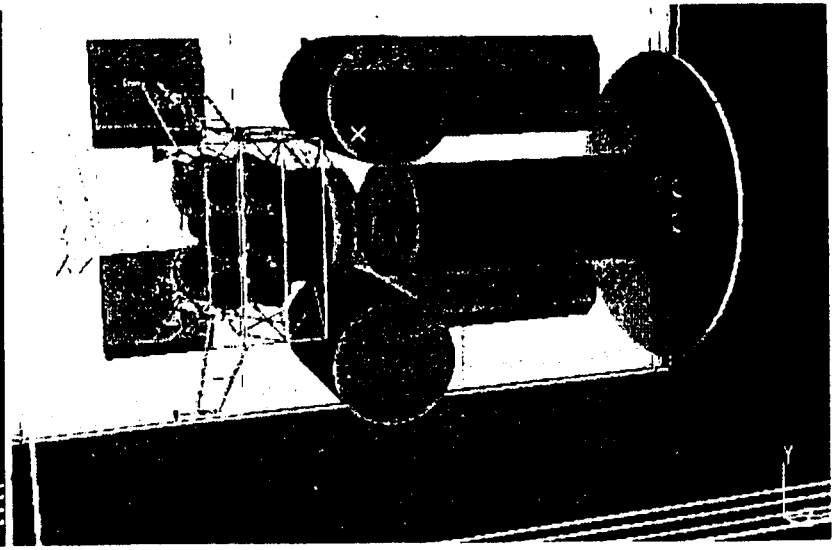
STEP 5: LTV CREW MODULE



STEP 6: LEV CREW MODULE



STEP 7: LEV INTEGRATION



STEP 8: LEV PAYLOAD INTEGRATION

GDSS-ISTD1-0130N

# LTV ASSEMBLY SEQUENCE (3 of 3)

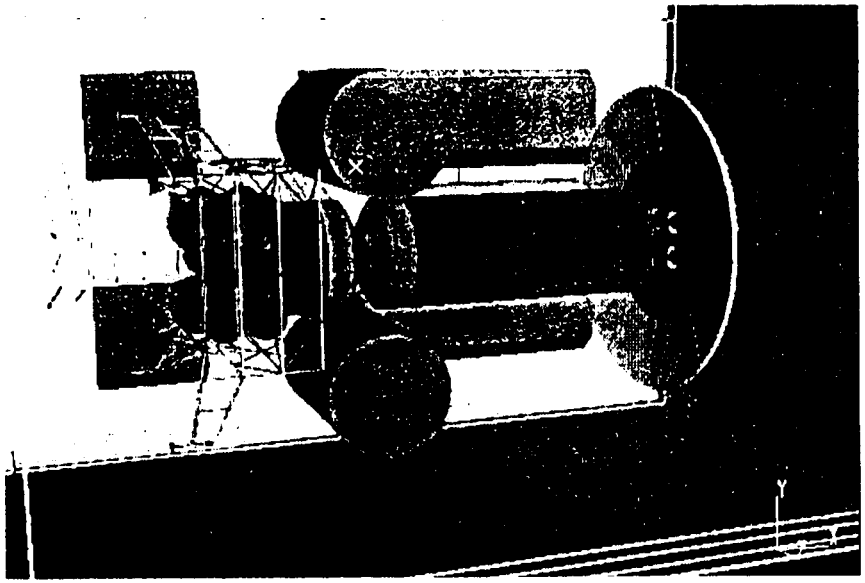
A computer model of SSF evolved to accommodate LTV operations was developed on GEOMOD to aid in visualizing and understanding the assembly operations and requirements. A model of the LTV was also developed, to be used with the accommodation concept.

The chart below is the third of three which identify the LTV assembly sequence inside the debris protection enclosure (DPE). This set of steps identifies the integration of the propellant tanks with the assembled LTV core and the LEV.

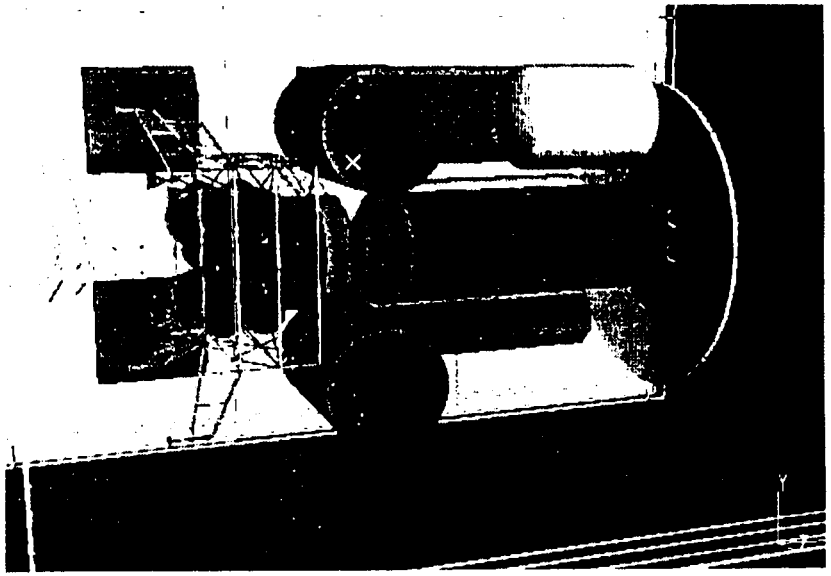
The first tank is integrated in Step 9. It is hidden behind the LTV core module and is only partially visible. There are two each of two different sized tanks to be integrated. The first tank is one of the large tanks.

The first small tank is integrated in Step 10, with the second large tank in Step 11 and the final tank in Step 12. This sequence completes the assembly of the LTV at the SSF based accommodation facility.

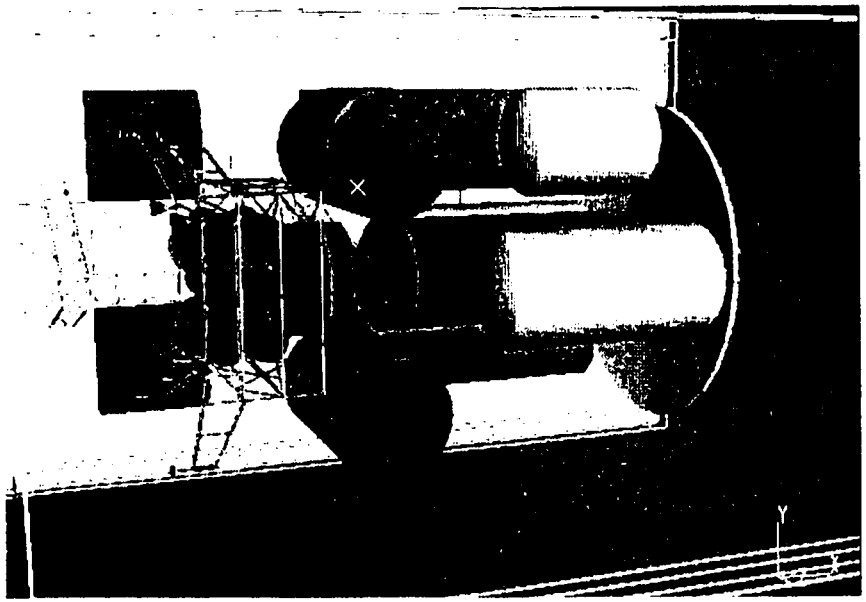
# LTV ASSEMBLY SEQUENCE (3 of 3)



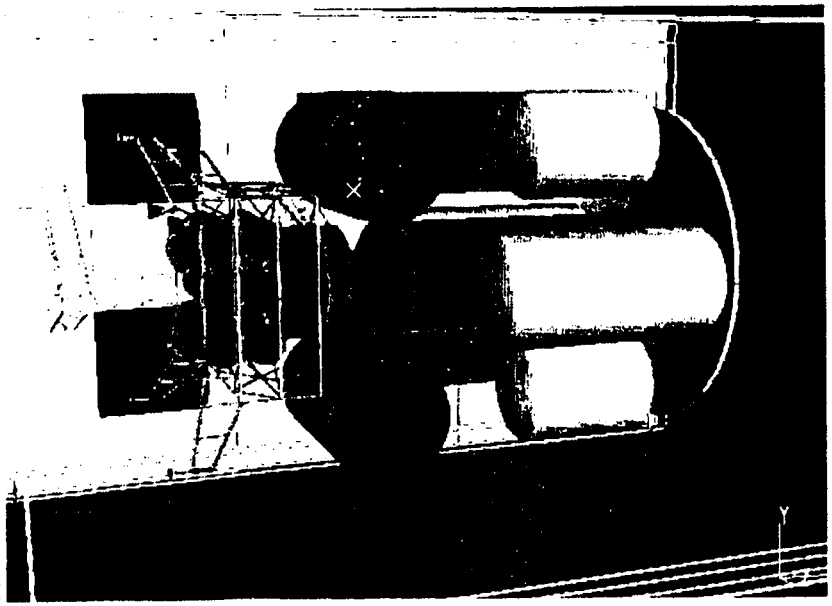
STEP 9: FIRST PROPELLANT TANK



STEP 10: SECOND PROPELLANT TANK



STEP 11: THIRD PROPELLANT TANK



STEP 12: FINAL PROPELLANT TANK

GDSS-ISTD1-0131N

# LTV ACCOMMODATIONS TECHNOLOGY REQUIREMENTS

There are a number of technologies which must be developed to support on-orbit LTV accommodations. Included in these are thermal control, zero g vent and low g propellant mass gauging for the LTV propulsion system and tanks. Automated fault detection/isolation and system checkout is an avionics technology requirement.

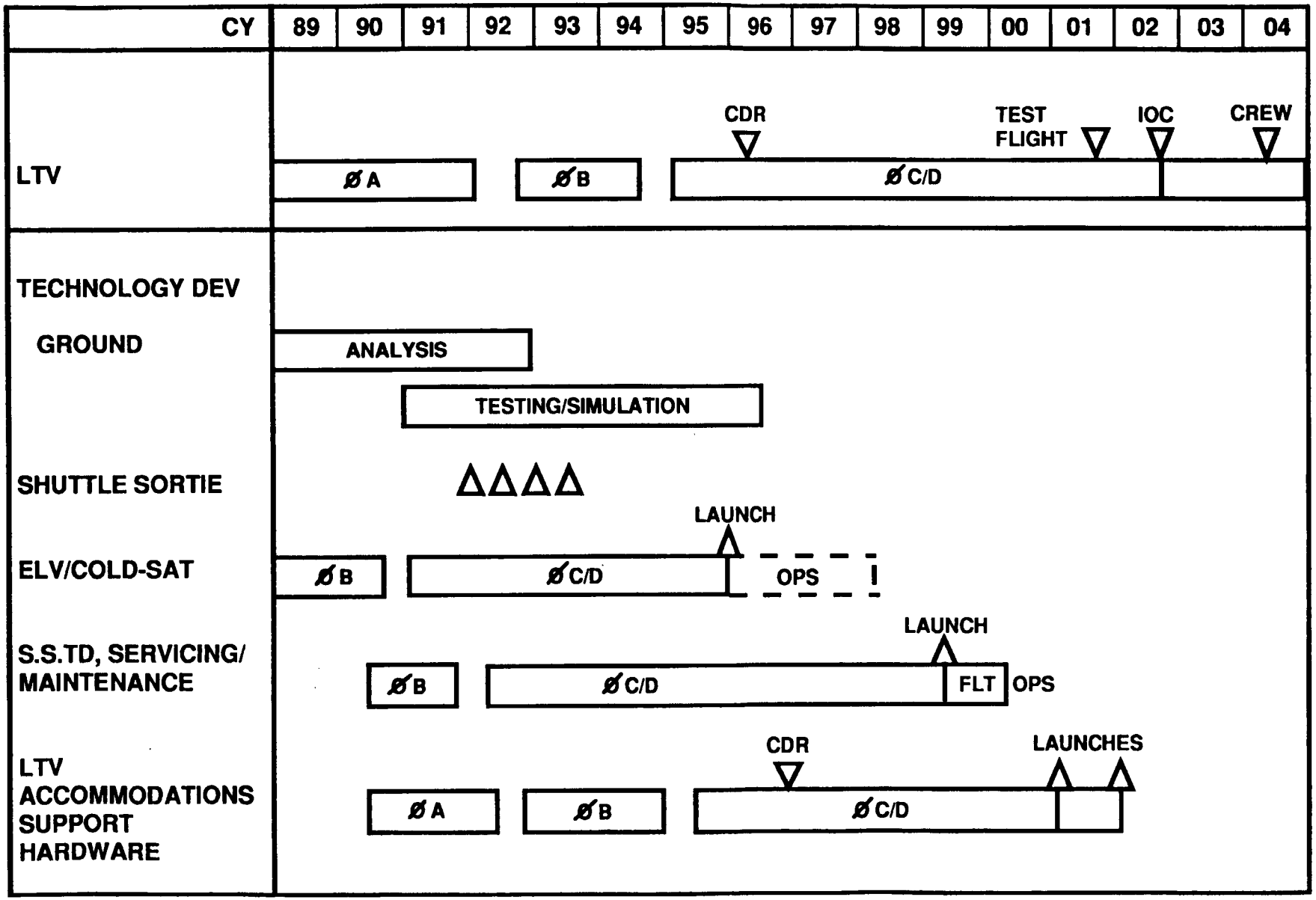
There are several technologies in the structure, materials and manufacturing area that must be developed including multi-use cryogenic vehicles, automated fluid and electrical disconnects, and reusable cryogenic tankage.

Ground and flight operations require the most technology development, particularly in the area of maintenance/servicing operations for the LTV and facilities/support equipment. Technologies in this area include teleoperation/robotics, crew translation equipment, LTV translating, berthing, & rotation equipment, controls and displays, EVA operations, visual inspection and leak check and detection, data management, and facility checkout and operations provisions. Also necessary are technologies for providing payload mating/interfaces for the LTV/LEV and lunar payload, and a automated docking and berthing technologies.

Technology demonstration missions for these technologies should be performed at the Space Station in the 1999 time period to influence the accommodations design in a timely manner. To meet an IOC earlier than 2004, the station will be unavailable for technology demonstration missions.

To support an IOC of 2004 for the man-rated aerobraked LTV, Phase A studies for the LTV accommodations support hardware should begin in 1990. Phase B studies for a space station technology demonstration on servicing and maintenance should begin in 1990 as well.

# LTV ACCOMMODATIONS TECHNOLOGY REQUIREMENTS




GDSS-ISTD1-0109N-L

## TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
## Outline

- INTRODUCTION
- REQUIREMENTS
- LUNAR TRANSFER VEHICLE ACCOMMODATIONS
- MARS TRANSFER VEHICLE ACCOMMODATIONS
- CONCLUSIONS

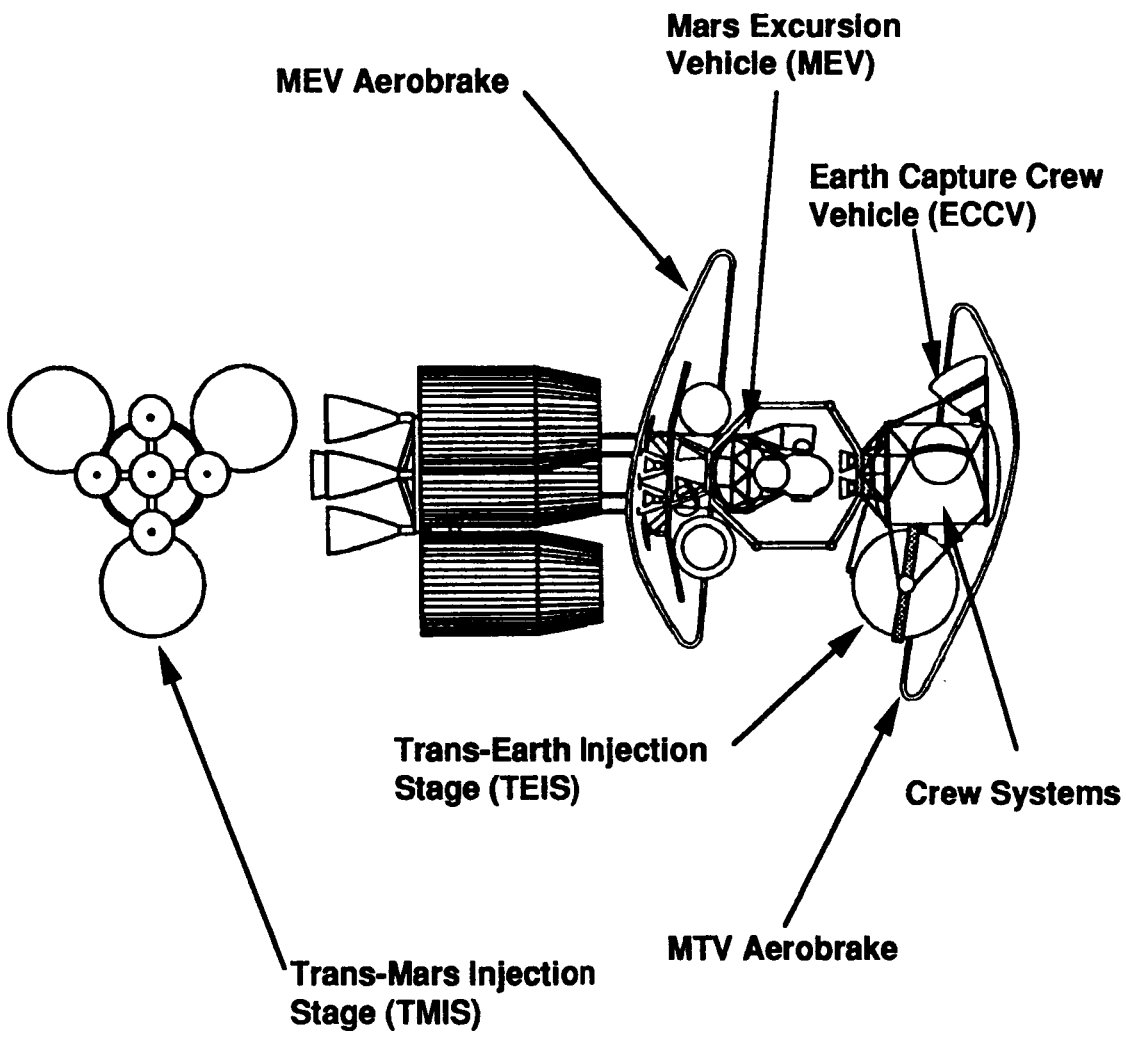
# MARS TRANSFER VEHICLE
## Vehicle Definition

The Mars Transfer Vehicle (MTV) used during this analysis appears below. This 3 component system is all cryogenic and utilizes aerobrakes at both Mars and Earth.

The Mars Excursion Vehicle (MEV) includes a 20m x 30m aerobrake with a 15.5m high ascent/descent stage. The MTV has a similar sized aerobrake with a 15.7m high stage.

The Trans-Mars Injection Stage (TMIS) is 23.7m in length with 4 clustered 8.2m dia tanksets. Mass properties for these components are shown below.

# MARS TRANSFER VEHICLE
## Vehicle Description




**TYPICAL DELIVERY SEQUENCE:**
**7 Launches (HLLV)**

1) Crew Systems, MTV A/B, Equip.
2) TEIS, Ascent Stage, Payload
3) MEV A/B, Descent Stage
4) TMI Stage with Engines
5-7) TMI Stages (1 each)

**MTV MASS PROPERTIES SUMMARY (t)**

| | |
|---|---|
| MEV | 71.6 |
| Crew Module | 3.9 |
| Ascent Stage | 19.2 |
| Descent Stage | 15.2 |
| Aerobrake | 8.3 |
| MEV Payload | 25.0 |
| MTV | 702.7 |
| Crew Module | 33.2 |
| TEIS | 100.7 |
| Aerobrake | 28.6 |
| ECCV | 7.5 |
| Misc "P/L" | 10.0 |
| TMIS / Interstage | 522.7 |
| TOTAL | 774.3 |

Source: NASA, BOEING, "Report of the 90-day study on Human Exploration of the Moon and Mars", November 1989

GDSS-ISTD1-0106N

# TYPICAL MARS MISSION SCENARIO
## Transportation Node / Infrastructure Element Interfaces

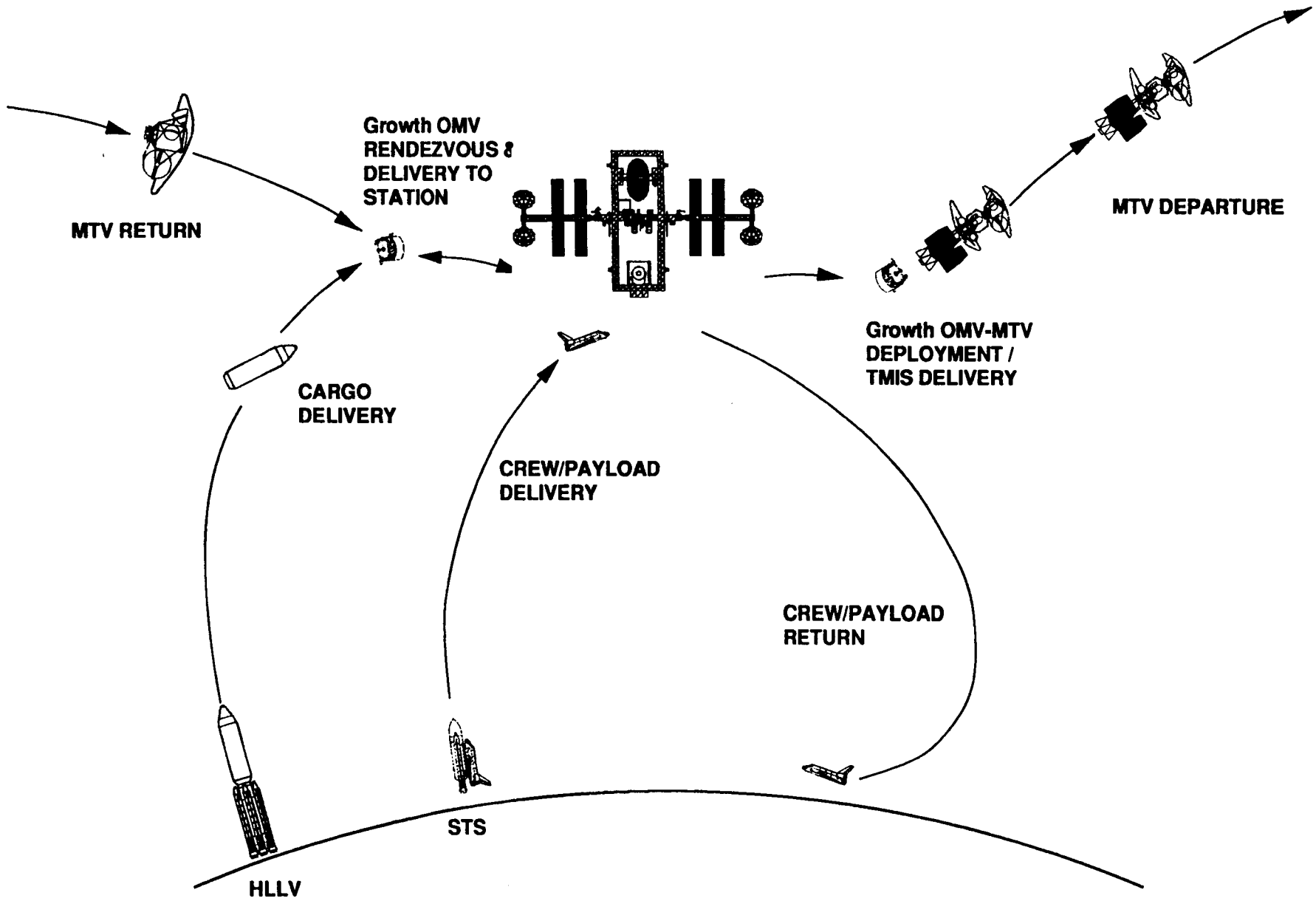
There are several infrastructure elements which must interface with the transportation node in support of a typical Mars mission scenario. These elements include ETO cargo vehicles and crew delivery vehicles, vehicles to provide transportation between cargo vehicles or returning spacecraft and the node, and the interface with the MTV for assembly, integration, and maintenance.

ETO cargo vehicles can have a significant impact on the operations at the transportation node. This is a function of the lift capability and the geometric cargo envelope of the vehicle. These factors affect the amount of vehicle assembly that must be done due to element sizing, and the number of elements, particularly propellant tanks that must be delivered and integrated on-orbit. An ETO vehicle being considered is the shuttle-derived HLLV, with an ETO lift capability of 140t.

The transfer of cargo between the ETO vehicle and the node is performed by a growth version of the orbital maneuvering vehicle (OMV). The capabilities of the growth OMV are determined by the lift capability of the ETO vehicle, and the size of the cargo it delivers. For the defined cargo vehicle, the growth OMV must have the capability to transfer a 140t payload.

Crew delivery and return is performed by the STS.

# TYPICAL MARS MISSION SCENARIO
## Transportation Node / Infrastructure Element Interfaces




GDSS-ISTD1-0107N

# MTV ACCOMMODATION OPTIONS

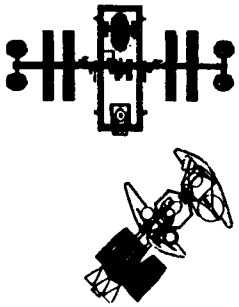
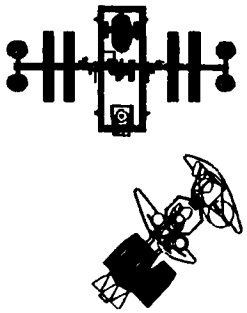
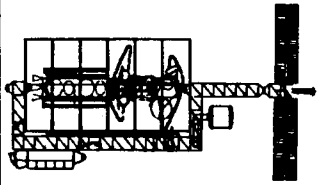
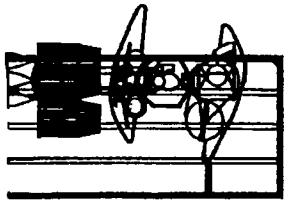
Five primary transportation node concepts have been identified for Mars Transfer Vehicle (MTV) accommodations. These configurations range from those utilizing an evolved SSF to a separate node supporting autonoumous vehicle assembly.

Options one through three are based on evolving the current SSF into a transportation node. These three options are similiar with the variable being the degree of operational impacts involved in transfering MTV components off of SSF for differerent degrees of off-station vehicle integration.

Option 4 portrays a free flying , man-tended platform at which vehicle components are assembled and integrated. The MTV is attached to two rotary joints at either end. These rotate allowing the robotic arm easy access circumferentially around the vehicle and along the strongback. There are no operational impacts to the SSF with this option.

In option five, the MTV autonomously assembles itself while being protected by a free flying debris protection enclosure (DPE).

# MTV ACCOMMODATION OPTIONS

| | OPTION 1 | OPTION 2 | OPTION 3 | OPTION 4 | OPTION 5 |
|---|---|---|---|---|---|
| | AEROBRAKE, MTV,MEV ASSEMBLED & MATED AT SSF | AEROBRAKE, MTV,MEV ASSEMBLED AT SSF, MATED OFF SSF | AEROBRAKE ASSEMBLY AT SSF, MATING OFF SSF | NEW FREE-FLYING NODE | AUTONOMOUS VEHICLE ASSEMBLE AT MTV NODE |
| CONFIGURATION | |  |  |  |  |
| DESCRIPTION | All MTV assembly is done at SSF, with TMIS integ done off the station. An upper keel, debris protection enclosure (DPE), add'l hab module and add'l power modules are the primary additions to the LTV accom station. | Option 2 utilizes similar SSF additions as option 1. Major components of the MTV are assembled at SSF and integrated off the station. TMIS stages are also integrated off the station. | MTV aerobrake assembly is done at SSF which has similar additions to Option 1. After assembly, the aerobrake acts as an integration platform and SSF is not used for the completion of the assembly and integration. | A free-flying transp node is used for Option 4. All on-orbit assembly and integration is done at the free-flyer. Hardware for the free-flyer is SSF derived. The MTV crew module houses the assembly crew. | Autonomous vehicle assembly is maximized for Option 5. A debris protection enclosure is provided, and the MTV uses on-board systems to perform assembly and integration. |
| MASS PROPERTIES [kg] | Structure..... 5,800<br>Power..... 5,579<br>DPE..... 26,104<br>Habitation..... 24,402<br>Misc..... 8,377<br><br>Total..... 70,262* | Structure..... 5,800<br>Power..... 5,579<br>DPE..... 26,104<br>Habitation..... 24,402<br>Misc..... 8,377<br><br>Total..... 70,262* | Structure..... 5,800<br>Power..... 5,579<br>DPE..... 26,104<br>Habitation..... 24,402<br>Misc..... 8,377<br><br>Total..... 70,262* | Structure..... 5,574<br>Power..... 5,616<br>DPE..... 26,104<br>Habitation..... 33,983<br>Misc..... 6,922<br><br>Total..... 78,199 | Structure..... 1,026<br>Power..... 3,297<br>DPE..... 26,104<br>Habitation..... 0<br>Misc..... 4091<br><br>Total..... 34,518 |

* Mass statements for Options 1,2 & 3 which use SSF are only the Δ weight above that for SSF Lunar accommodations, necessary for MTV accommodations

# MTV ACCOMMODATION OPERATIONS SUMMARY
## By Primary Resource Utilization

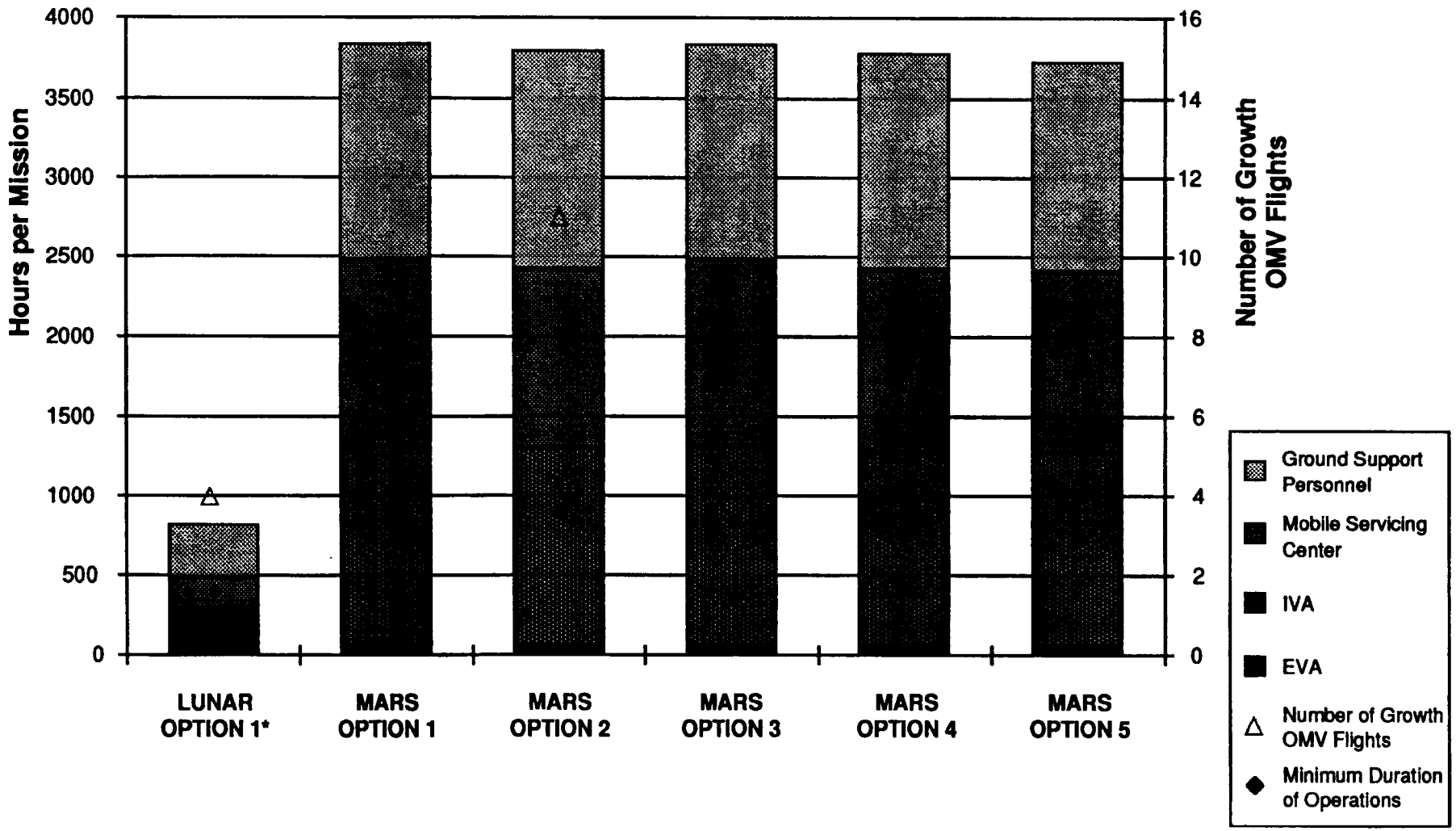
Operational scenarios and timelines for each of the five MTV accommodation options have been generated to develop a sense of the differences between the options.

There are several resources used for on-orbit operations necessary to support MTV missions, and the utilization of these resources has been identified in our analyses. The primary resources we identify include EVA, IVA, use of the mobile servicing center (MSC), and ground support personnel (GSP). The hours shown on this chart are the cumulative hours for each of these resources over the duration of the assembly or turnaround operations. EVA hours include the time for two EVA astronauts, and the GSP hours include the time for ten personnel.

The line showing minimum duration of operations is the sequential duration of the operations in terms of the estimated time the operations take. If one eight hour shift per day were assumed, then an operation with a minimum duration of 480 hours would take 60 working days to complete. These values are lower than the total hours per mission due to parallel operations.

The triangles shown on the chart correspond with the axes on the right and indicate the number of growth OMV flights necessary to support the given operations. There is a significant difference in number of growth OMV flights for the five options, ranging from 11 for Option 2 to only 7 for Option 5.

# MTV ACCOMMODATION OPERATIONS SUMMARY
## By Primary Resource Utilization




*Lunar Option 1 average (Accommodations at SSF) is shown for comparison purposes

GDSS-ISTD1-0116N

# MTV ACCOMMODATION OPERATIONS COSTS
## By Primary Resource Utilization

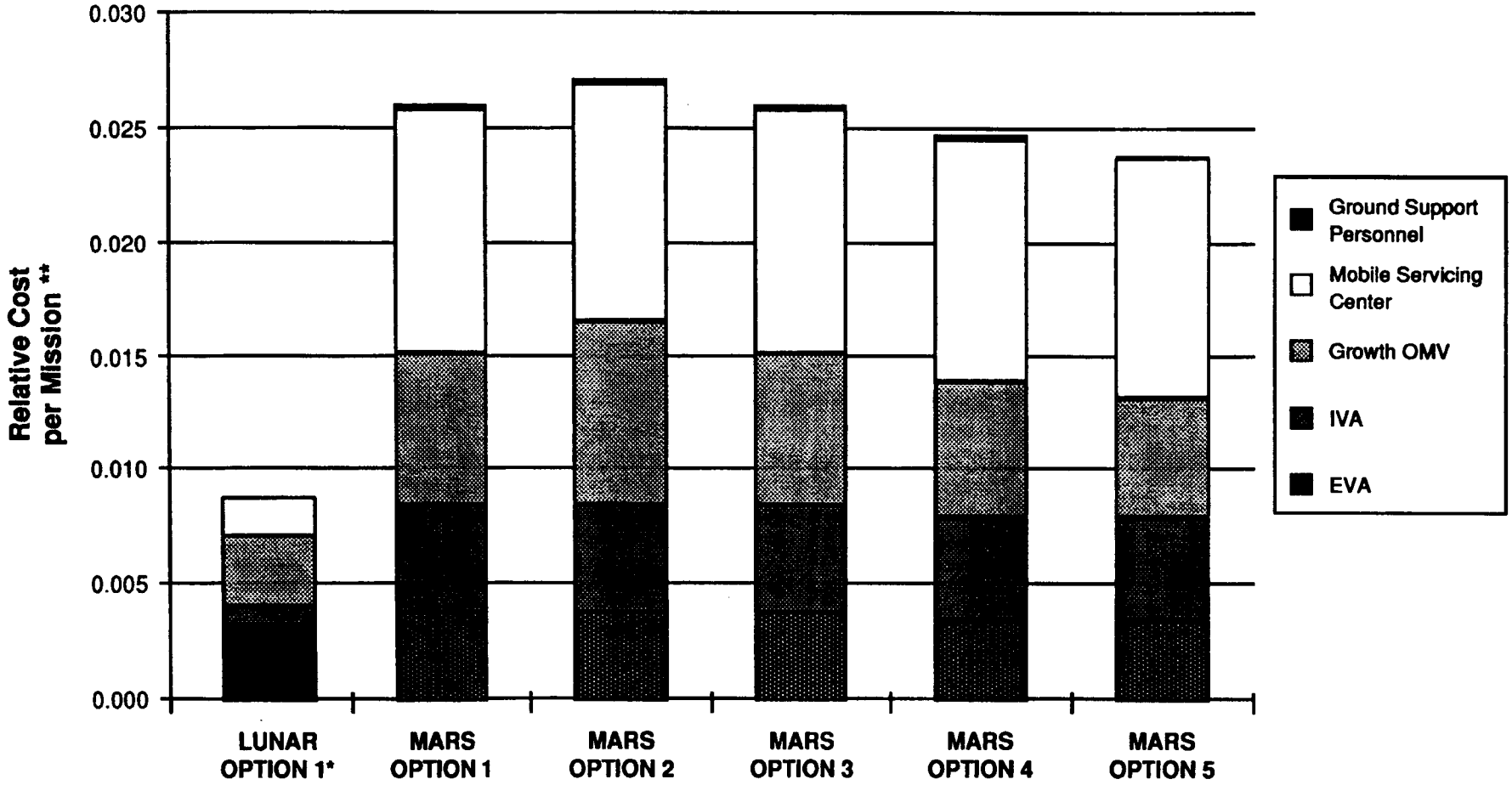
The hours identified in the previous chart have been multiplied by estimates of the costs of each of the respective resources to generate cost estimates of each of the MTV accommodation options.

EVA costs estimates per hour for two EVA astronauts have been applied for each hour shown on the previous chart. IVA costs estimate per hour for a single IVA astronaut have been similarly applied. Costs for each flight of the growth OMV have been included. The MSC costs estimates per hour have been included, as well as GSP costs per hour which include 10 personnel.

The costs shown on this chart are estimates for comparison purposes and do not include many other costs which would be associated with on-orbit accommodations for transfer vehicles. These costs are maintenance and repair of the facility, logistics resupply, and additional GSP which are necessary for regular operation and monitoring of on-orbit assets.

This analysis was intended to be comparative between the options being considered and not an estimate of the total actual costs associated with on-orbit operations.

# MTV ACCOMMODATION OPERATIONS COSTS
## By Primary Resource Utilization




* Lunar Option 1 average cost (Accommodations at SSF) is shown for comparison purposes
** Relative costs are shown for comparison purposes only.

# MTV ACCOMMODATION OPTIONS EVALUATION

There are several criteria which should be used in the evaluation of alternative MTV accommodation options. These include the relative cost of the alternatives (DDT&E, production, and operations), the schedule and technical risk associated with each option, the complexity of operations, the impact to the MTV design of each option, the degree of on-orbit safety, and the impacts to SSF in terms of disturbances to on-going science and LTV accommodation activities as well as software hooks and hardware scars necessary for evolution and growth.

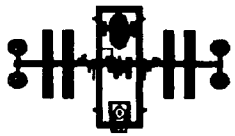
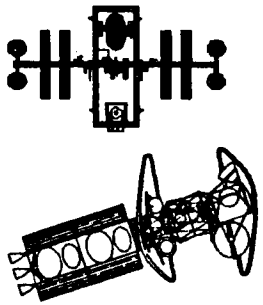
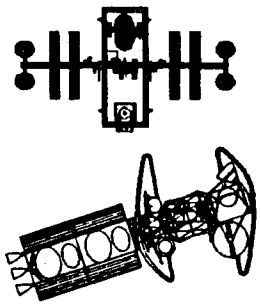
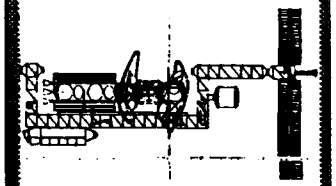
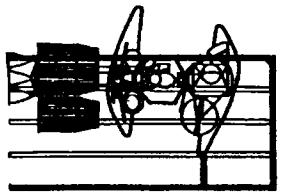
All relative cost estimates are in constant year dollars. The relative DDT&E and production costs include the NASA provided wraparound factors and the operations cost exclude the NASA provided wraparound factors.

Each of the options being considered has been evaluated against each of these criteria and assigned a relative ranking of high, medium, or low. The ***most*** favorable option(s) for each criteria has been highlighted. For all criteria but on-orbit safety, the low ranked options are most favorable.

Option 4, which places the accommodations at a new free-flying transportation node is the preferred option of the five. This option is somewhat higher in DDT&E cost than the other options, but has other advantages which offset this including low operations costs. This option is most favorable in terms of schedule and technical risk, because it has limited technical development, incorporates many SSF developed hardware items, and is allowed ample development time. The operational complexity of Option 4 is relatively low, with all operations occurring at the node and a minimum of transfer of payloads between different platforms or locations. The impact which this option will have on the MTV design is relatively low, and it will have no impacts on SSF.

Using SSF for accommodating the MTV to a lesser degree is feasible, but there would be a high degree of impact on the SSF in terms of scientific disruption as well as software hooks and hardware scars. The autonomous vehicle assembly of Option 5 is somewhat risky from a technical and schedule standpoint. This is because of the added complexity placed on the MTV for performing these tasks in an autonomous mode.

# MTV ACCOMMODATION OPTIONS EVALUATION

| | OPTION 1 | OPTION 2 | OPTION 3 | OPTION 4 | OPTION 5 |
|---|---|---|---|---|---|
| | AEROBRAKE, MTV,MEV ASSEMBLED & MATED AT SSF | AEROBRAKE, MTV,MEV ASSEMBLED AT SSF, MATED OFF SSF | AEROBRAKE ASSEMBLY AT SSF, MATING OFF SSF | NEW FREE-FLYING NODE | AUTONOMOUS VEHICLE ASSEMBLY AT MTV NODE |
| CONFIG-URATIONS |  |  |  |  |  |
| RELATIVE DDT&E COST** | MED 0.61* | MED 0.61* | MED 0.61* | MED 0.61 | LOW 0.37 |
| REL PRODUCT-ION COST** | MED 0.30* | MED 0.30* | MED 0.30* | MED 0.33 | LOW 0.17 |
| REL MTV OPS COST ** | LOW 0.26 | LOW 0.28 | LOW 0.26 | LOW 0.24 | LOW 0.24 |
| SCHED RISK (2013 IOC) | LOW Long lead time, Mod tech devel | LOW Long lead time, Mod tech devel | MED Long lead, but some Adv Tech | LOW Long lead time, Mod tech devel | MED Long lead, but some Adv Tech |
| TECHNICAL RISK | LOW SSF h/w with new DPE | MED SSF common, some autoops | MED SSF common, adv automated ops | LOW SSF common elements | MED SSF common, adv automated ops |
| OPERATIONS COMPLEXITY | LOW All ops at SSF, with supervision | MED Ass'y at SSF, Integ off station | HIGH Most off station, adv automated ops | LOW All ops at node, with supervision | HIGH Requires advanced automated ops |
| MTV DESIGN IMPACTS | LOW Impacts driven by assembly ops | MED Must allow auto integration ops | HIGH A/B impacts and automated ops | LOW Impacts driven by assembly ops | HIGH Built in cap for auto ass'y & integration |
| SAFETY CONCERNS | LOW TMIS integration off station | LOW TMIS & vehicle integ off station | LOW TMIS & vehicle integ off station | MED All ops at node, some hazardous | MED All ops at node, some hazardous |
| SSF IMPACTS/ Hooks & Scars | HIGH Hooks & Scars, and μ-G environ | HIGH Hooks & Scars, and μ-G environ | MED Hooks & Scars, and μ-G environ | LOW No impact on SSF | LOW No impact on SSF |

* Option 1-3 costs include Solar Dynamics, which options 4&5 do not.

** Cost estimates are preliminary and for comparison only in constant year dollars. Ops Costs are for 10 flights over 20 years.

Preferred Option

GDSS-ISTD1-0117N-R

# MTV ASSEMBLY SEQUENCE (1 of 2)

A computer model of the free-flying transportation node designed to accommodate the MTV was developed on GEOMOD to aid in visualizing and understanding the assembly and integration operations and requirements. A model of the MTV was also developed, to be used with the accommodation concept.

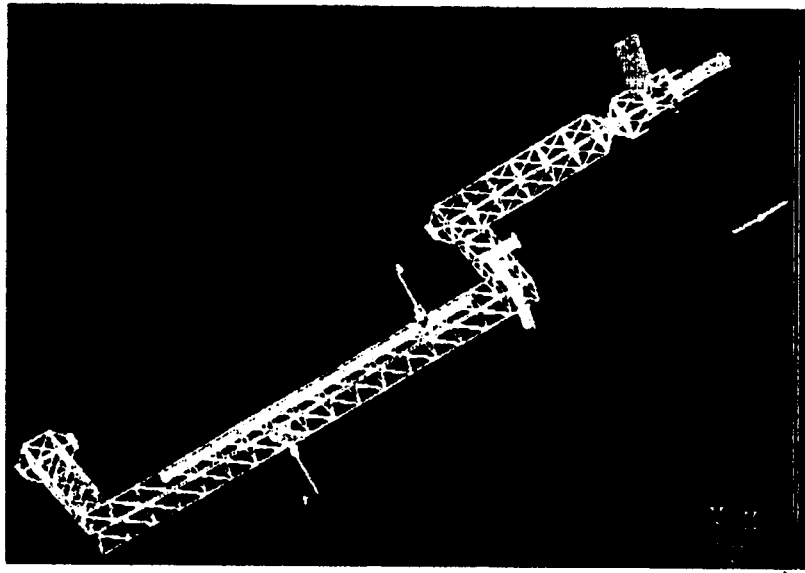
The chart below is the first of two which identify the MTV assembly sequence at the transportation node. For clarity the debris protection enclosure (DPE) is not shown. The first four steps are delivery and integration of the crew module with the node, and buildup of the MTV and MEV aerobrakes.

The first step shows the node in a dormant mode prior to the delivery of any MTV components. The fixtures on either end are fitted with a rotary berthing fixture (RBF) which provides the mechanical, electrical and fluid interfaces between the accommodation facility and the vehicle. The section of truss members opposite the power module on the node is a moveable support which adjusts to the degree to which the MTV is assembled.

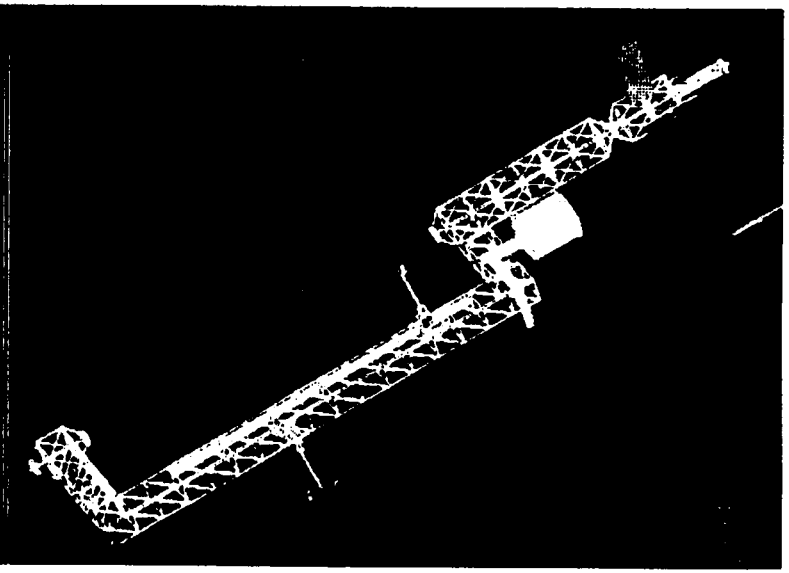
Step 2 indicates shows the crew module integrated into its position on the node for the assembly process. The crew module houses the assembly crew during the assembly, and is connected by pressurized tunnel, to an STS docking fixture. Once assembly is complete, the crew module is integrated with the assembled MTV.

The MTV aerobrake is assembled in Step 3 and integrated with the trans-Earth injection stage (TEIS). The MEV and its aerobrake are assembled and integrated with the MTV aerobrake in Step 4 of the assembly sequence.

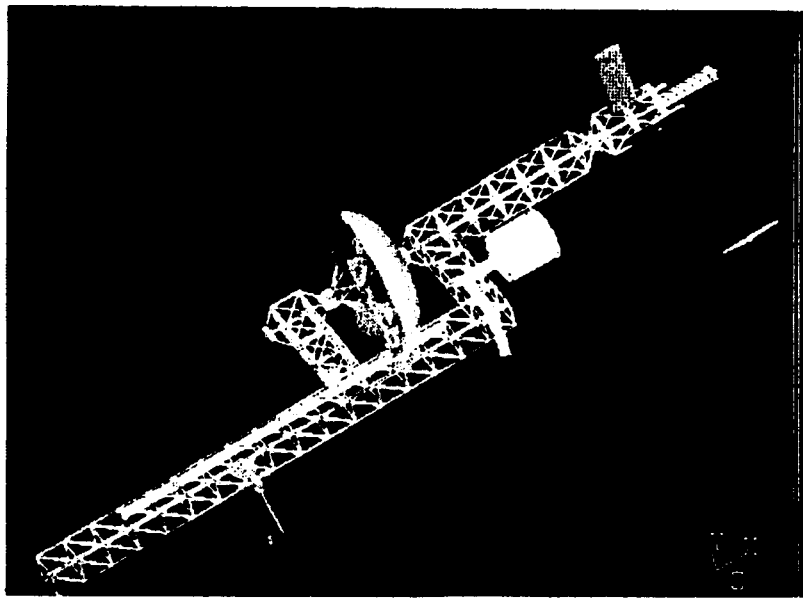
# MTV ASSEMBLY SEQUENCE (1 of 2)



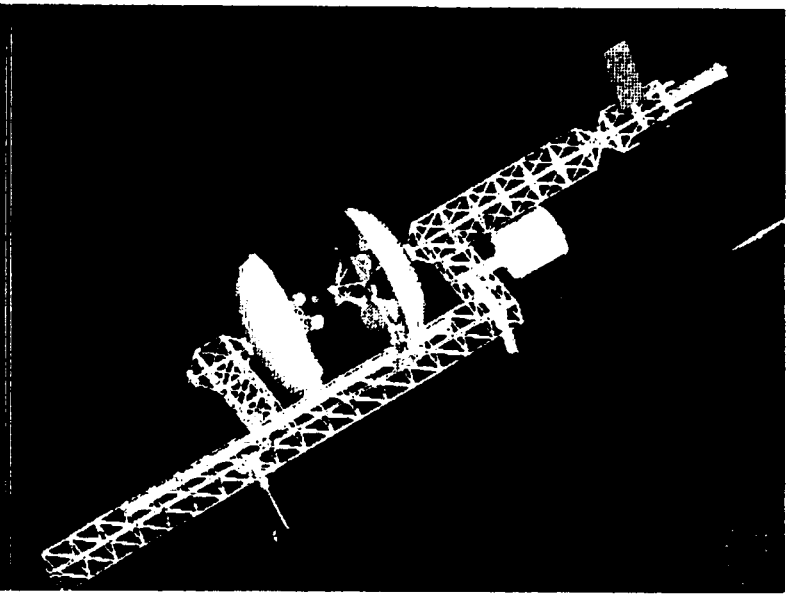
STEP 1: DORMANT NODE



STEP 2: CREW MODULE INTEGRATION



STEP 3: MTV AEROBRAKE ASSEMBLY



STEP 4: MEV & MEV AEROBRAKE ASSEMBLY

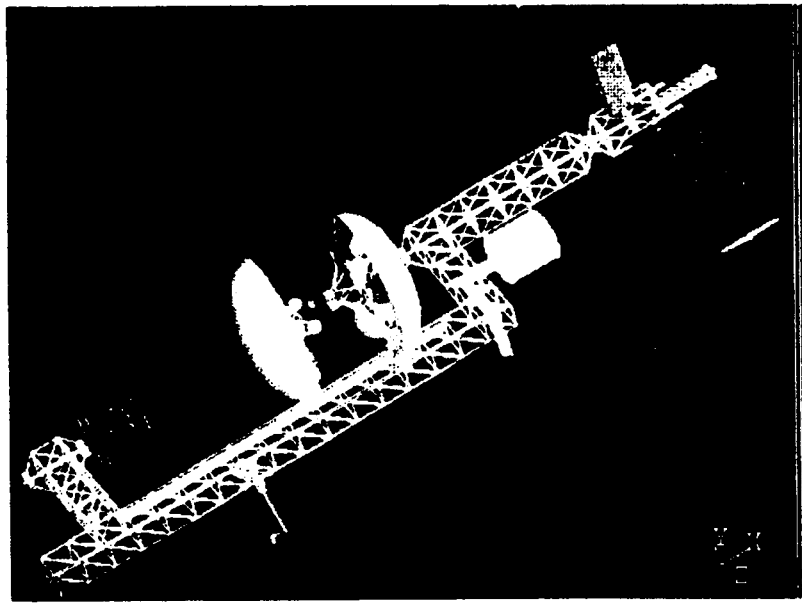
# MTV ASSEMBLY SEQUENCE (2 of 2)

A computer model of the free-flying transportation node designed to accommodate the MTV was developed on GEOMOD to aid in visualizing and understanding the assembly and integration operations and requirements. A model of the MTV was also developed, to be used with the accommodation concept.

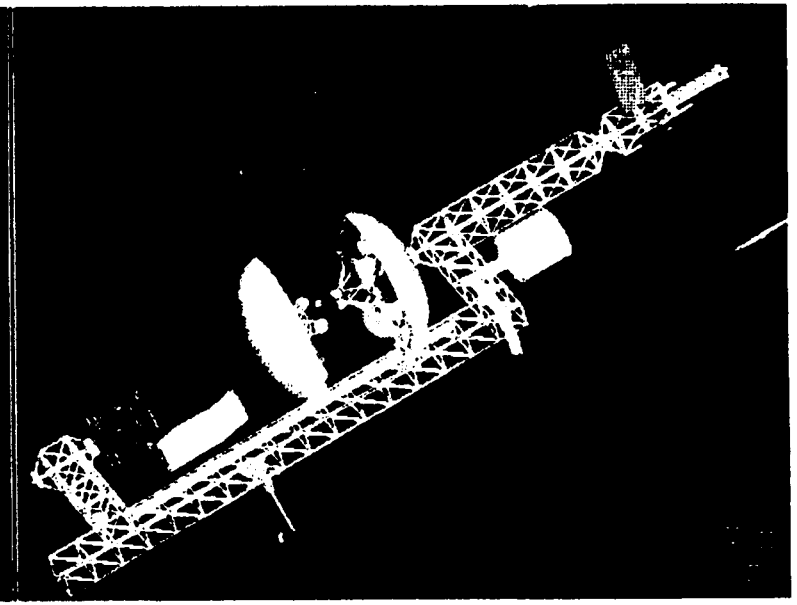
The chart below is the second of two which identify the MTV assembly sequence at the transportation node. For clarity the debris protection enclosure (DPE) is not shown. The final steps shown below are integration of the four trans-Mars injection stages (TMIS).

The first TMIS tank is delivered and integrated in step 5. This TMIS tank includes the TMIS propulsion system while the remaining three are only propellant. Steps 6, 7, and 8 integrate the remaining three TMIS tanks, with the crew module being integrated with the rest of the MTV in Step 8.

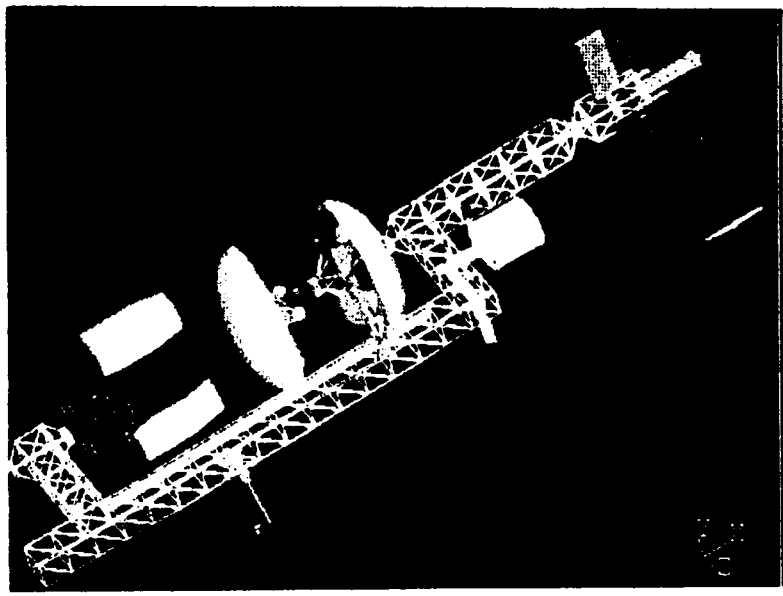
# MTV ASSEMBLY SEQUENCE (2 of 2)



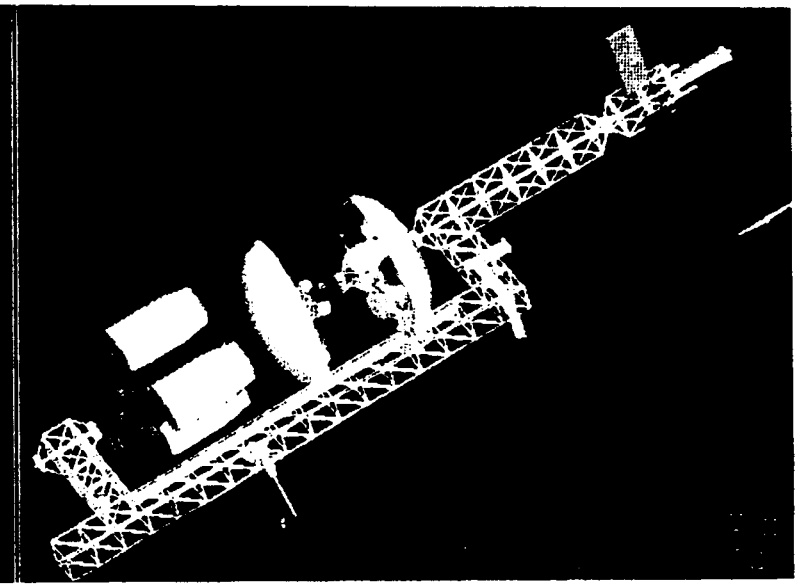
STEP 5: FIRST TMIS TANK INTEGRATION



STEP 6: SECOND TMIS TANK INTEGRATION



STEP 7: THIRD TMIS TANK INTEGRATION



STEP 8: FINAL TMIS TANK INTEGRATION

# MTV ACCOMMODATIONS TECHNOLOGY REQUIREMENTS

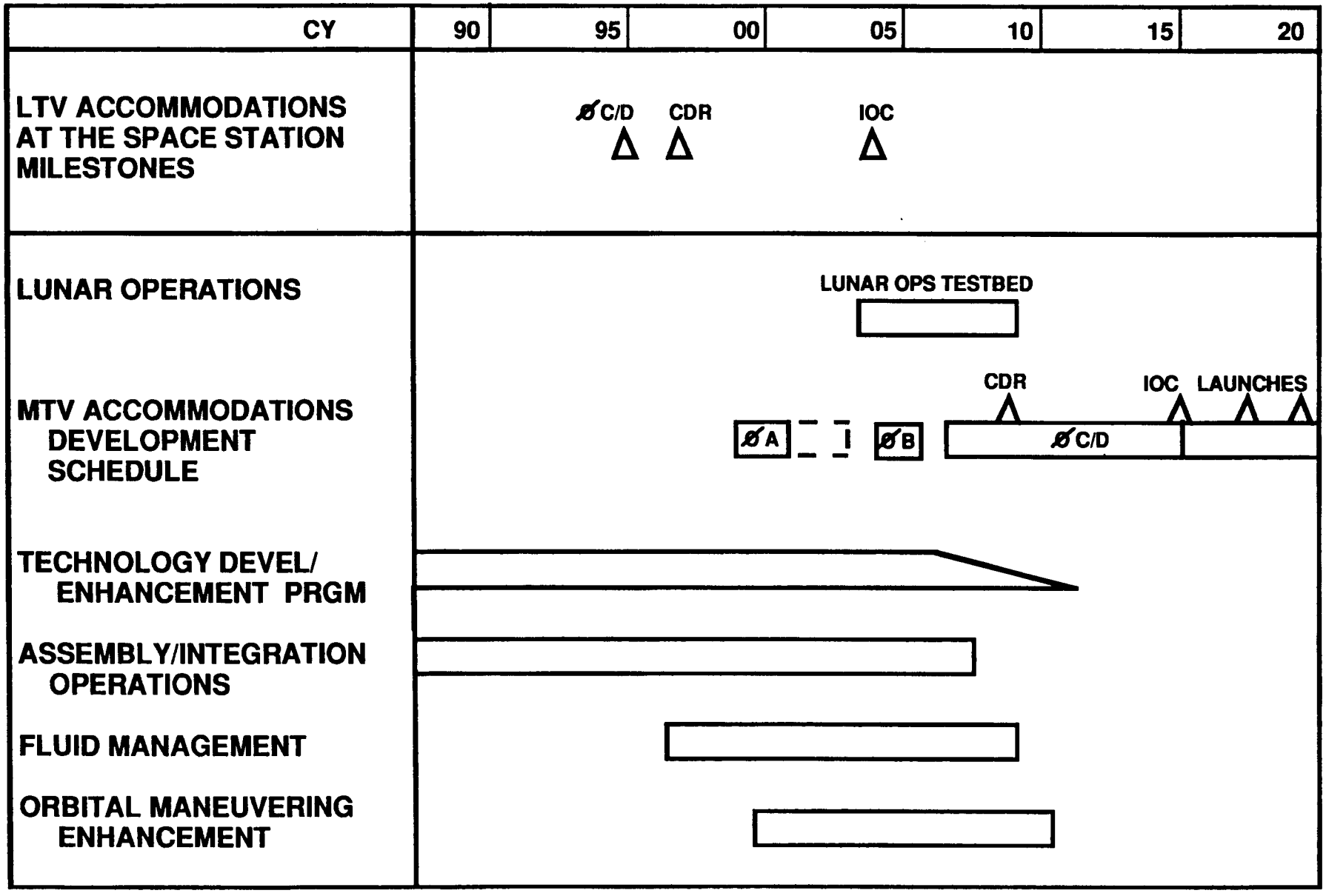
There are a number of technologies which must be developed to support on-orbit MTV accommodations. Most of the technologies needed for accommodation of the MTV will be developed for the Lunar missions, although some enhancements may be required for the MTV. Operating the Lunar missions will provide a base for determining what technology areas need enhancement for accommodation support of Mars missions.

Technology enhancements for the Mars missions are largely a result of the increase in the size of the vehicle, the degree of on-orbit operations, and the duration of vehicle assembly and integration on-orbit prior to launch. The size increase in the MTV tanks over the LTV tanks may require enhancement of several technologies. Technologies associated with storing and integrating the large propellant tanks used by the MTV include thermal control, zero g vent and low g propellant mass gauging, and automated fluid and electrical disconnects.

Ground and flight operations technologies may require enhancement as well, in the areas of teleopration/ robotics, MTV translating, berthing, & rotation equipment, proximity operations, and orbital maneuvering capability.

To support an IOC of 2015 for the MTV, phase A studies for the MTV accommodations support hardware should begin in 1998-1999. Technology development should be currently underway.

# MTV ACCOMMODATIONS TECHNOLOGY REQUIREMENTS




GDSS-ISTD1-0108N-L

## TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
### Outline

- INTRODUCTION
- REQUIREMENTS
- LUNAR TRANSFER VEHICLE ACCOMMODATIONS
- MARS TRANSFER VEHICLE ACCOMMODATIONS
- CONCLUSIONS

# TRANSPORTATION NODE CONCLUSIONS

Basing the LTV accommodations at SSF, man tended or permanently manned free flying platforms are each good options. However, if piloted LTV missions prior to 2004 are desired, SSF deployment and evolutionary capabilities development must be accelerated.

The majority of operations performed on-orbit for assembly, servicing, integration & checkout of the LTV and LEV can be done using teleoperations and robotics. EVA may be required for some tasks, but is generally used as a backup.

Accommodation facilities for a single vehicle appear sufficient to support the proposed flight rates of 1 to 2 per year.

The favored option for MTV accommodations is basing at a free-flying transportation node. Most tasks necessary for assembly and integration of the MTV on-orbit can be done using teleoperation and robotics. EVA may be required for complex tasks and for visual inspection, but is usually used as a backup.

The mass of the MTV, duration of MTV assembly operations, and debris protection requirements create significant impacts to SSF if based there. These impacts include software hooks and hardware scars as well as disturbances to the microgravity environment necessary for many scientific users aboard SSF.

Debris protection is a significant issue for on-orbit accommodations. The size and mass of the debris protection becomes prohibitive if a high probability of no-penetration over time is desired. Innovative methods of providing debris protection may reduce many of the impacts this requirement has on the accommodation design.

# TRANSPORTATION NODE CONCLUSIONS

## LTV ACCOMMODATIONS

- LTV ACCOMMODATIONS AT SSF, MAN TENDED OR PERMANENTLY MANNED FREE FLYING PLATFORMS ARE GOOD OPTIONS
- SSF DEPLOYMENT AND EVOLUTIONARY CAPABILITIES DEVELOPMENT MUST BE ACCELERATED IF THE FIRST PILOTED LTV MISSION IS PRIOR TO 2004
- MAJORITY OF LTV/LEV ASSEMBLY, CHECKOUT AND SERVICING CAN BE ACCOMPLISHED USING TELEOPERATIONS/ROBOTICS WITH EVA AS BACKUP
- ACCOMMODATION FACILITIES FOR A SINGLE LTV ARE SUFFICIENT FOR LTV FLIGHT RATES OF 1 OR 2 PER YEAR
- DEBRIS PROTECTION IS A SIGNIFICANT ISSUE, AND INNOVATIVE METHODS OF PROVIDING DEBRIS PROTECTION CAN REDUCE IMPACTS ON FACILITIES

## MTV ACCOMMODATIONS

- MTV ACCOMMODATIONS AT FREE-FLYING TRANSPORTATION NODE IS FAVORED OPTION
- MASS OF MTV, DURATION OF OPERATIONS, AND DEBRIS PROTECTION REQUIREMENTS CREATE SIGNIFICANT IMPACTS ON SSF, PARTICULARLY ON MICROGRAVITY ENVIRONMENT
- MAJORITY OF MTV ASSEMBLY AND INTEGRATION CAN BE ACCOMPLISHED USING TELEOPERATIONS/ROBOTICS WITH EVA AS BACKUP
- DEBRIS PROTECTION IS A SIGNIFICANT ISSUE, AND INNOVATIVE METHODS OF PROVIDING DEBRIS PROTECTION CAN REDUCE IMPACTS ON FACILITIES

# TRANSPORTATION NODE RECOMMENDATIONS

The requirements for a growth OMV capable of supporting LTV and MTV operations should be more fully defined. Concepts for a growth OMV should be formulated based on those requirements, stressing commonality and evolution between LTV and MTV support.

On-orbit accommodation concepts should be developed which emphasize commonality and evolution between LTV and MTV accommodations.

The scope of operations and cost estimates for transportation nodes should be broadened. Included in these estimates should be scheduled spares and consumables requirements and resupply, steady state support from the ground for regular operations, as well as many other considerations.

The impacts to SSF science operations should be more fully explored. Alternative concepts and methods should be developed for providing debris protection.

# TRANSPORTATION NODE RECOMMENDATIONS

- FURTHER DEFINE GROWTH OMV REQUIREMENTS AND FORMULATE CONCEPTS WHICH SATISFY THOSE REQUIREMENTS, ADDRESSING COMMONALITY AND EVOLUTION
- EVALUATE ON-ORBIT ACCOMMODATION CONCEPTS WHICH WILL EMPHASIZE COMMONALITY AND EVOLUTION BETWEEN LTV AND MTV ACCOMMODATIONS
- BROADEN THE SCOPE OF OPERATIONS AND COST ESTIMATES FOR TRANSPORTATION NODES TO INCLUDE SCHEDULED SPARES AND CONSUMABLES REQUIREMENTS, STEADY STATE GROUND SUPPORT, AND OTHER CONSIDERATIONS
- CONSIDER FURTHER THE IMPACTS TO SSF SCIENCE OPERATIONS FROM THE ACTIVITIES REQUIRED FOR TRANSPORTATION NODE SUPPORT
- DEVELOP ALTERNATIVE CONCEPTS AND METHODS FOR PROVIDING DEBRIS PROTECTION FOR EXTENDED PERIODS ON-ORBIT

# ACCOMMODATION OF NUCLEAR POWER AND PROPULSION CONCEPTS

STEVEN M. STEVENSON
ADVANCED SPACE ANALYSIS OFFICE
LEWIS RESEARCH CENTER

DR. WESLEY E. BOLCH
DR. J. KELLEY THOMAS
DEPT. OF NUCLEAR ENGINEERING
TEXAS A&M UNIVERSITY

# INTRODUCTION

The use of nuclear systems for propulsion and power are being examined as system options for implementing the lunar and Mars human exploration missions currently being studied by NASA. Systems might include nuclear electric propulsion (NEP) and nuclear thermal rocket (NTR) vehicles, operating reactors on coorbiting platforms, radioisotope thermoelectric generators, and others. The space station, as a transportation node, would have to store, assemble, launch, and refurbish elements containing these systems. Care must be taken to safeguard humans from the radiation imposed by these systems, in addition to the naturally occuring background of the space environment. Key issues need to be identified early to enable their proper consideration in planning activities and the baseline space station design. A study was conducted over the past year with Texas A&M University to identify and explore key issues and quantify findings in a way useful to the Space Station Program.

# INTRODUCTION

- THE HUMAN EXPLORATION INITIATIVES BEING PROPOSED BY NASA MAY REQUIRE POWER AND PROPULSION CAPABILITIES THAT ONLY NUCLEAR SYSTEMS CAN PROVIDE
- SPACE STATION FREEDOM, AS A TRANSPORTATION NODE, WILL HAVE TO ACCOMMODATE THESE SYSTEMS
- KEY ISSUES SHOULD BE IDENTIFIED EARLY TO ENABLE PROPER INCORPORATION IN PLANNING ACTIVITIES AND IMPACT TO BASELINE SPACE STATION DESIGN
- STUDY CONDUCTED OVER THE PAST YEAR WITH TEXAS A&M UNIVERSITY (DEPT. OF NUCLEAR ENGINEERING) TO IDENTIFY AND EXPLORE KEY ISSUES AND QUANTIFY FINDINGS IN A WAY USEFUL TO THE SPACE STATION PROGRAM

# OBJECTIVE

IDENTIFY SPACE STATION OPERATIONAL IMPLICATIONS, SAFETY ISSUES, AND SYSTEM IMPACTS ASSOCIATED WITH THE ASSEMBLY, LAUNCH, AND REFURBISHING OF NUCLEAR-POWERED VEHICLES AND OTHER NUCLEAR COMPONENTS OPERATING NEAR OR STORED AT THE SPACE STATION

## STUDY ORGANIZATION/APPROACH

This chart shows the study organization and the analysis approach taken. The potential radiation sources, both man-made and natural, were identified and treated with respect to the recommended radiation dose limits for astronauts working in space. The issues pertaining to human interaction with each of the radiation sources were identified and operating parameters for keeping radiation exposure within the recommended limits were formulated.

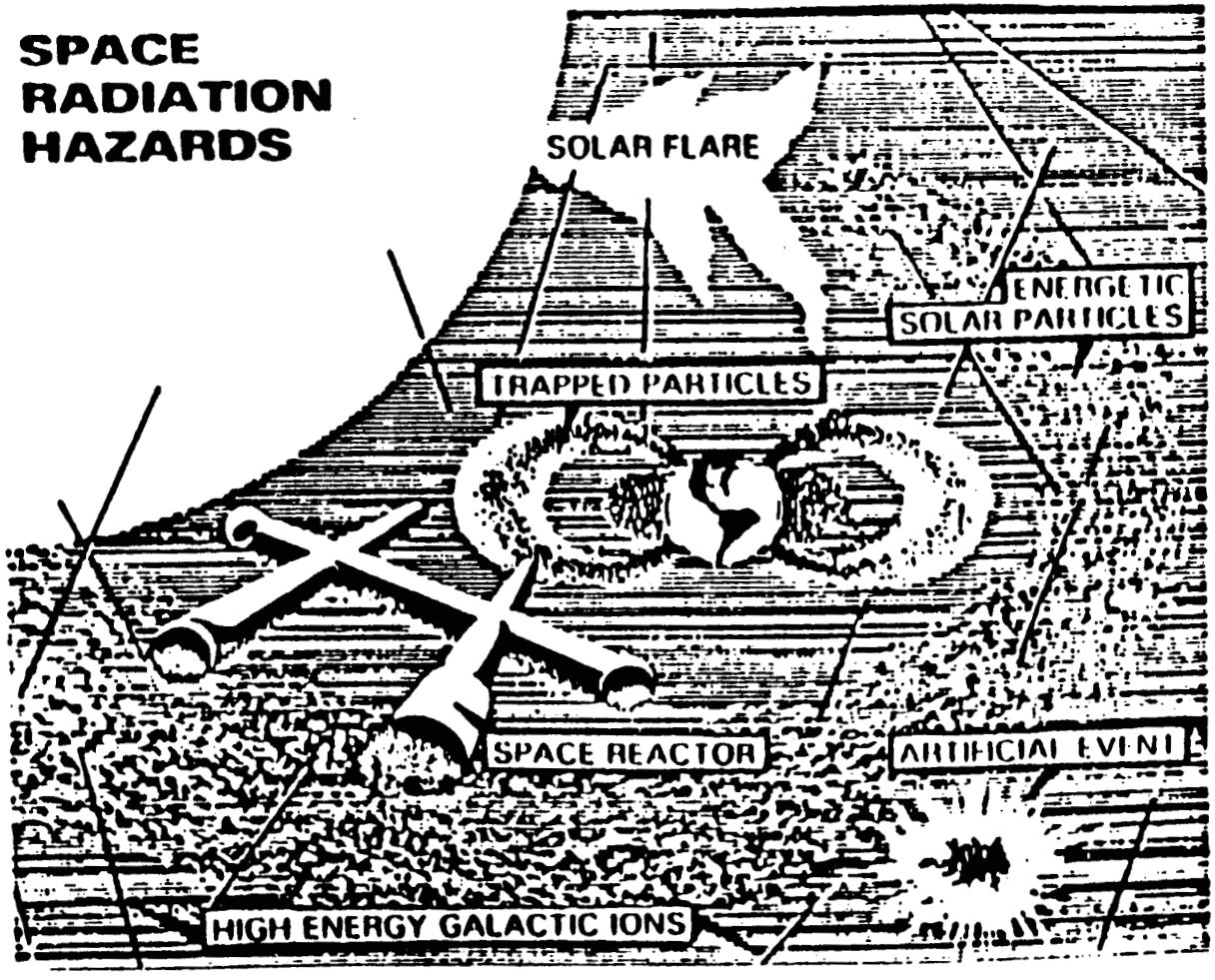
## STUDY ORGANIZATION/APPROACH

- HUMAN RADIATION EXPOSURE CONSIDERATIONS
  - NATURAL SPACE RADIATION ENVIRONMENT
  - POTENTIAL MAN-MADE RADIATION SOURCES IN SPACE
  - RECOMMENDED HUMAN RADIATION EXPOSURE STANDARDS
  - RADIATION DOSE BUDGETS FOR SPACE STATION FREEDOM CREW
- SERVICING/PARKING OF NUCLEAR POWERED SPACE TRANSFER VEHICLES
  - NUCLEAR ELECTRIC PROPULSION (NEP) AND NUCLEAR THERMAL (NTR) VEHICLES
  - LAUNCH/RETURN CONSIDERATIONS
  - PRELIMINARY DESIGN OF A PORTABLE REACTOR SHIELD
- PROXIMITY OF OPERATING REACTORS TO SPACE STATION
  - EVA IN VICINITY
  - DISTANCE FROM SPACE STATION
- STORAGE AND HANDLING OF RADIOISOTOPE POWER SOURCES
- STORAGE AND HANDLING OF FRESH AND PREVIOUSLY OPERATED REACTOR CORES AT SPACE STATION
- POTENTIAL FOR MATERIAL ACTIVATION NEAR OPERATING REACTORS
- CONCLUSIONS

## SPACE RADIATION HAZARDS

Space presents a significant radiation environment whether mad-made sources are in the vicinity or not. The major constituents of naturally occuring radiation consist of high energy protons from solar flares, galactic cosmic rays (protons and heavier nuclei), trapped particles in the earth's magnetic field (protons and electrons in the inner and outer Van Allen radiation belts, respectively) and other solar-related proton sources. A spacecraft venturing into interplanetary space would be exposed to all these sources. The low earth orbit (LEO) environment at the space station is, however, much more benign because the earth's magnetic field deflects high energy proton emissions from the sun. The natural radiation experienced at the space station is caused by trapped protons at the lower edge of the inner Van Allen radiation belt. The cumulative radiation experienced by a space station crewman on a six-month tour of duty would be about half the recommendec annual dose for a space worker or one-quarter the annual dose if on a three-month tour of duty per year. Man-made or artificial radiation sources (primarily gamma rays and neutrons) would add to the background and the sum of the two would have to be kept within the recommended limits.

# SPACE RADIATION HAZARDS




TYPES OF HAZARD

HIGH DOSES YIELD:
- RADIATION SICKNESS AND DEATH IN 1 TO 8 WEEKS
- CATARACTS

NON-LETHAL DOSES YIELD:
- CANCER
- MUTATIONS
- FETAL ABNORMALITIES

## NCRP PROPOSED STANDARDS

Current radiation protection guidelines for NASA space personnel were formulated in 1970. The career limit was set at 4 Sv (400 rem) to the blood forming organs (BFO). Since that time, our knowledge of both radiation risks and of the natural space environment has improved. In addition, the space population has changed in its distribution with respect to age and gender. For these reasons, the National Council on Radiation Protection and Measurements (NCRP) has reexamined NASA's earlier guidelines and is currently recommending the dose limits shown in this table (NCRP 1989).

The career limits correspond to a 3% lifetime excess risk of fatal cancer where a career is assumed to be approximately 10 years. Annual and 30-day limits are also specified as to prevent nonstochastic radiation effects such as bone marrow depletion, cataracts, and skin erythema; for nonstochastic effects, the severity increases with increasing dose, and there is a threshold dose below which the response is not detected clinically. As indicated in the table, an individual may receive 0.5 Sv to the blood forming organs in a given year of space activity, yet cannot receive more than one half the annual limit in any 30-day period.

# RECOMMENDED DOSE LIMITS FOR SPACE WORKERS

- National Council on Radiation Protection and Measurements (NCRP)
- Radiation Dose Limits corresponding to a 3% Lifetime Excess Risk of Fatal Cancer

| | Dose Equivalent (Sv) | | |
|---|---|---|---|
| | Bone Marrow | Lens | Skin |
| Career | 1.0 - 4.0* | 4.0 | 6.0 |
| Annual | 0.50 | 2.0 | 3.0 |
| 30 Day | 0.25 | 1.0 | 1.5 |

*Age and sex dependent limits

# STUDY APPROACH

(1) For each scenario, calculate cumulative doses as a function of various operational parameters.

(2) Indicate range of operations which can be considered "safe".

- Most permissive (dose budget)
- Most restrictive (ALARA)

# RADIATION EXPOSURE BUDGETS FOR SPACE STATION CREWS

We can compare these dose limits to natural doses received in LEO. At SSF at an inclination of 28.5°, doses to the BFO delivered over a 30-day period range from a low of 0.015 Sv at an altitude of 450 km during solar maximum to a high of 0.053 Sv at 500 km during solar minimum (Nachtwey 1989). If the station were allowed to vary its altitude over several years so as to achieve a constant atmospheric drag, an average 30-day radiation dose of 0.01 Sv can be achieved. Dose rates thus range from a low of 0.01 Sv/month (best case conditions) to a high of 0.05 Sv/month (worst case conditions). The primary contributor to radiation doses in LEO is energetic protons trapped within the Earth's lower magnetic field.

By subtracting an estimate of natural dose from the NCRP limits, an "allowable radiation dose budget" for individual crew members is obtained. This dose budget could be expended through exposures from man-made sources such as nuclear reactors or medical examinations. It is current radiation protection practice to ensure that such exposures are kept "As Low As Reasonably Achievable" (ALARA). Nevertheless, mission planners should be cognizant of the operational limits imposed by these allowable dose budgets. Consequently, we have defined two dose budgets: LBAD-st and LBAD-lt. The acronym LBAD stands for Lower Bound on Available Dose and is obtained by subtracting from the NCRP limits, an upper estimate of the natural dose at SSF (0.05 Sv in 30 days). The suffixes "st" (short-term) and "lt" (long-term) correspond to the NCRP's 30-day and annual dose limits to the blood forming organs, respectively. Thus, LBAD-st is calculated as (0.25 Sv/mo - 0.05 Sv/mo) = 0.20 Sv in 30 days. Assuming a six-month crew rotation at space station, the LBAD-lt is calculated as [0.50 Sv/yr - (6 mo./yr.) (0.05 Sv/mo.)] = 0.20 Sv in 180 days.

If the LBAD-lt is prorated over a full 180-day crew rotation period, only 0.033 Sv from man-made sources would be allowed within any 30-day period; thus, the LBAD-lt is more restrictive than the LBAD-st. The LBAD-st is a more appropriate limit when considering short-term, infrequent exposures such as during extravehicular activity (EVA) near a

# RADIATION DOSE BUDGETS FOR SSF CREW
## (6 Month Duty Tour)

- **Natural Radiation Doses at SSF:**
  - ranges from 0.01 to 0.05 Sv/mo

- **Lower Bound on Available Dose (LBAD)**
  (Benchmark dose level contrived to identify problem thresholds)

  Dose Budget = Max. Dose Limit - Dose from Nat. Space Env.

  1) Short-term exposures (LBAD-st)
     Dose Budget = 0.25 Sv/mo - 0.05 Sv/mo
     = 0.20 Sv in 30 days

  2) Continuous or long-term exposures (LBAD-lt)
     Dose Budget = 0.50 Sv/y - (6 mo/y)(0.05 Sv/mo)
     = 0.20 Sv in 180 days

# LAUNCH AND RECOVERY OF NUCLEAR POWERED VEHICLES IN SPACE STATION VICINITY

# MARS MISSION SCENARIOS WITH NUCLEAR POWERED VEHICLES

Two reference scenarios were considered in this study. In the first scenario, a cargo vehicle utilizing an NEP propulsion system were assumed to make a 1810 day round trip to Mars starting from LEO. The power system employed a single SP-100 reactor scaled by a factor of 10.4 to a power level of 25 MWt. The vehicle spent 150 days in orbit around Mars with the reactor operating at 0.4 MWt and a total of 373 days coasting at a power level of 0.2 MWt. Operating neutron and gamma fluxes for this reactor were obtained by scaling values calculated for the SP-100 reactor.

In the second scenario, a personnel vehicle utilizing an NTR propulsion system was assumed to make a 486 day round trip to Mars also starting from LEO. Trans-Mars Insertion (TMI) was performed by a stage containing a Phoebus-class reactor which was discarded upon completion of the TMI burn. A NERVA-class reactor was used during the remaining burns operating at a power level of 1575 MWt. The vehicle spent 30 days in Mars orbit with the NERVA reactor at 0.4 MWt and a total of 456 days coasting with a housekeeping power level of 0.2 MWt.

For these two mission scenarios, the total integrated power for the NEP reactor was 32,310 MWth-days of which 96.5% was consumed by the propulsion system. The total integrated power for the second stage NTR reactor was 210.3 MWth-days of which only 50.9% was consumed by the propulsion system. Thus, even though the NTR reactor has a rated thermal power ~ 60 times that of the NEP reactor, its total integrated power was over 150 times smaller. Fission product inventories and their associated gamma radiation levels are dependent, not only upon the total integrated power, but upon the time history of reactor operation. At short shutdown times, the gamma source term of the NTR reactor will be dominated by the decay of short-lived radionuclides produced during the Earth Orbital Capture (EOC) burn. At longer shutdown times, the gamma source terms of both reactors will be dominated by longer-lived radionuclides, and the fission product inventory of each will become a stronger function of the total integrated power than of the specific time history of reactor operation.

To show the contribution to the fission product build-up due to the production of housekeeping power, a second NTR scenario was run with zero housekeeping power production (reactor shutoff during coast). The effect on cooldown time is shown on a later chart.

## MARS MISSION SCENARIOS WITH NUCLEAR POWERED VEHICLES

- NEP CARGO MISSION
  - 25 $MW_{th}$ REACTOR 5 $MW_e$ OUTPUT
  - 1810 DAYS TOTAL
  - 150 DAYS AT MARS
  - 1287 DAYS AT HIGH POWER (25 $MW_{th}$)
  - 523 DAYS AT LOWER POWER (0.2, 0.4 $MW_{th}$)
- NTR PILOTED SPRINT MISSION
  - 1575 $MW_{th}$ REACTOR, 75,000 LBS. THRUST
  - 3 BURNS: MOC, TEI, EOC (TMI PERFORMED WITH EXPENDABLE STAGE)
  - 486 DAYS TOTAL TRIP TIME
  - 30 DAYS AT MARS
  - 98 MINUTES OF HIGH THRUST OPERATION
- TWO NTR CASES:
  1. DUAL MODE: REACTOR RUN AT LOW LEVEL FOR HOUSEKEEPING POWER DURING COAST AND AT MARS
  2. REACTOR FOR PROPULSION ONLY

# LAUNCH OF NUCLEAR POWERED VEHICLES IN SPACE STATION VICINITY

THE SSF CREW'S RADIATION EXPOSURE WILL NOT EXCEED THE MAXIMUM RECOMMENDED 30-DAY LIMIT IF THE LAUNCH (TANGENTIAL THRUST) OF THESE VEHICLES IS CONDUCTED SUCH THAT:

- THE NEP INITIALLY LAGS SSF BY 3 km
- THE NTR INITIALLY LEADS SSF BY 7 km

# RETURNED NUCLEAR POWERED VEHICLE (NEP OR NTR) IN SSF VICINITY

In the scenarios, the vehicle arrives in LEO at some large distance from the station. After a variable period of reactor cooldown, the vehicles are then towed to some variable parking distance. It is after this variable shutdown time that we calculate integrated 4-hour EVA doses at close distances from the reactor and integrated 30-day and 180-day parking doses at relatively larger distances. The 4-hour doses represent those that might be received during EVA unloading operations, while the 30-day and 180-day doses represent those that might be received by the crew living at SSF. The 4-hour EVA and 30-day doses are compared to the maximum recommended 30-day dose (one half the major annual dose) while the 180-day dose is compared to the maximum long-term exposure (annual) dose. Both reactors are treated as point sources with no vehicle or shadow shielding. The shutdown gamma dose rates were computed as the product of the operating gamma dose rate and the ratio of shutdown to operating gamma source strengths (LaBauvre et al. 1982). Gamma flux-to-dose equivalent conversion factors were obtained from Report 43 of the International Commission on Radiation Units and Measurements (ICRU 1988).

The following charts address these issues quantitatively by addressing the following cases:

1. How long after the NEP or NTR reactor is shutdown and at what distance from SSF can the vehicle be parked while maintaining 6-month cumulative doses to SSF below recommended limits? Here the long-term limit of 0.2 Sv applies for doses received from the reactor. When combined with doses received from natural radiation sources, the total 6-month cumulative dose would equal 0.5 Sv, or the annual recommended dose limit.

2. How long after the NEP or NTR reactor is shutdown and at what distance from SSF can the vehicle be parked while maintaining the 30-day cumulative dose below recommended limits? Here the short-term limit applies (0.2 Sv in 30 days from the reactor or 0.25 Sv total). This case represents a scenario in which the vehicle might be moved in close to SSF for 30 days for unloading and refurbishing, but would then be moved away so as not to exceed for long-term limit.

3. How long after the NEP or NTR reactor is shutdown and at what distance from the reactor can a 4-hour EVA be performed while maintaining doses below the short-term (30-day) limit?

# RETURNED NUCLEAR POWERED VEHICLE (NEP OR NTR) IN SPACE STATION VICINITY

**ISSUE:** DOES A RETURNED NEP OR NTR (SHUTDOWN) REACTOR PARKED NEARBY PRESENT A RADIATION HAZARD TO SSF PERSONNEL?

**CONCLUSION:** NOT IF PROPER SAFETY PRECAUTIONS ARE TAKEN.

**SOLUTIONS:**

- SHUT DOWN THE REACTORS FOR SUFFICIENT TIME TO KEEP DOSES WITHIN RECOMMENDED LIMITS

  1) DOSE TO SPACE STATION CREW AT A GIVEN DISTANCE FROM VEHICLE
     - OVER 6-MONTH DUTY TOUR
     - BRING VEHICLE INTO CLOSE PROXIMITY FOR 30 DAYS, THEN MOVE AWAY

  2) DOSE TO EVA ASTRONAUT NEAR VEHICLE

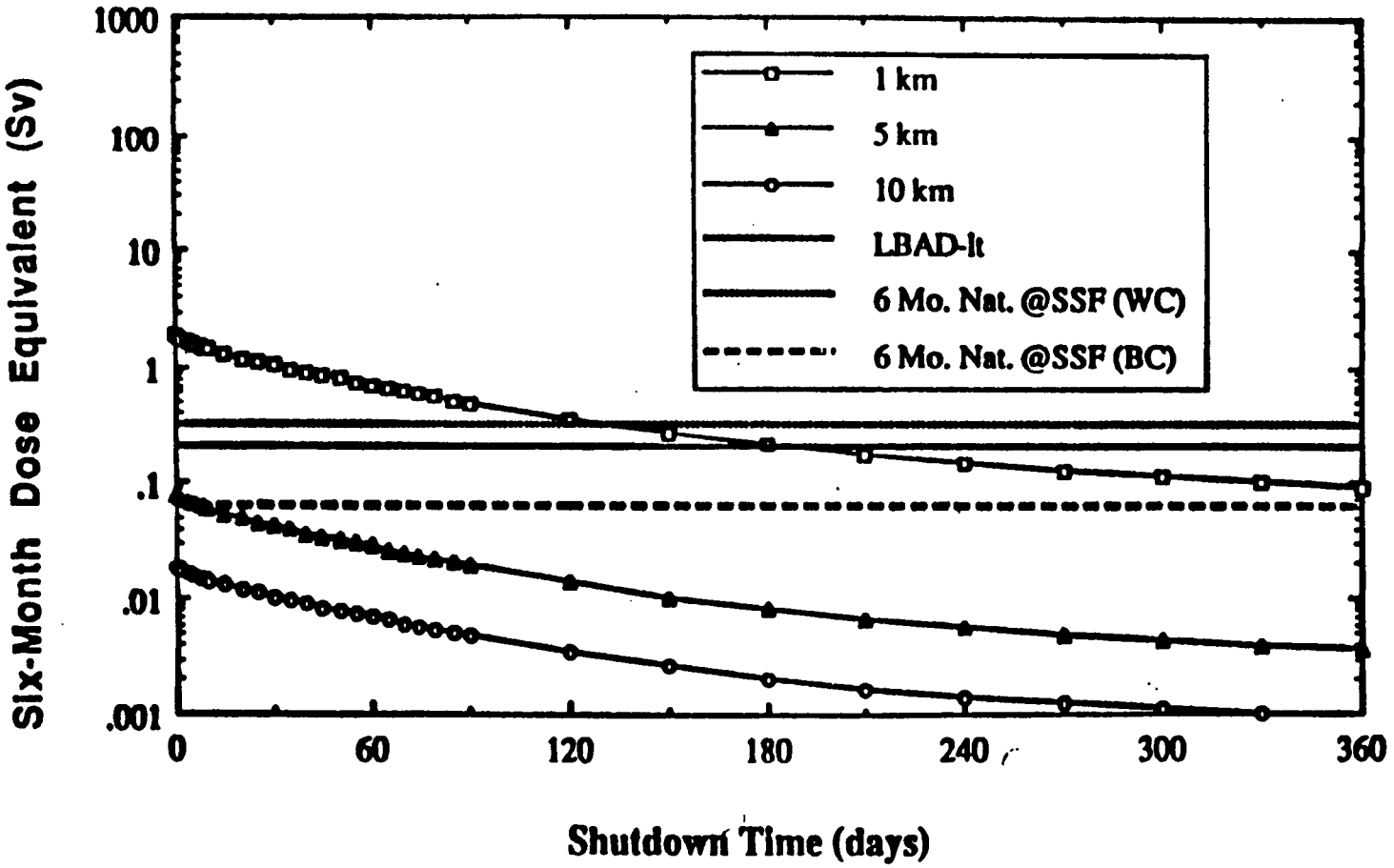
- USE A PORTABLE REACTOR SHIELD STORED AT SSF

## SIX-MONTH PARKING DOSE TO SSF PERSONNEL FROM AN NEP VEHICLE REACTOR AFTER SHUTDOWN

This chart represents the dose received by the SSF crew (ignoring the small amount of shielding provided by the walls of the aluminum modules) in six months after an initial NEP reactor shutdown time.

The long-term limit ($LBAD_{lt}$) applies and allows for a cumulative dose of 0.20 Sv in six months. This is shown as the solid line. The point at which the cooldown curves cross this line represent the reactor cooldown times required to limit doses to within the six-month radiation dose limit. The curves are shown with distance from the space station as a parameter. For example, the NEP requires > 180-day cooldown time before it can be parked 1 km from the space station for 6 months. The dose falls off rapidly with distance, and results indicate the vehicle can be brought to 5 km from SSF within the first day and parked for 6 months. The other horizontal lines represent the worst case (WC) and best case (BC) natural radiation at the space station orbit as explained earlier.

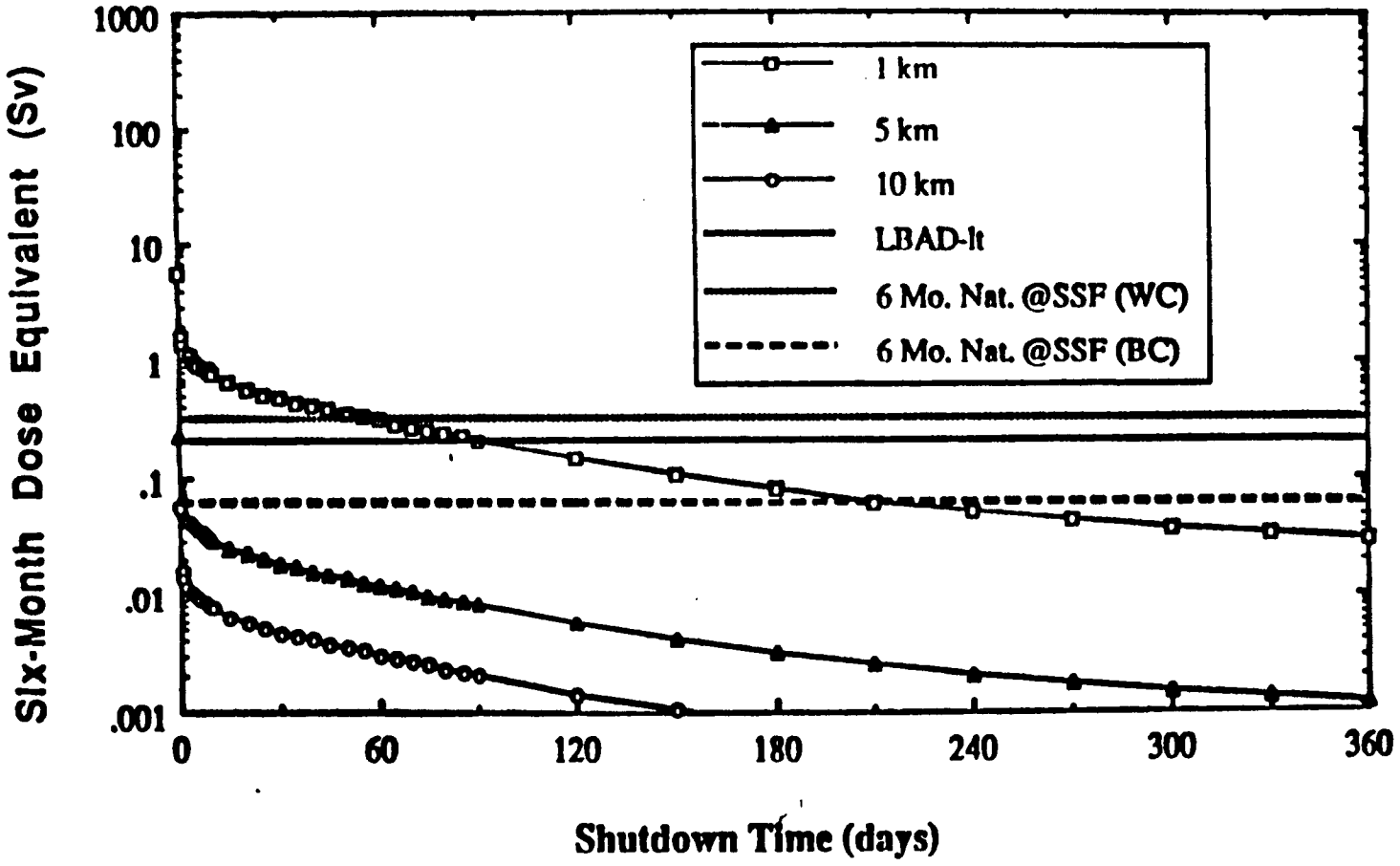
# SIX-MONTH PARKING DOSE TO SSF PERSONNEL FROM NEP REACTOR AFTER SHUTDOWN (OUTSIDE SHADOW SHIELD)



## SIX-MONTH PARKING DOSE TO SSF PERSONNEL FROM AN NTR REACTOR AFTER SHUTDOWN

These curves are similar to the NEP case except that the NTR cools off somewhat faster due to its shorter operating time history and can be moved into the SSF proximity sooner. For example, the NTR can be moved to 1 km of the space station for six months after a cooldown time of 90 days (compared to NEP's 180 days). As with the NEP, it is safe to move within a few kilometers of the space station almost immediately after the vehicle arrival. Initially upon return and shutdown, the NTR is "hotter" than the NEP due to the very high power earth orbit capture (EOC) burn just performed. Within a few days, however, dose rates around the NTR reactor fall below those around the NEP reactor at comparable distances.

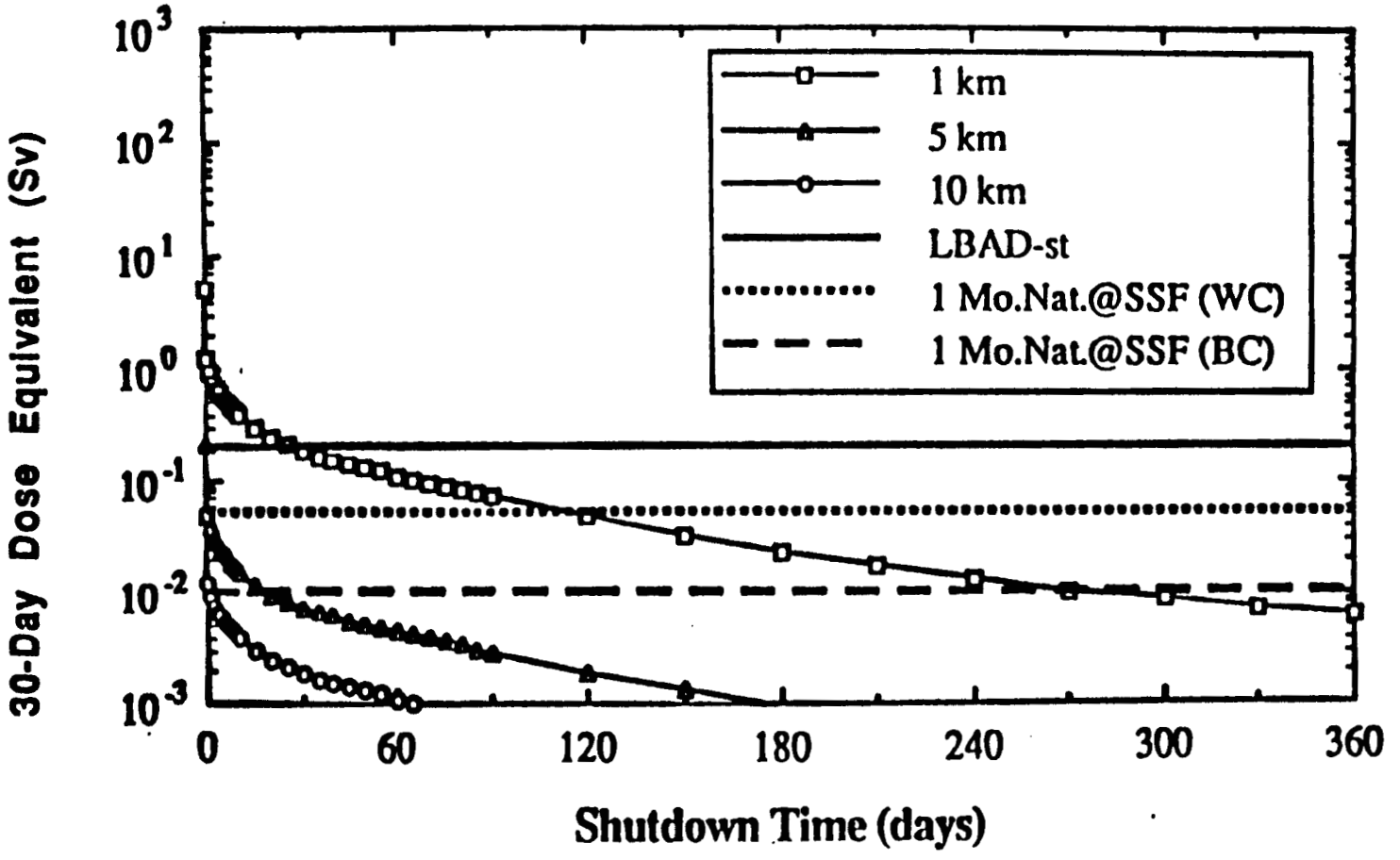
# SIX-MONTH PARKING DOSE TO SSF PERSONNEL FROM NTR REACTOR AFTER SHUTDOWN (OUTSIDE SHADOW SHIELD)



## 30-DAY PARKING DOSE TO SSF PERSONNEL FROM NTR REACTOR AFTER SHUTDOWN

This curve demonstrates that, for the particular NTR scenario examined, the vehicle can be moved to 1 km from SSF for 30 days without exceeding the short-term limit after a cooldown period of 25 days.

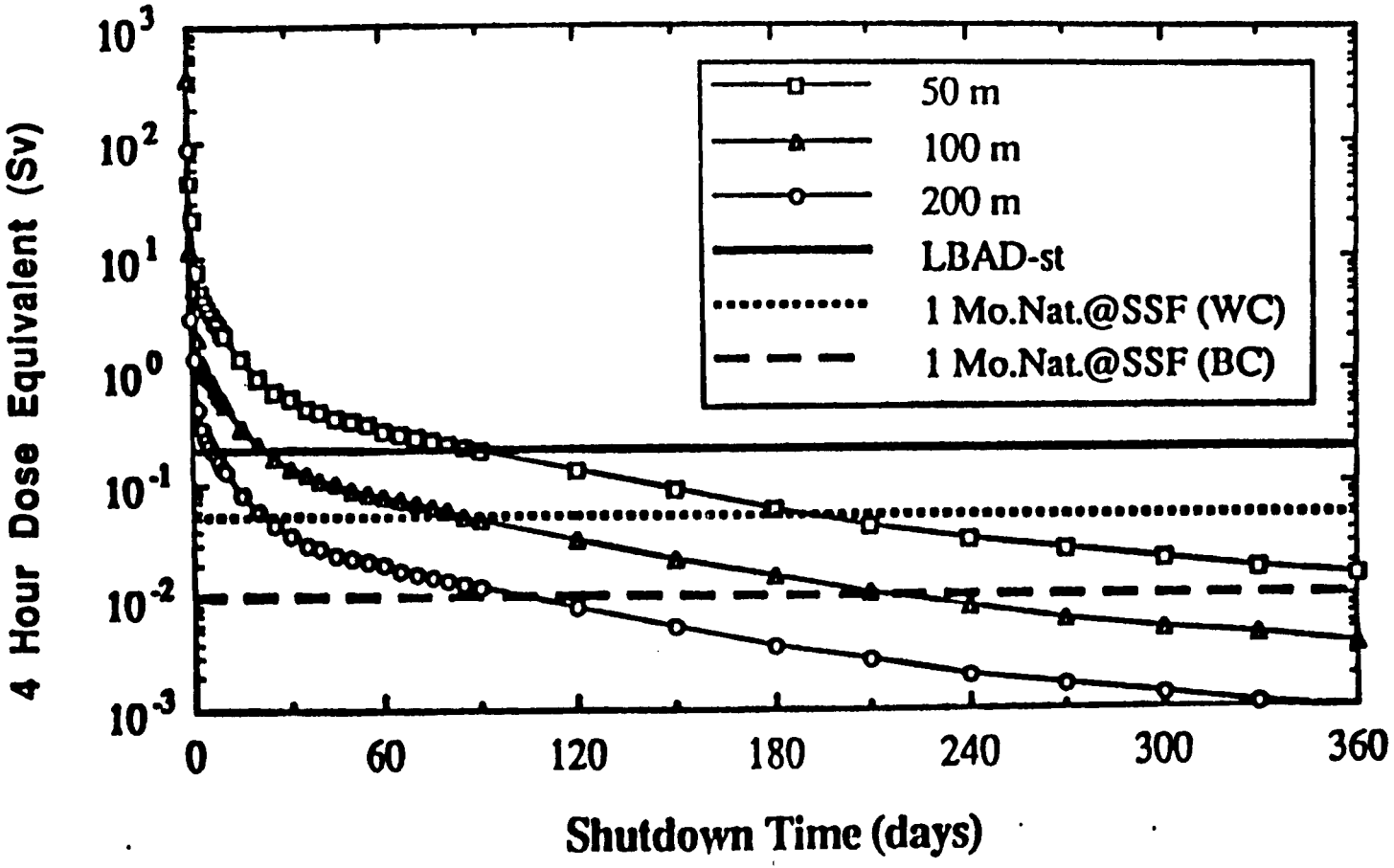
## 30-DAY PARKING DOSE TO SSF FROM NTR REACTOR AFTER SHUTDOWN (OUTSIDE SHADOW SHIELD)



## EVA DOSE FROM NTR REACTOR AFTER SHUTDOWN

The curves for the shutdown NTR reactor are shown here. In order to achieve the same integrated doses at the same distances as for the NEP case, a reactor shutdown time of only 90 days is needed for the NTR reactor. At shutdown times less than approximately 10 days, the gamma doses due to the NTR reactor are greater than those due to the NEP reactor at the same distance. This difference can be attributed to the NTR reactor's higher power level and its correspondingly greater inventory of short-lived radionuclides produced during the final earth orbit capture (EOC) burn. At shutdown times greater than 10 days, doses due to the NEP reactor are greater, yet both continue to decrease with increasing shutdown time.

## EVA DOSE FROM NTR REACTOR AFTER SHUTDOWN (OUTSIDE SHADOW SHIELD)



## RADIOISOTOPE POWER SOURCES AT THE SPACE STATION

Radioisotope power sources such as radioisotope thermoelectric generators (RTG's) have been used by the U.S. space program for many years. The standard unit produces about 250 watts of electrical power and is safe to handle for short periods of time. The space station, as a transportation node, may have to store these devices or systems containing these devices for longer periods of time. A preliminary examination of the safety issues associated with RTG's at the space station was made. The results indicate that beyond a few meters from several RTG units, the SSF crew would receive less than their maximum allowed dose in a 6-month period. The devices could be stored somewhere on the truss structure, preferably as far away as possible to minimize the dose. The RTG's are cylindrical in form and, therefore, are directional in their radiation fields. The radial direction is the more critical, so the RTG's should be stored with the radial direction away from the space station modules.

# STORAGE OF RADIOISOTOPIC POWER SOURCES ON SSF

**ISSUE:** DOES THE PRESENCE OF RADIOISOTOPIC POWER SOURCES REPRESENT A RADIOLOGICAL HAZARD TO THE SSF CREW?

**CONCLUSION:** ONLY FOR VERY SMALL SEPARATION DISTANCES OF LARGE NUMBERS OF POWER SOURCES.

**SOLUTION:**
1) STORE UNITS ON A BOOM
2) ORIENT UNITS TO MINIMIZE DOSE
3) EMPLOY PORTABLE RADIATION SHIELD

**EXAMPLE:** THE 6-MONTH AXIAL DOSE FROM AN RTG UNIT DOES NOT EXCEED THE DOSE BUDGET FOR SEPARATION DISTANCES IN EXCESS OF 6 METER.

# MULTIPURPOSE PORTABLE RADIATION SHIELD

- REDUCE RADIATION HAZARDS DURING LAUNCH AND RETURN OF MARS VEHICLES.
- ENHANCE EVA CAPABILITIES NEAR SHUTDOWN AND OPERATING REACTORS.
- FACILITATE STORAGE AND HANDLING OF RADIOISOTOPIC POWER SOURCES AT THE SPACE STATION.
- REDUCE DOSES FROM THE NATURAL SPACE ENVIRONMENT. THIS WILL INCREASE RADIATION DOSE BUDGETS FOR CREW MEMBERS POSSIBLY LEADING TO GREATER FLEXIBILITY IN CREW ROTATION SCHEDULING.

# CONCLUSIONS

- SPACE STATION FREEDOM CAN BE USED AS A TRANSPORTATION NODE FOR SPACE NUCLEAR-POWERED VEHICLES.
- NUCLEAR POWER SOURCES CAN BE USED IN SSF VICINITY.
- RADIOISOTOPIC POWER SOURCES CAN BE STORED AND/OR USED ON SSF.
- NONE OF THESE ACTIVITIES POSE AN UNACCEPTABLE RADIOLOGICAL HAZARD PROVIDED PROPER PRECAUTIONS ARE TAKEN.
- A PORTABLE RADIATION SHIELD IN LEO WOULD PROVIDE FOR INCREASED OPERATIONAL FLEXIBILITY.

# Platform Evolution Studies

Barbara Walton
Goddard Space Flight Center

February 7, 1990

Presented at the Conference on
Space Station Evolution, Beyond the Baseline
League City, Texas

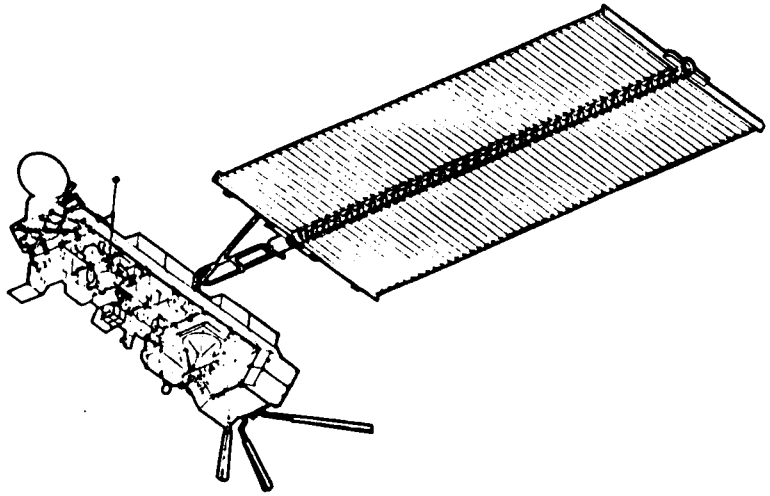
G375.001

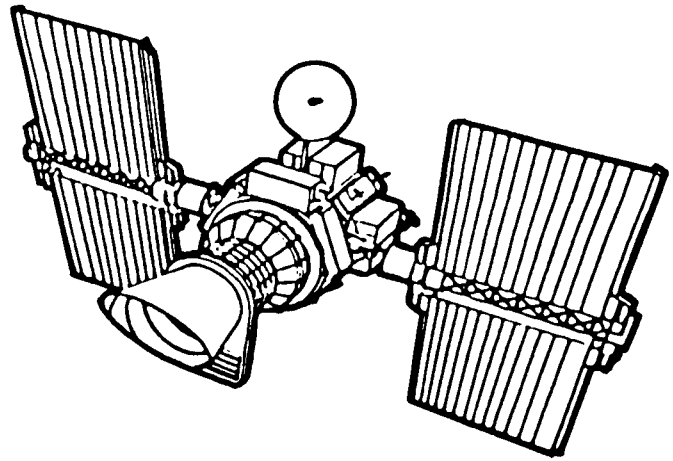
Platform evolution studies have focused on developing two types of platforms: the Geostationary Platform, for use as an observatory in NASA's Mission-to-Planet-Earth (MPE) initiative, and a co-orbiting platform, for use as a branching mechanism for the Space Station Freedom manned base. In 1989, platform evolution efforts also documented existing polar platform scars for servicing and for co-orbiting platform configurations.

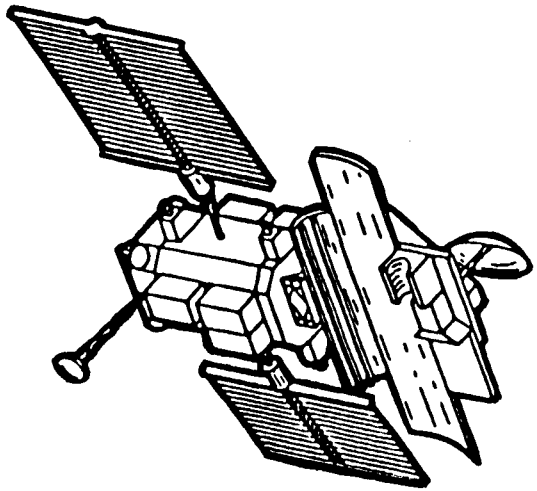
Shown on this viewgraph are various platform configurations. An Astrophysics Co-orbiting Platform was studied during Phase B of the Space Station Program. The Stationkeeping Platform was the subject of a Goddard study.

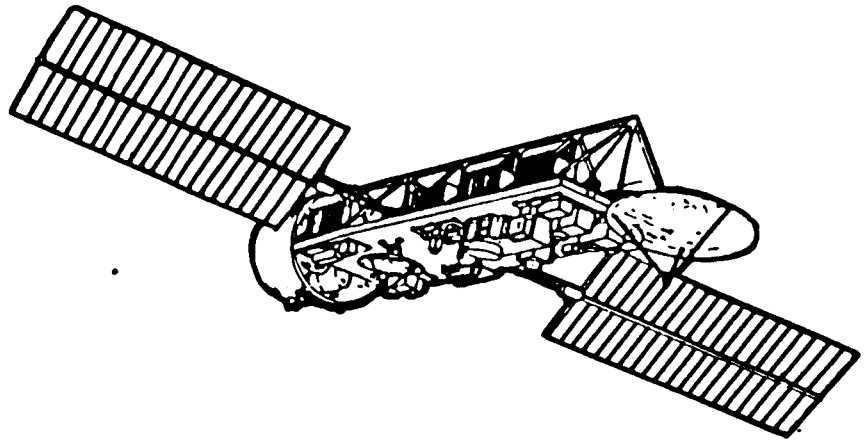
In January, 1990, NASA Administrator, Richard Truly, approved a plan to shift management of the NASA Polar Orbiting Platform Development Program from the Space Station Freedom Office to the Office of Space Science and Applications, which oversees Eos. The platform in combination with Eos payloads will become an Eos observatory. None of the international agreements has been affected.

Today I will briefly describe the NASA Polar Platform and discuss the studies of evolutionary configurations for geostationary and co-orbiting platforms. General Electric Astro-Space Division was selected to perform these studies because of its role as designer of the Polar Platform.



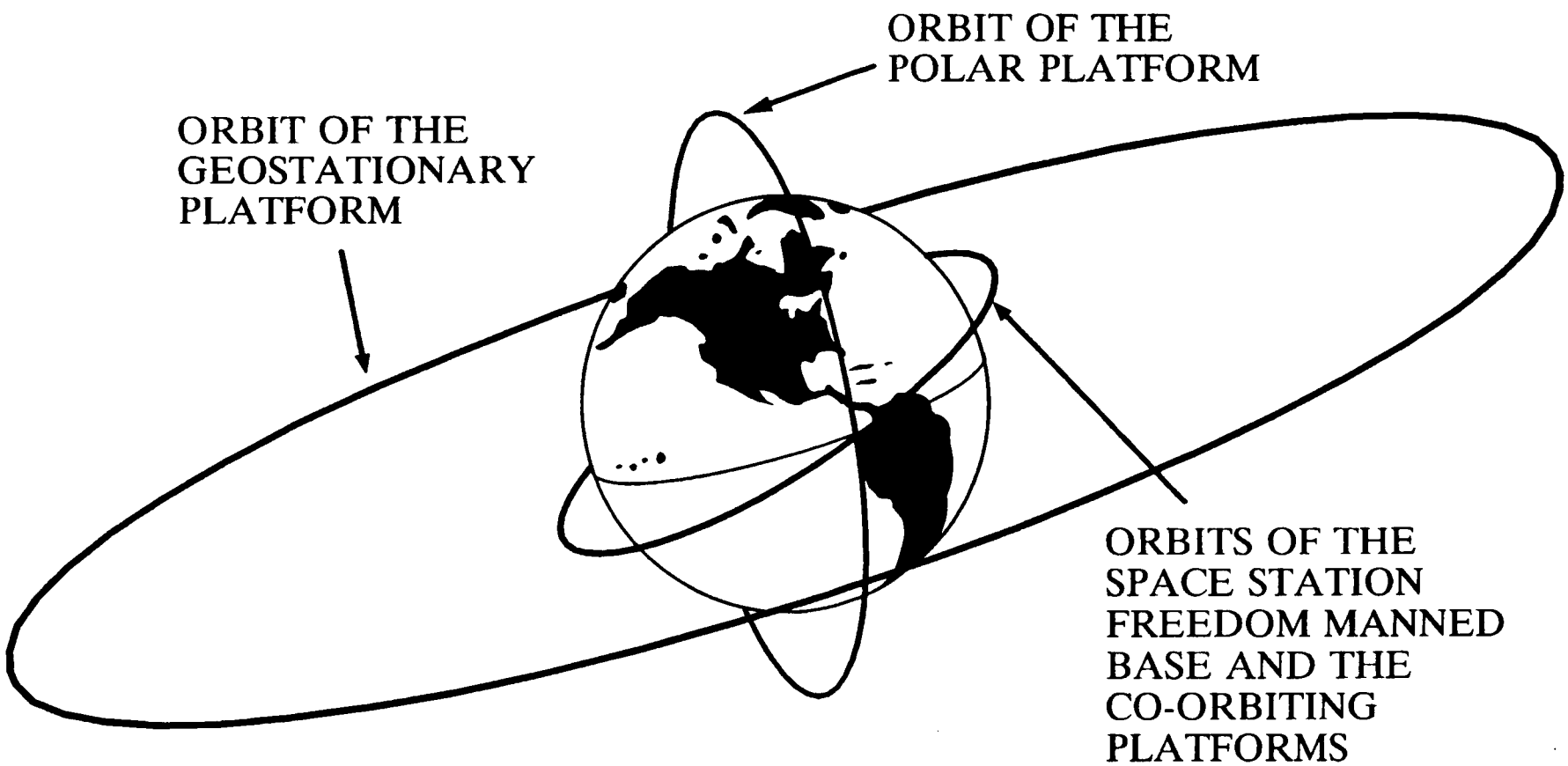






# PLATFORM EVOLUTION STUDIES - INTRODUCTION

**Space Station Freedom will be in an orbit approximately 333 to 444 km high and inclined at 28.5 degrees. The co-orbiting platforms will be in a similar orbit. The Polar Platform will be in a sun-synchronous orbit, 705 km high at an inclination of approximately 98.2 degrees. The Geostationary Platform will be in a geostationary orbit, 35,754 km high at zero degrees inclination.**



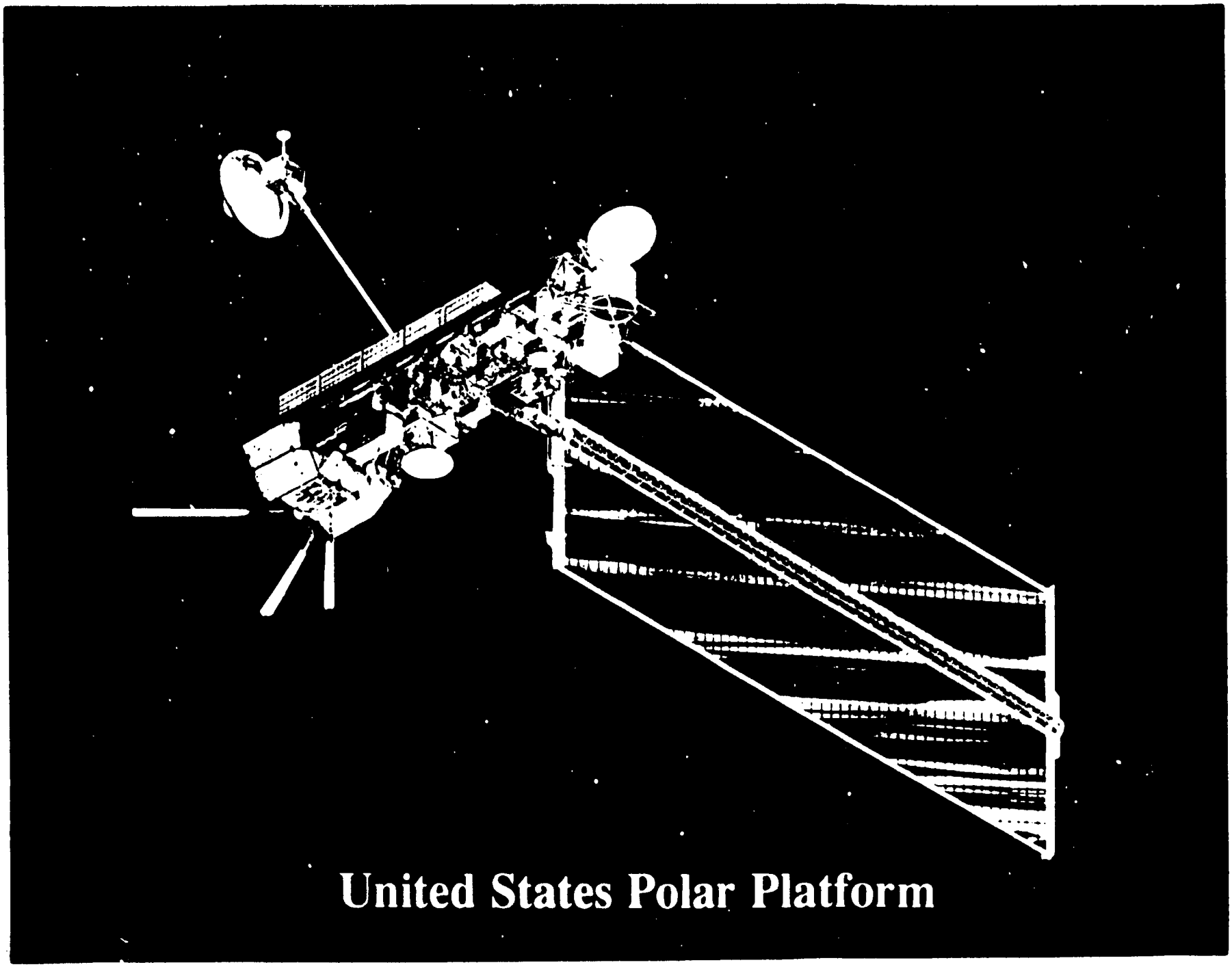

# PLATFORM ORBITS

F375.006

**The Polar Platform is a highly modular design with distributed systems packaged in Orbital Replacement Units (ORUs) which facilitates on-orbit servicing. Its design was driven by the Earth Observing System (Eos) instrument complement. It supports a total payload mass of 3500 kg.**

**During nominal flight, the Polar Platform will maintain its long axis parallel to the velocity vector. A single solar array is mounted on the sun-side of the platform in order to provide a cold field-of-view for payloads. The spinning microwave instrument on the front of the platform requires special accommodation, as shown.**

**The Polar Platform Payload accommodation features included in the evolution studies are Payload Mounting Plates (2 sizes, one has same footprint as the ORU) attached to the structure using standard interface connectors and payload central thermal bus.**


United States Polar Platform

In March 1988, a study was begun to assess the utility of polar platform ORUs and the Space Station Freedom infrastructure for geostationary earth-observing missions. Two test cases, representative of Mission-to-Planet-Earth payloads, were studied. Case A was used to emphasize the Geostationary Platform configuration and design. Case B, considered to be much further in the future, included some assembly at Freedom's manned base. Requirements on the manned base to support such a mission were emphasized. This work was funded by NASA Headquarters Office of Space Station (Code ST) Strategic Plans and Programs Division.

The overall study objectives were to determine the feasibility of using polar platform designs, to identify needed scarring, and to satisfy the test case instrument requirements. All polar platform payload accommodation features, modularity, and serviceability were to be retained.

# GEOSTATIONARY PLATFORM STUDY

- March 1988 - April 1989
- Objective

  Determine feasibility of using polar platform designs and identify needed scarring

G375.008

**A reference set of instruments was defined and basic interface requirements established. The total mass and average power for each payload set were overriding criteria. Estimates for the total payload mass, power, and data requirements were less than for the Polar Platform.**

# GEOSTATIONARY PLATFORM TEST CASES

| SENSOR DESCRIPTION | MASS kg | POWER W | DATA Mbps | CASE A | CASE B |
|---|---|---|---|---|---|
| MICROWAVE IMAGER/SOUNDER (20m MESH + 10m SOLID) | 1,000 | 300 | 0.1 | | X |
| MICROWAVE IMAGER/SOUNDER (4.4m SOLID) | 200 | 250 | 0.1 | X | |
| INFRARED SOUNDER (MICHELSON) | 165 | 130 | 7.4 | X | X |
| LIGHTNING MAPPER | 30 | 100 | 0.1 | X | X |
| ACTIVE CAVITY RADIOMETER | 30 | 25 | <0.1 | X | X |
| SOLAR SPECTROMETER | 105 | 65 | <0.1 | X | X |
| CLIMATE RADIATION RADIOMETER | 50 | 30 | <0.1 | X | X |
| OZONE MAPPER | 20 | 30 | <0.1 | X | X |
| OPERATIONAL IMAGER/SOUNDER (GOES-NEXT ENHANCED) | 300 | 300 | 3 | X | X |
| SPACE ENVIRONMENT MONITOR | 40 | 25 | <0.1 | X | X |
| OPERATIONAL/RESEARCH DATA COLLECTION | 25 | 40 | <0.1 | X | X |
| SEARCH AND RESCUE | 10 | 30 | <0.1 | ? | X |
| OPERATIONAL/RESEARCH DATA DISTRIBUTION | 40 | ? | ? | X | X |
| MODERATE RESOLUTION IMAGING SPECTROMETER | 110 | 100 | 20 | X | |
| VISIBLE/INFRARED IMAGER (1.5 X 1.5m SEOS) | 1,000 | 150 | 80 | | X |
| PAYLOAD TOTAL - CASE A | 1,200 | 1,200 | 40 | | |
| PAYLOAD TOTAL - CASE B | 3,000 | 1,500 | 100 | | |

F375.003

The Polar Platform design features which enable serviceability, standard interface connectors, orbital replacement units, and payload mounting plates also facilitate ease-of-assembly at the manned base.

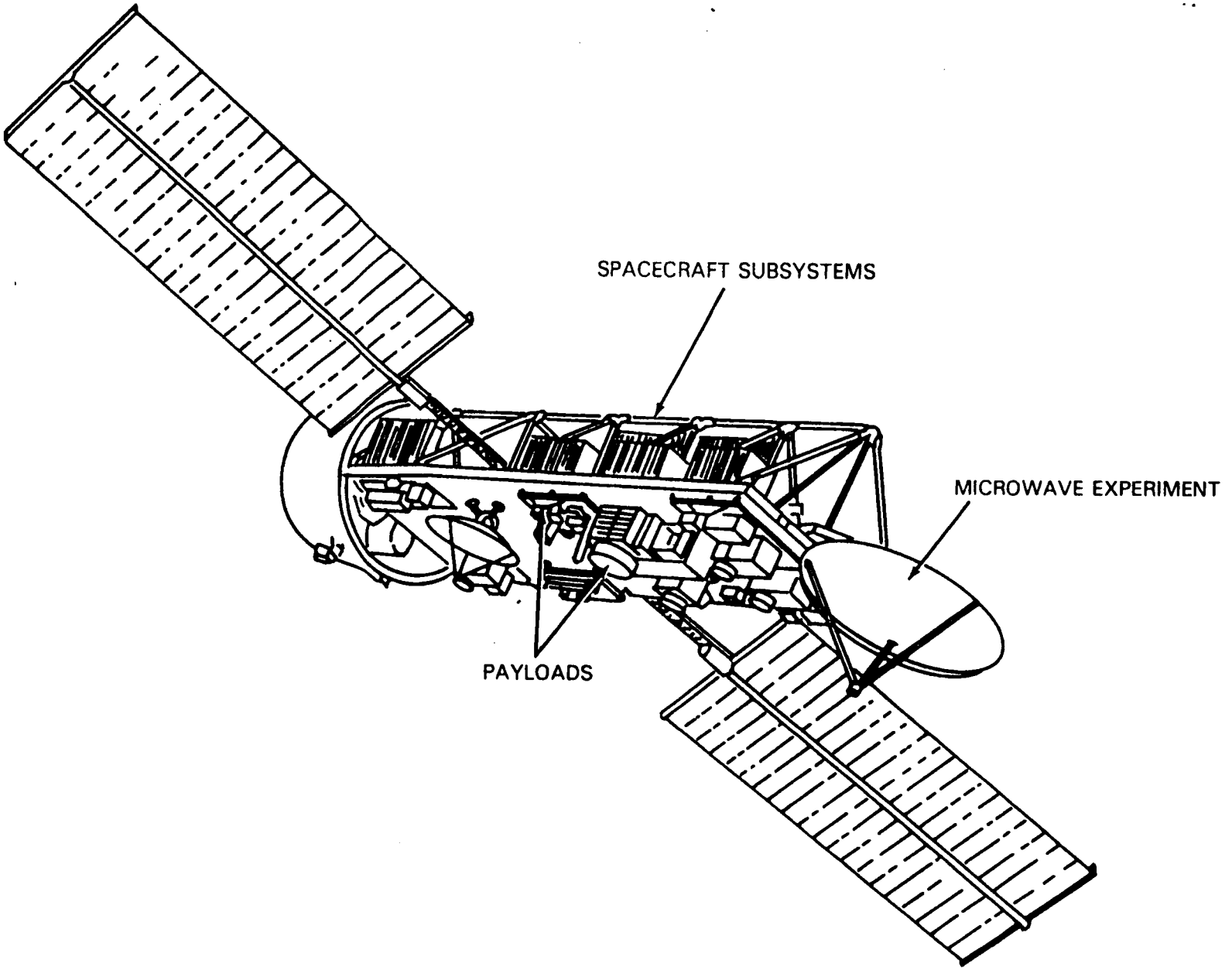
A lifetime of 10 years without servicing for Case A and 20 years with servicing for Case B were design goals. To meet these goals, reliability requirements imposed on the Polar Platform were applied to the geostationary platform design and a replaceable propulsion module, sized for 10 years, was included.

The electrical power subsystem is sized to maximize science operations, including full operations during solar eclipse. Solar eclipse occurs at the vernal equinox and at the autumnal equinox when the Geostationary Platform is opposite the sun.

# DESIGN GOALS

- Facilitate ease-of-assembly at the manned base
- Provide long lifetime
- Maximize science operations, including during solar eclipse

The configuration derived for the Case A platform uses composite longerons and a honeycomb core panel with composite skin. The solar arrays, with a total area of 415 square feet, are located with their rotational axis close to the platform's center of gravity to promote control and stability. The propulsion module is attached to the platform with an intermodule connector. The 4.4 meter dish of the microwave image/sounder is deployed on-orbit.




GEOSTATIONARY PLATFORM CONFIGURATION - CASE A

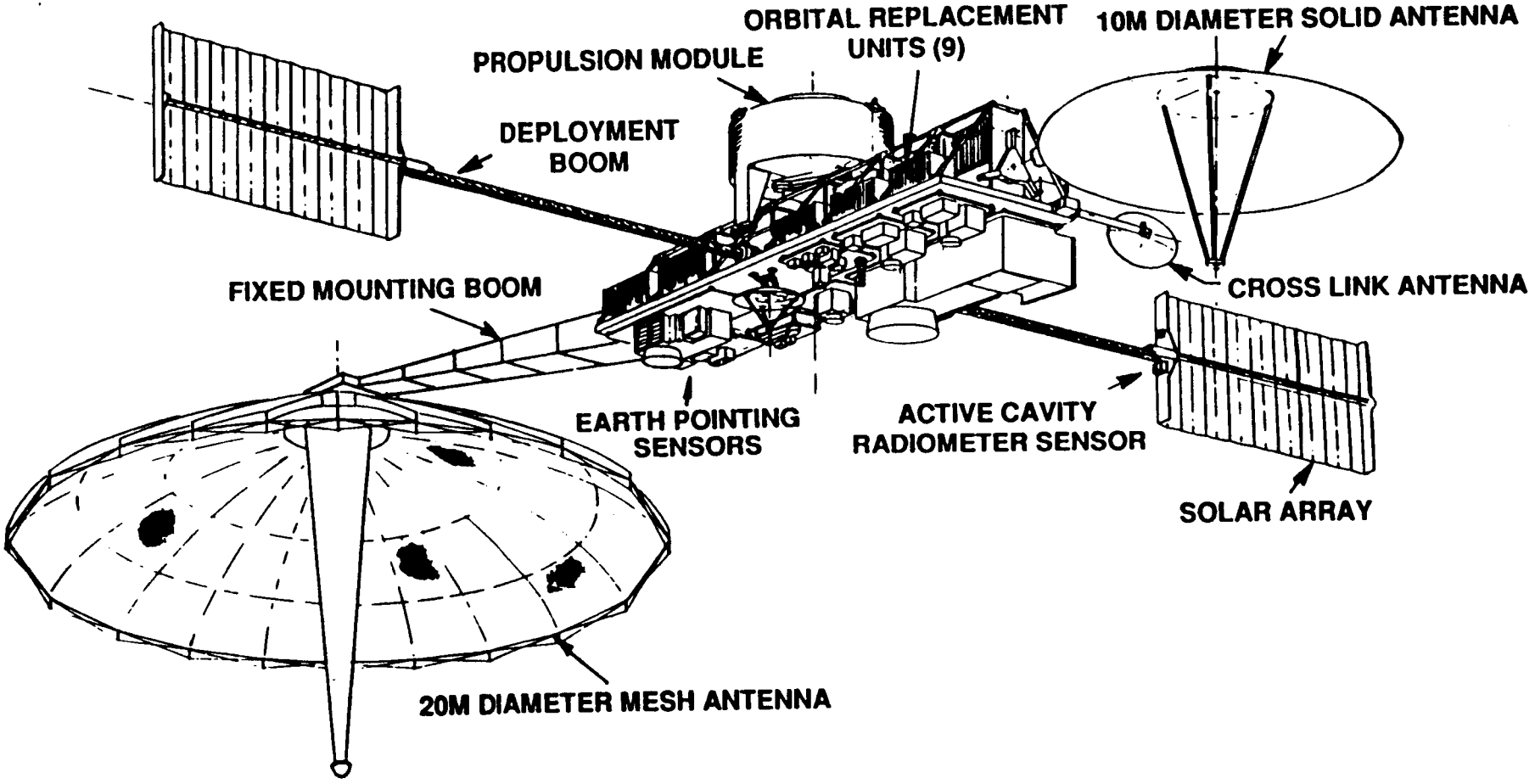
**The total estimated launch mass for this platform is 13,175 pounds, which includes fuel for 10 years of operation. This platform can be placed in orbit with a Titan IV Centaur, expected to be capable of placing 15,000 pounds into the required geostationary orbit by the mid 1990s.**

# GEOSTATIONARY PLATFORM CASE A WEIGHT SUMMARY

| | WEIGHT (LB) | COMMENT |
|---|---|---|
| PAYLOAD | 2645 | CASE A, 1200 kg |
| SPACECRAFT | 6810 | STRUCTURE PLUS ORBITAL REPLACEMENT UNITS |
| TOTAL SPACECRAFT DRY | 9455 | PAYLOAD PLUS SPACECRAFT |
| PROPELLANT | 3610 | MONOPROPELLANT HYDRAZINE |
| LAUNCH VEHICLE INTERFACE | 110 | CENTAUR-G |
| LAUNCH MASS | 13175 | BEGINNING OF LIFE AT GEOSTATIONARY ORBIT |
| PLATFORM MARGIN | 1825 | |

F375.004

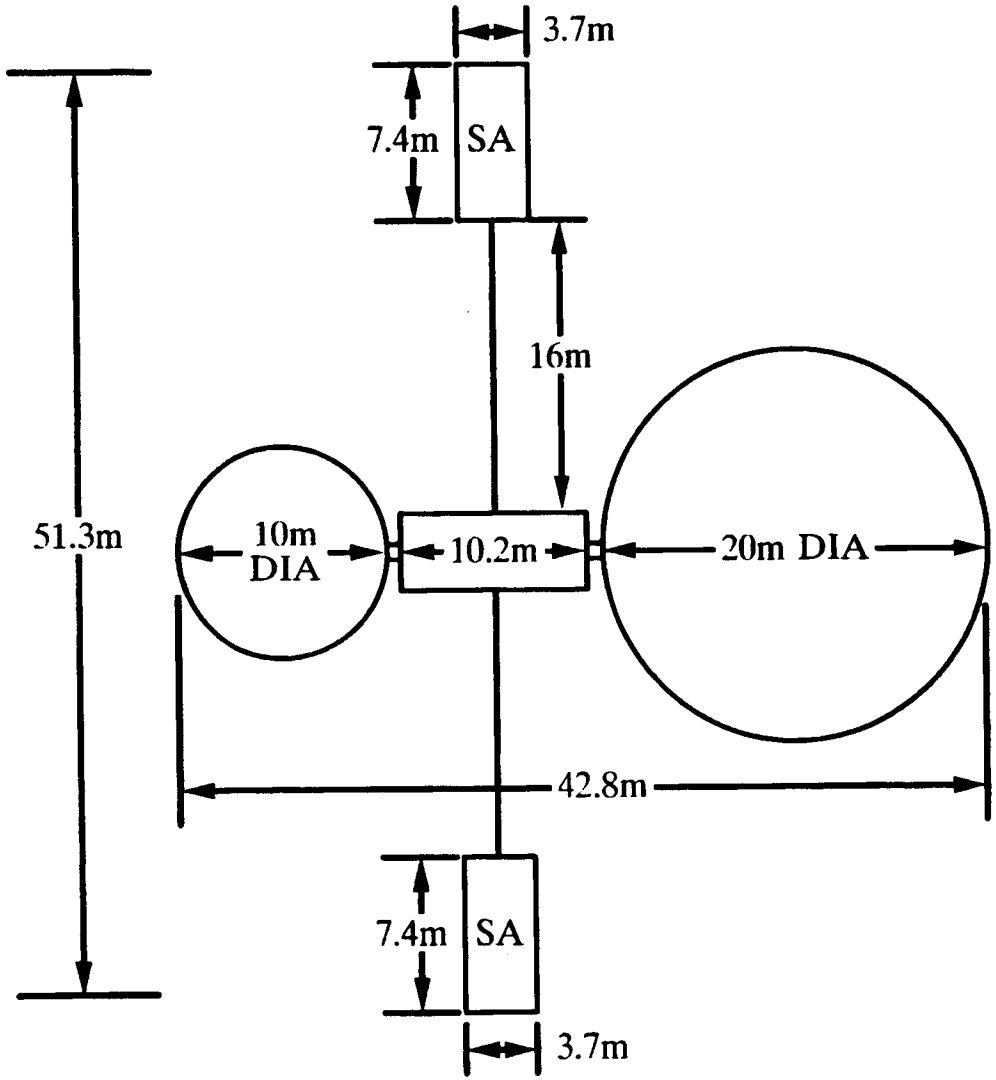
This is a much larger platform than Case A, primarily due to the two large microwave payload antennas, which are mounted at the ends with intermodule connectors. The propulsion module is placed behind the earth-viewing face close to the center of gravity to minimize the center of gravity/center of pressure offset and therefore the frequency of control maneuvers.




GEOSTATIONARY PLATFORM CONFIGURATION - CASE B
ORBITING VIEW

**The overall east-west dimension of the on-orbit spacecraft, driven by the length of the platform body and the diameters of the two microwave instruments, is 42.5 m (139.4 ft). The solar arrays have been moved beyond the shadow of the large 20 m diameter antenna. This results in the platform being approximately 51.3 m (168.3 ft) in the north-south dimension.**

**The platform body is comparable to the baseline Polar Platform, 10.2 m (33.5 ft) long and 3.9 m (12.5 ft) wide. The solar arrays are 3.7 m long by 7.4 m wide—smaller than the polar platform's array.**




# GEOSTATIONARY PLATFORM DIMENSIONS - CASE B

F375.002

Case B is designed to be assembled at the manned base. Easy assembly requires that platform components be combined into reasonably sized modules. In one scenario, these modules are further combined into three packages for shuttle launch in the logical order of the assembly. The size of these launch packages is constrained by length, not weight, so that the remaining shuttle cargo capacity can be used for other Freedom logistics.

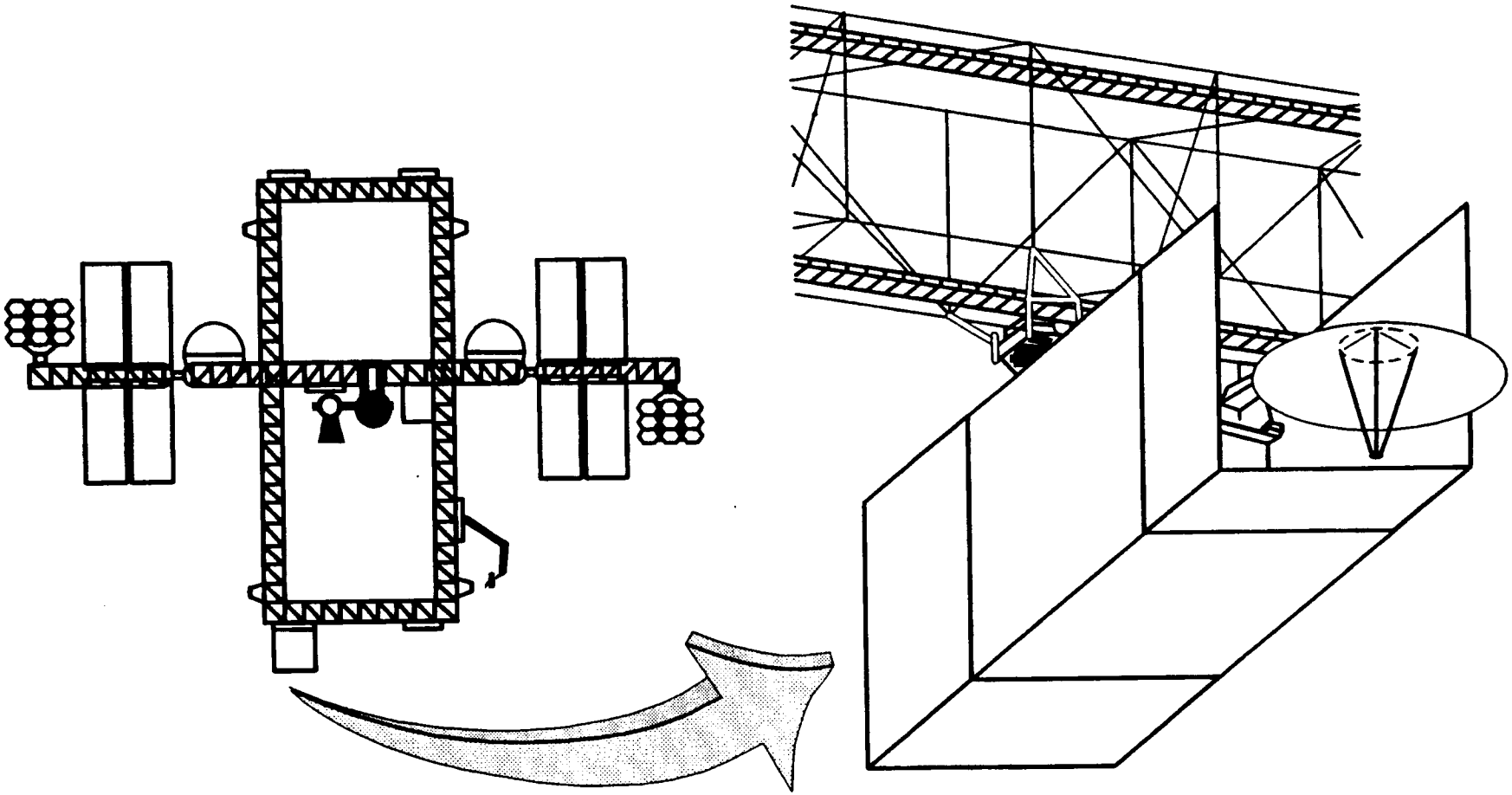
The assembly sequence is described in the Geostationary Platform Study Final Report.

# REPRESENTATIVE CASE B LAUNCH MODULES

- Geostationary platform primary carrier structure with smaller payloads
- Visible/infrared imager with carrier
- Microwave imager/sounder, 20m mesh antenna with carrier
- Microwave imager/sounder, 10m solid antenna with carrier
- Monopropellant propulsion module with propellant

G375.005

**The potential location for assembly of the Geostationary Platform is on a nadir-facing side of the truss, such as the lower boom of the dual keel of the evolutionary manned base.**



POTENTIAL LOCATION FOR GEOSTATIONARY PLATFORM ASSEMBLY

F375.005

In general, the study found it is possible to derive a robust platform for geostationary earth-observing missions from polar platform hardware, with some minor modifications. Two types of changes were required for the ORUs:

Modification to use only one surface for heat rejection. For the battery ORU, this meant 'opening up' the ORU to retain the radiator area with a corresponding decrease in depth.

Deletion of unneeded equipment.

The Case A configuration can be placed in geostationary orbit by a Titan/Centaur.

For Case B, the scars on the manned base are to provide for boost/deboost, storing, assembling, fueling, servicing, and protecting the Geostationary Platform and the Orbital Transfer Vehicle.

The geostationary payload pointing requirements of some of the instruments may be more stringent than polar platform requirements. For example, a few instruments might require special accommodations, such as star trackers, attitude transfer, or ground truth measurements.

In addition, the study showed that the six antennas of the ATDRSS payload conveniently fit on the configuration. Except power which increased from 1200 to 1920 watts, for the payload, the payload mass and resource margins are larger than those for Case A.

The results of this study were published in the final report, dated November 15, 1989.

# RESULTS OF GEOSTATIONARY PLATFORM STUDY

- POLAR PLATFORM SUBSYSTEMS MORE THAN ADEQUATE
- MINOR MODIFICATIONS TO ORUs REQUIRED:

  USE ONLY ONE SURFACE FOR HEAT REJECTION

  DELETE UNNEEDED EQUIPMENT
- PLANNED TITAN/CENTAUR CAPABLE OF LAUNCHING CASE A CONFIGURATION TO GEOSTATIONARY ORBIT
- REQUIREMENTS FOR SPACE STATION FREEDOM SUPPORT IDENTIFIED
- PAYLOAD REQUIREMENTS SATISFIED

A study has recently been completed to test the flexibility of the polar platform design in yet another configuration. This configuration, an Attached Payload Co-orbiting Platform, would serve as a branching mechanism for Space Station Freedom attached payloads. This means that a new concept can be tested as an attached payload on Freedom and if successful, could migrate to the Attached Payload Co-orbiting Platform.

The overall study objectives were to determine the feasibility of using polar platform designs, to identify needed scarring, and to satisfy the test case instrument requirements. All polar platform payload accommodation features, modularity, and serviceability were to be retained.

# ATTACHED PAYLOAD CO-ORBITING PLATFORM STUDY

- June 1988 - January 1990
- Objective

  Determine the feasibility of a co-orbiting platform configuration, using polar platform designs, to provide a branching mechanism for Space Station Freedom attached payloads

G375.004

**The selection of attached payloads by NASA's Office of Space Science and Applications (Code E) was announced June 29, 1989. The press release stated that: "Eight of the nine earth science investigations selected as attached payloads involve copies of Eos polar platform instruments." Five of these, also currently planned for flight on the first Polar Platform, were included in the test case used for this effort, in addition to TRAMAR, also selected from the Eos January 1988 Announcement of Opportunity.**

# ATTACHED PAYLOAD CO-ORBITING PLATFORM TEST CASE

| Instrument | Estimated resource requirements | | |
|---|---|---|---|
| | Mass (kg) | Power peak (W) | Data peak (Kbps) |
| CERES | 104 | 138 | 5 |
| HIMSS | 300 | 115 | 36 |
| LIS | 10 | 20 | 4 |
| TRIS-N* | 260 | 390 | 13000 |
| TRIS-T* | 135 | 270 | 11475 |
| SAGE III | 72 | 66 | 84 |
| TRAMAR | 740 | 1594 | 11700 |
| Totals | 1621 | 2592 | 36304 |
| Design to value | 2000 | 3000 | 50000 |

*MODIS values assumed

G375.003

**For the test case, the following assumptions were used. The platform would:**

**Be launched by the shuttle to Space Station Freedom for assembly or direct to orbit by an expendable launch vehicle,**

**Operate in an orbit of between 460 and 600 km at 28.5 degrees of inclination,**

**Be serviced at the manned base by the Mobile Servicing Centre and its dexterous manipulator or by the Flight Telerobotic Servicer, with extravehicular activity as backup,**

**Use the Orbital Maneuvering Vehicle to return to Freedom,**

**Satisfy estimated resource requirements of test case payloads, and**

**Be disposed of safely (including payloads) at end of life by an internal propulsion system or by Freedom logistics.**

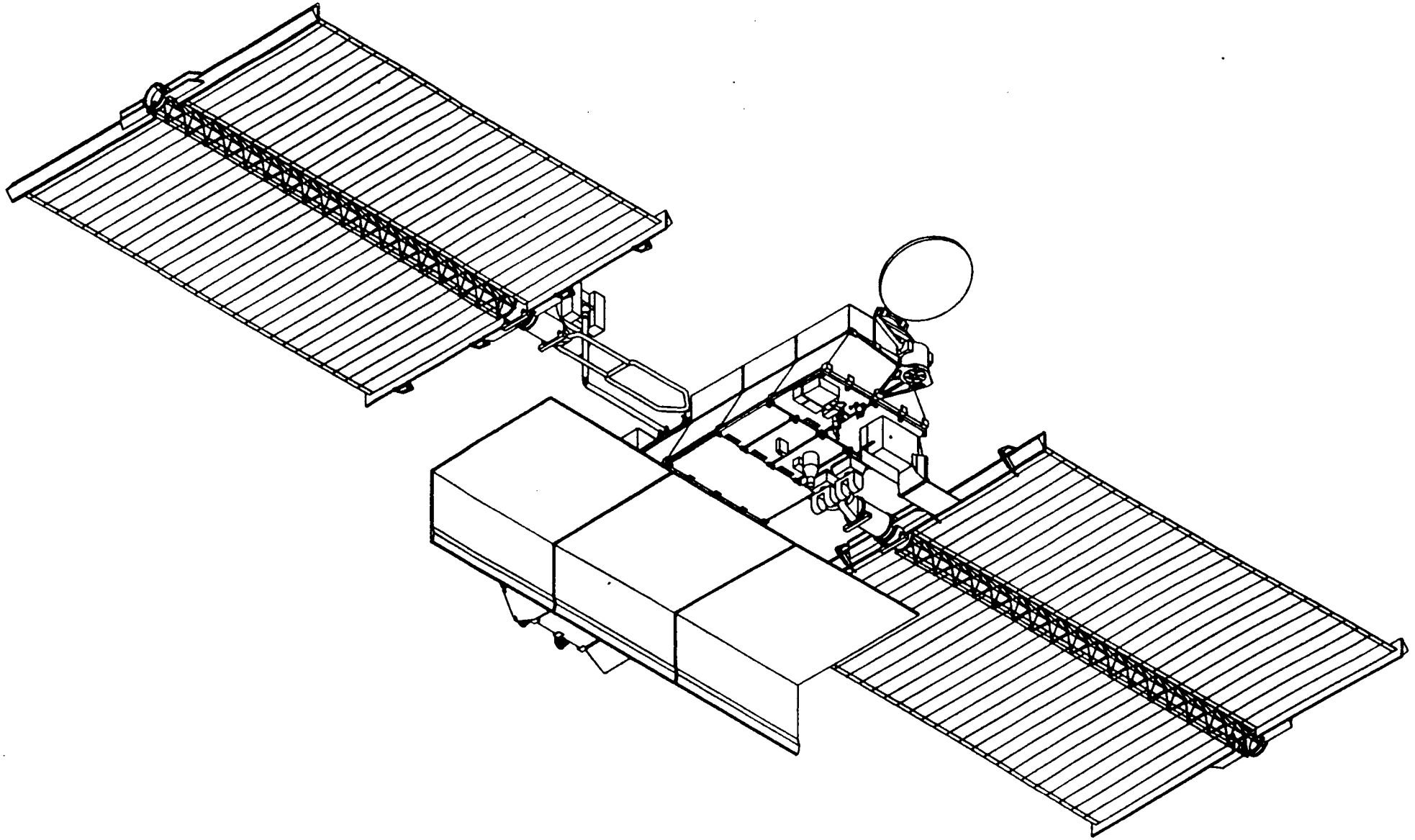
# ATTACHED PAYLOAD CO-ORBITING PLATFORM STUDY ASSUMPTIONS

- Launch
- Orbit
- Servicing
- Transportation to manned base
- Payloads
- Safe disposal

G375.002

**The structure of the configuration is based on that of the Polar Platform. It has two solar arrays, which are mounted above the TRAMAR near the center of gravity for control purposes.**

**The major study efforts were in analysis of thermal aspects of ORUs and in control analysis.**



ATTACHED PAYLOAD CO-ORBITING PLATFORM CONFIGURATION

NASA - JSC
TECHNICAL
LIBRARY
Call No:
TL
797
.B49
1996
v.1
pt.1
c.1

The feasibility of using polar platform designs for a co-orbiting platform was demonstrated. The original plan was to do additional test cases for non-earth observing payloads; however, the funding was not available.

A major benefit of a co-orbiting platform of this type is to free up attached payload accommodations equipment on Space Station Freedom to enable use by a succession of attached payloads.

Benefits to the payloads include:

Operations which are not interrupted as they are expected to be on the manned base,

A cleaner environment,

An altitude which is constant when compared to that of the manned base, and

The capability for a long lived mission.

# ATTACHED PAYLOAD CO-ORBITING PLATFORM STUDY

RESULTS

- CONFIGURATION FEASIBLE
- BRANCHING FOR FREEDOM ATTACHED PAYLOADS POSSIBLE

BENEFITS FOR PAYLOADS

- UNINTERRUPTED OPERATIONS
- CLEAN ENVIRONMENT
- CONSTANT ALTITUDE
- LONG LIFE

# REPORT DOCUMENTATION PAGE

| | | |
|---|---|---|
| 1. Report No.<br>NASA CP-10044 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>Beyond the Baseline - Proceedings of the Space Station Freedom Evolution Symposium at League City, Texas, February 6, 7, & 8, 1990<br>Volume 1: Space Station Freedom; Part 1 | | 5. Report Date<br>May 1990 |
| | | 6. Performing Organization Code<br>HQ MT |
| 7. Author(s)<br>NASA and support contractor personnel funded under the Transition Definition line item - UPN 488 | | 8. Performing Organization Report No.<br>S-606 |
| 9. Performing Organization Name and Address<br>Space Station Engineering<br>NASA Headquarters<br>Washington D.C. 20546<br>MC:MT | | 10. Work Unit No. |
| | | 11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address<br>National Aeronautics and Space Administration<br>Washington D.C. 20546 | | 13. Type of Report and Period Covered<br>Conference publication |
| | | 14. Sponsoring Agency Code |

15. Supplementary Notes

16. Abstract

This report contains the individual presentations delivered at the Space Station Evolution Symposium in League City, Texas on February 6, 7, 8, 1990. Personnel responsible for Advanced Systems Studies and Advanced Development within the Space Station Freedom Program reported on the results of their work to date. Systems Studies presentations focused on identifying the baseline design provisions (hooks and scars) necessary to enable evolution of the facility to support changing space policy and anticipated user needs. Also emphasized were evolution configuration and operations concepts including on-orbit processing of space transfer vehicles. Advanced Development task managers discussed transitioning advanced technologies to the baseline program, including those near-term technologies which will enhance the safety and productivity of the crew and the reliability of station systems. Special emphasis was placed on applying advanced automation technology to ground and flight systems.

| | |
|---|---|
| 17. Key Words (Suggested by Author(s))<br>evolution; "hooks and scars"; advanced automation; knowledge-based systems; robotics | 18. Distribution Statement<br>Unclassified - unlimited<br><br>Subject category: 18 |

| | | | |
|---|---|---|---|
| 19. Security Classification (of this report)<br>U | 20 Security Classification (of this page)<br>U | 21. No. of pages<br>355 | 22. Price |

For sale by the National Technical Information Service, Springfield, VA 22161-2171