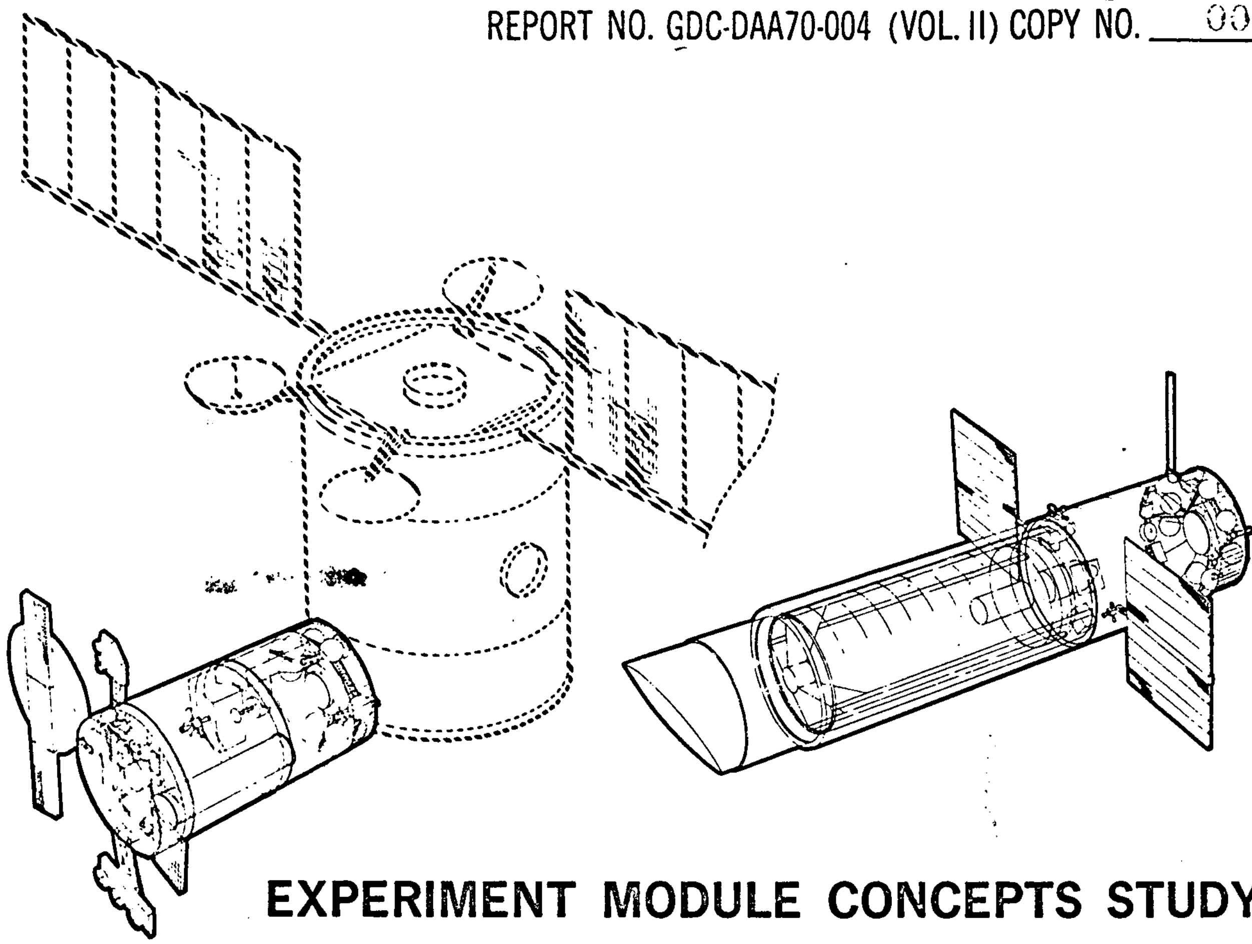
A04184

REPORT NO. GDC-DAA70-004 (VOL. II) COPY NO. 001



EXPERIMENT MODULE CONCEPTS STUDY

FINAL REPORT

VOLUME II - EXPERIMENTS AND MISSION OPERATIONS

October 1970

FACILITY FORM 602		
188 (ACCESSION NUMBER)	(THRU)
(PAGES)	(CODE)
CR-117655 (NASA CR OR TMX OR AD NUMBER)	31 (CATEGORY)

Prepared for
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama
Contract NAS8-25051

Advanced Space Systems, Research and Engineering
CONVAIR AEROSPACE DIVISION OF GENERAL DYNAMICS
San Diego, California

N72-14892 (NASA-CR-117655) EXPERIMENT MODULE CONCEPTS STUDY. VOLUME 2: EXPERIMENTS AND MISSION OPERATIONS Final Report J.M. MacDonald (General Dynamics/Convair) Oct. 1970 188 p CSCL 22B G3/31

Unclas
12045

Rpt - 64612

INDEX OF FUNCTIONAL PROGRAM ELEMENTS

FPE NO.	TITLE	BASIC STUDY ASSIGNMENT
5.1	Grazing Incidence X-Ray Telescope	Module
5.2A	Stellar Astronomy Module	Module
5.3A	Solar Astronomy Module	Module
5.4	UV Stellar Survey	Space Station
5.5	High Energy Stellar Astronomy	Module
5.6	Space Physics Airlock Experiments	Space Station
5.7	Plasma Physics & Environmental Perturbations	Module
5.8	Cosmic Ray Physics Laboratory	Module
5.9	Small Vertebrates (Bio D)	Module
5.10	Plant Specimens (Bio E)	Module
5.11	Earth Surveys	Module
5.12	Remote Maneuvering Subsatellite	Module
5.13	Biomedical & Behavioral Research	Space Station
5.14	Man/System Integration	Space Station
5.15	Life Support & Protective Systems	Space Station
5.16	Materials Science & Processing	Module
5.17	Contamination Measurements	Module
5.18	Exposure Experiments	Module
5.19	Extended Space Structure Development	Space Station
5.20	Fluid Physics in Microgravity	Module
5.21	Infrared Stellar Survey	Space Station
5.22	Component Test & Sensor Calibration	Module
5.23	Primates (Bio A)	Module
5.24	MSF Engineering & Operations	Space Station
5.25	Microbiology (Bio C)	Space Station
5.26	Invertebrates (Bio F)	Space Station
5.27	Physics & Chemistry Laboratory	Module

GDC-DAA70-004
Contract NAS8-25051

EXPERIMENT MODULE CONCEPTS STUDY

FINAL REPORT

VOLUME II
EXPERIMENTS AND MISSION OPERATIONS

October 1970

Prepared by:
J. M. Macdonald

Approved by:
D. J. Powell, Study Manager

W. W. Withee, Director
Advanced Space Systems
Research and Engineering

Prepared for
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama
Contract NAS8-25051

Advanced Space Systems, Research and Engineering
CONVAIR AEROSPACE DIVISION OF GENERAL DYNAMICS
San Diego, California

FOREWORD

This final report is submitted in accordance with the requirements of Appendix 3 — Reports and Visual Aids Requirements, Statement of Work, Experiment Module Concepts Study, Contract NAS8-25051, as amended by Amendment No. 2 dated 9 March 1970.

It comprises the following documents:

Volume I — Management Summary
Volume II — Experiments & Mission Operations
Volume III — Module & Subsystem Design
Volume IV — Resource Requirements
Volume V — Book 1 Appendix A
Book 2 Appendices B & C

The study was conducted under the program and technical direction of Max E. Nein and Jean R. Olivier, PD-MP-A, of the George C. Marshall Space Flight Center, National Aeronautics and Space Administration. Dr. Rodney W. Johnson, OMSF (Code MF), as study sponsor furnished valuable guidance and assistance.

Other NASA centers and offices made significant contributions of advice, consultation, and documentation to the performance of the tasks, the results of which are reported here. Personnel from OMSF, OSSA, OART, MSFC, MSC, GSFC, LeRC, and Ames RC took part in periodic reviews during the study.

Convair Aerospace Division of General Dynamics was assisted by TRW Systems Group, Redondo Beach, California, in the performance of this contract. Personnel of both companies who contributed to this report are listed in Vol. I, Management Summary.

Comments or requests for additional information should be directed to the following:

M. E. Nein, PD-MP-A
J. R. Olivier, PD-MP-A
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Alabama 35812
Telephone: (205) 453-3427

D. J. Powell
Convair Aerospace Division of General Dynamics
P.O. Box 1128, Mail Zone 501-10
San Diego, California 92112
Telephone: (714) 277-8900, Ext. 1941

OBJECTIVES AND GROUND RULES

OBJECTIVES

The primary objectives of this study are:

- To define the minimum number of standardized module concepts that will satisfy the NASA Candidate Experiment Program for Manned Space Stations at least cost.
- To define the module interfaces with other elements of the manned space program such as the space station, space shuttle, ground stations, and the experiments themselves.
- To define the total experiment module program resource and test requirements including SRT-ART.
- To determine the effect on experiment program implementation of shuttle-only operations.

GROUND RULES

The ground rules listed here evolved during the course of the study from the set provided at initiation of effort. They illustrate the reference framework within which results were developed.

General

Primary consideration will be given to the development of the minimum number of basic module concepts that through reasonable modification will be capable of accommodating all of the candidate experiment groups at least cost.

Experiments

1. NHB 7150.XX, "Candidate Experiment Program for Manned Space Stations" (Blue Book) will be used as an illustrative program of experiments to be integrated into the space station core module or into separately launched experiment/laboratory modules to assure that the system has the inherent capabilities to support those specific experiments and other experiments not yet identified.

2. Where not otherwise stated, the Blue Book period of experiment implementation will be two years.

3. All experiment equipment shall be assumed to have self-contained calibration capability.

Mission and Operations

1. The modules shall be capable of operating in conjunction with a space station in an orbit of 55 degrees inclination and 200-300 n.mi. altitude. The modules will not necessarily operate in this altitude range and inclination.

2. For a limited number of experiment groups the preferred alternate missionof sun synchronous (polar) orbit at an altitude of 200 n.mi. may be specified.

3. Experiment/laboratory modules may be operated in free-flying, docked, or permanently attached modes and may or may not be manned during their operation. However, all experiment modules operating in detached mode will be unmanned.

4. NASA will specify the operating mode and servicing mode for each experiment group. In some cases, concepts for particular experiment groups may be required for more than one operating and/or servicing mode.

5. Modules that operate in a free-flying mode and do not require the frequent attention of man for operation should have the capability of command and control by a station or logistics spacecraft.

6. Modules docked to the space station for servicing or operation should be assumed to be docked to a zero gravity station or a non-rotating hub of an artificial gravity station.

7. Unless a space tug is available, all modules designed for detached operation shall have the inherent capability of returning to and docking with the space station.

8. Rendezvous operations bring the module within 3000 feet of the space station with a maximum relative velocity of 5 ft/sec. Docking operations continue from there to contact. Automatic docking will be the preferred mode.

9. Attached modules shall have the capability of changing docked position on the space station once during a two-year period.

10. All detached modules shall operate depressurized.

Configurations

1. Where practical from a payload standpoint, the modules should be compatible with manned logistics systems consisting of Saturn IB-Modified CSM, Titan III – Big Gemini, S-IC/S-IVB-Modified CSM, and S-IC/S-IVB Big Gemini. Consideration should also be given to launching the modules in an unmanned mode on the above launch vehicles. The possibility of transporting the modules in an advanced logistics system should also be examined.

2. To the extent practical, experiment/laboratory modules will be designed to be compatible for launch on both expendable and reusable launch vehicles.

3. Modules and equipment will be designed for the axial and lateral accelerations associated with the launch vehicle specified.

4. Experiment equipment and module subsystems will be completely assembled/installed on the ground and checked out prior to launch. Assembly in space will be avoided. However, to permit flexibility in updating equipment (and meeting maintenance requirements) designs should provide the capability for equipment replacement both on the ground and in orbit.

5. When docked to the space station, the modules will derive, for the most part, the electrical power, communications support, environmental control and life support, data processing facilities, and crew sytems needs (food preparation, hygiene, sleeping quarters) from the main space station. Careful attention should be given to the definition of the support required from the station and/or manned logistics spacecraft for each module and the module-station, module-logistics spacecraft, and module-experiment interfaces.

6. The experiment/laboratory modules will be designed for efficient utilization of the support services that the space station and the logistics systems can provide. The experiment/laboratory modules will supply services or supplement services that are inadequate (e.g., the space station cannot accept rejected heat).

7. All fluid interfaces with the space station may be assumed to be umbilical at the docking port.

8. A means will be provided to jettison modules from the space station as an emergency measure in event of a major hazard (fire, overpressure, etc.).

9. Modules shall be designed for a nominal two-year mission, with refurbishment in space at end of two years to extend life up to 10 years.

10. Servicing and maintenance of the modules and their experiments will be accomplished without EVA and in a shirtsleeve environment to the maximum practical extent. Possible exception to this would be the inspection and maintenance of externally mounted subsystems such as solar panels and RCS motors.

11. Means will be provided to accomplish inspection, servicing, repair and/or replacement of all equipment items not accessible from the module interior.

12. Modules will be designed for crew servicing, maintenance, and updating in a docked or hangared mode or by on-site repair from a docked tug.

13. Appropriate safety features (such as high voltage protection, adequate ingress/egress provisions, non-toxic and non-flammable materials, protrusion protection, etc.) will be incorporated into the design and maintenance aspects of each module concept. A crew safety analysis will be conducted to identify potential safety problems associated with the operation, servicing and maintenance of each module concept.

14. For the baseline module system no electronic data storage capability will be provided aboard modules. Centralized facilities on the space station/ground will be used. Over-the-horizon capability for detached modules will be studied as a modular add-on subsystem and costs.

15. Optical surfaces will be protected during the firing of RCS thrusters.

16. Leakage from pressurized modules will be assumed as follows:

0.08 lb per day per linear foot of breakable seal

0.04 lb per day per linear foot of static seal

0.0001 lb per day per square foot of pressurized surface area.

Shuttle-Only Mode

Ground rules peculiar to this task are given in Volume V, Appendix A.

TABLE OF CONTENTS

PRECEDING PAGE BLANK NOT FILMED

TABLE OF CONTENTS, Contd

LIST OF FIGURES

LIST OF FIGURES, Contd

LIST OF TABLES

LIST OF TABLES, Contd

LIST OF TABLES, Contd

SECTION 1

CANDIDATE EXPERIMENT PROGRAM

The experiment program provided by NASA for use during the experiment module study as a basis for development of experiment module concepts is a portion of the total NASA space experiment plans considered as representative of space experiments associated with manned space station programs in the 1975 to 1985 time era.

The experiment program provided is defined as being for module and space station design purposes only, and neither the program nor the identified experiments are approved by NASA as planned projects.

The baseline experiment program is concerned with future space experiments and covers the scientific disciplines shown in Table 1-1. Experiments within each of these scientific disciplines are grouped into functional program elements (FPE). Two dominant features determine experiment grouping: (1) experiments that support a particular area of research or investigation, and (2) experiments that impose similar or related demand on space station support systems.

FPEs as currently assigned to each discipline are listed in Table 1-2. FPEs that are candidates (as defined by study ground rules) for experiment module application are noted, as are those FPEs that are integral to the space station. The three biomedical FPE's (5.13, 5.14 and 5.15) were not assigned to the experiment module program but were to be investigated for compatibility with the module concepts derived for the assigned FPEs. All FPEs were included in the special case of shuttle-only operations contained in Volume V.

1.1 SUMMARY OF MODULE CANDIDATE EXPERIMENT PROGRAM

Shown in Table 1-3 is a summary of the experiment program assigned by NASA/MSFC as candidates for modular application for purposes of this study.

The program totals 17 FPEs covering roughly 120 experiment areas, plus the manned centrifuge portion of FPE 5.13 Biomedical and Behavioral.

1.2 STATUS OF EXPERIMENT DEFINITION

The baseline experiment program provided by NASA at the start of the study is defined by the NASA document, commonly called the Blue Book, of 15 May 1969 (Reference 1-1). Augmentations and revisions of this document during the course of the study are shown in Figure 1-1.

Table 1-1. NASA Candidate Experiment Program

ASTRONOMY	SPACE PHYSICS	SPACE BIOLOGY	BIOMEDICINE & BIOTECHNOLOGY	EARTH APPLICATIONS	MATERIALS SCIENCE	ADVANCED TECHNOLOGY
GRAZING INCIDENCE X-RAY TEL.	AIRLOCK EXPERIMENTS	SMALL VERTEBRATES (BIO D)	BIOMEDICAL & BEHAVIORAL RESEARCH	EARTH SURVEYS	MATERIALS SCIENCE & PROCESSING	CONTAMINATION MEASUREMENTS
ADVANCED STELLAR	PLASMA PHYSICS & ENVIRONMENTAL PERTURBATIONS	PLANT SPECIMENS (BIO E)	CENTRIFUGE			EXPOSURE EXPERIMENTS
ADVANCED SOLAR	COSMIC RAY PHYSICS LAB	PRIMATES (BIO A)	MAN/SYSTEM INTEGRATION			EXTENDED SPACE STRUCTURE DEVELOPMENT
IR STELLAR SURVEY	PHYSICS & CHEMISTRY LAB	MICROBIOLOGY (BIO C)	LIFE SUPPORT & PROTECTIVE SYSTEMS			FLUID PHYSICS IN MICROGRAVITY
UV STELLAR SURVEY	REMOTE MAN. SUBSATELLITE	INVERTEBRATES (BIO F)				COMPONENT TEST & SENSOR CALIB.
HIGH-ENERGY STELLAR						MSF ENGINEERING & OPERATIONS

APPLICABILITY

BASELINE EXPERIMENTS (solid box)

EXAMINE FOR COMPATIBILITY (dashed box)

ALL APPLICABLE FOR SHUTTLE-ONLY CASE

Table 1-2. NASA Candidate Experiment Program

Discipline	FPE No.	Title	Assignment	
			Module Candidate	Station Integral
Astronomy	5.1	Grazing Incidence X-Ray Telescope	X	
	5.2A	Advanced Stellar Astronomy	X	
	5.3A	Advanced Solar Astronomy	X	
	5.4	UV Stellar Survey		X
	5.5	High Energy Stellar Astronomy	X	
	5.21	Infrared Stellar Astronomy		X
Space Physics	5.6	Space Physics Airlock Experiment		X
	5.7	Plasma Physics & Environment Perturbations	X	
	5.8	Cosmic Ray Physics Laboratory	X	
	5.12	Remote Maneuvering Subsatellite	X	
	5.27	Physics & Chemistry Laboratory	X	
Space Biology	5.9	Small Vertebrates (Bio D)	X	
	5.10	Plant Specimens (Bio E)	X	
	5.23	Primates (Bio A)	X	
	5.25	Microbiology (Bio C)		X
	5.26	Invertebrates (Bio F)		X
Earth Application	5.11	Earth Surveys	X	
Biomedicine and Biotechnology	5.13	Biomedical & Behavioral Research	*	X
	5.13C	(Centrifuge)	X	
	5.14	Man/System Integration	*	X
	5.15	Life Support & Protective Systems	*	X
Materials Science	5.16	Materials Science & Processing	X	
Advanced Technology	5.17	Contamination Measurements	X	
	5.18	Exposure Experiments	X	
	5.19	Extended Space Structure Development		±
	5.20	Fluid Physics	X	
	5.22	Component Test & Sensor Calibration	X	
	5.24	MSF Engineering & Operations		X

*To be examined for compatibility with module design concepts.
±Cancelled 5-15-70

Table 1-3. Summary of Experiment Program - Module Candidates

ASTRONOMY											SPACE PHYSICS				BIOLOGY			EARTH APP	BIOMED	ADVANCED TECHNOLOGY				
5.1 X-RAY	5.2A STELLAR		5.3A SOLAR				5.5 HIGH ENERGY STELLAR				5.7 PLASMA	5.8 COSMIC	5.12 RMS	5.27 PHYS & CHEM	5.9 VERTEBRATES	5.10 PLANTS	5.23 PRIMATES	5.11 SURVEYS	5.13C CENTRIFUGE	5.16 MTLS. SC.	5.17 CONTAM.	5.18 EXPOSURE	5.20 FL. PHYSICS	5.22 COMP. TEST
Telescope 1000 cm^2 0.1 - 62 A X-Ray	Telescope 3 Meter 900 - 10K A UV - VIS - IR	Telescope 1.5 Meter 1300-3000 A UV - VIS	Telescope 0.25 Meter Spectroheliograph XUV	Telescope 0.5 Meter 1 - 24 A X-Ray	Coronograph 1-6 Radii White Light	Coronograph 5-30 Radii White Light	Telescope 0.5 Meter X-Ray	Telescope 0.5 Meter 1.55-124 A X-Ray	Nuclear Spectrometer Gamma Ray	Spark Chamber Nuclear Emulsion Gamma Ray	Wake & Plasma Generators & Sensors	Ionization Spectrograph Detectors & Magnet in Laboratory	Sub-Satellite Sensors	Research Laboratory	Laboratory Specimen Housing & Centrifuge	Laboratory Specimen Housing & Centrifuge	Laboratory & Specimen Housing	Remote Sensors, Calib. Lab Data System	Manned Centrifuge	Research Laboratory	Sensors & Specimens	Sensors & Specimens	Research Laboratory & Test Tanks	Test Chambers
Polarimeter	70 mm Video	Spectrograph 3-Range	Image Photo	Spectrograph	Image Film	Image Film	Imaging Video	Spectrograph Point Source	Spectrometer	Photo Emulsions	Plasma Wake	Astro-physics	Radio Occultation - Atm Density	Artificial Meteorites	Cardiovascular (rats)	Response 0-1g (wheat seeds)	Physiology of Chimps	Cameras (2) VIS & IR Multispectra	Walking	Thin Films	Sky Brightness	Meteoroid Composition	Interface Stability	Fuel Cells & Batteries
Crystal Spectrometer	225 mm Photo	Hα Monitor Vidicon		Image Photo			Spectrometer	Spectrograph Scan		Spark Chamber	Cyclotron Harmonic Resonance	Interaction Physics (H_2 Target)		Ultra Pure Materials	Birth-Growth (rats & other)	Seedling Growth (pea)	Hemodynamic & Metabolic — Monkeys	Infrared Sensors (4)	Work Tasks	Glass Casting	Particle Size	Meteor Flash Analyzer	Boiling Heat Transfer	Liquid-Gas Separation & Measurement
Imaging Spectrometer	70 mm Photo	White Light Vidicon		Image Video				Counters (2)		Detectors	Electron Accelerator			Fluid Critical State	Immunization (Marmots)	Morphogenesis (Aribidopsis)		Microwave Devices (5)	Habitability & Hygiene	Spherical Casting	Contamination Monitor	Meteoroid Impact	Capillary	Heat Pipes & Exchangers
Detector	Spectrograph Photo	UV Vidicon		Counters							Wave Particle Interaction			Capillary Dyn-Static	Birth Growth (Frogs)	Dorsoventrality		Polarimeter Visible	Tolerance g	Crystal Growth	Optical Samples	Meteoroid Velocity	Condensing Heat Transfer	Air Bearings
Image TV	Spectrograph Video	Magnetograph									Plasma Jet			Bubble Formation	Reptile Growth (Turtles)	Auxin Reaction (Wheat Seedlings)		UHFSferics	Re-Entry Simulation	Composites Casting	Thermal Surface Samples	Meteoroid Flux & Velocity	Fluid Properties	Film Processing
	Image TV	Field Image TV									Barium Cloud			Free Liquid Drops	Gravity to 1g (Rats)	Evolution (Cucumbers)		Absorption Spectrometer	Centrifuge Value	Variable Density Cast.	Contaminant Cloud Composition	Fatigue Samples	Rotating Liquid Globules	Welding
															Bio-Rythyms (Rats)	Circadian Rythyms (Pinto beans)		Laser Altimeter	Mass Measurement		Dispersal RCS Plums	Spacecraft Surface Samples	Two Phase Flow	Cryogenic Flowmeter
															Hibernation (Marmots			UV Imager Spectrometer			Charged Contaminant Cloud	Material Bulk Properties	Film Stability	LWIR & MW Radiometers
																		Radar Altimeter Scatterometer					Propellant Transfer	Radiometer Optics
																		Photo Imaging Camera					Long Term Cryogenic Storage	Atmosphere Variability
																		Data Collection					Zero g Combustion	
																							Slush Hydrogen	
											Uses RMS in FPE 5.12		Used also for FPE 5.7 Plasma Wake											

FOLDOUT FRAME 1

FOLDOUT FRAME 2

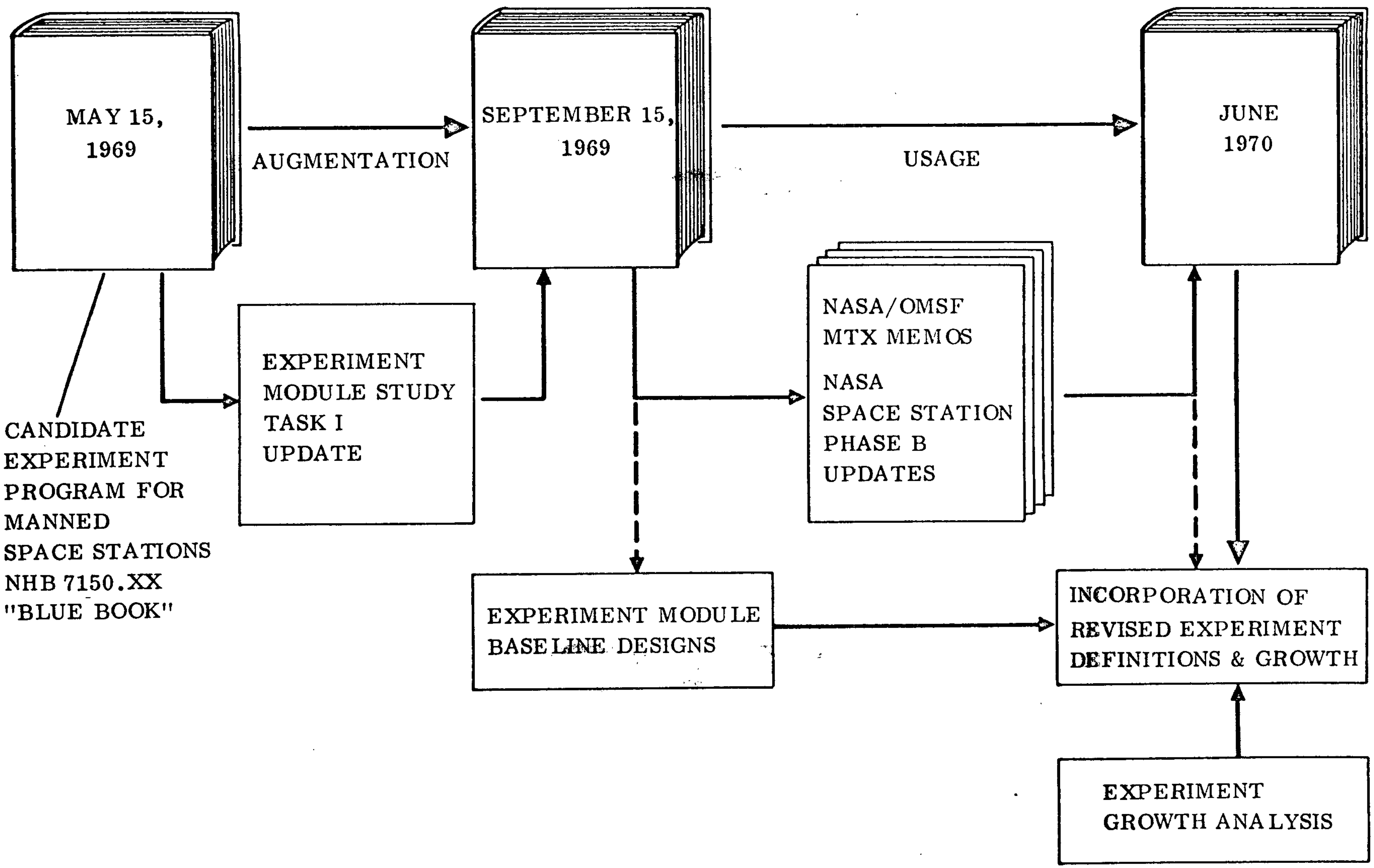


Figure 1-1. NASA Candidate Experiment Program

Task I of the Experiment Module Study updated the initial experiment program using additional experiment definition provided by NASA, and supplemented from several authorized sources. The resulting program was published as an updated version of Reference 1-1, dated 15 September 1969.

Certain portions of the updated experiment program were authorized for further revision by NASA under space station study efforts, and by responsible scientific offices within NASA. Certain experiment requirements were also revised or deleted by NASA after examination of the potentially difficult or costly implementation requirements uncovered through experiment module and space station study efforts.

All experiment program revisions were authorized by NASA/OMSF/MTX memos. Table 1-4 summarizes the revisions incorporated into the Blue Book issue of June 1970. In addition to these authorized revisions, results of the experiment growth analysis (see Section 1.3) were considered during module conceptual design and operations studies.

1.3 EXPERIMENT GROWTH ANALYSIS

Experiment modules are designed to accommodate experiments based on the requirements contained in NHB 7150.XX, "Candidate Experiment Program for Manned Space Stations," dated June 1970 (Blue Book).

However, study ground rules require that the experiment modules not be constrained to the specific experiment definitions in the Blue Book since the Blue Book experiment program is defined as being only representative of the experiments that will be performed. Experiment modules are therefore to consider accommodation of variations and growth in the specified experiments.

Following the initial commonality analysis, an analysis was conducted to determine what future variations and growth in the various FPEs might be expected to occur in these experiments, the extent of these variations and growth that should be accommodated in experiment module design, and the resulting effect on module commonality.

The general approach to growth prediction was to consider experiment groups as forming the basic requirements for general purpose laboratories associated with each discipline, and projecting what additional experiments or research capability should be provided for in order to further the general purpose aspect of each lab. For the astronomy experiments, this general purpose capability is satisfied by considering the telescopes as basic observatories and attempting to project what additional sensors might be added to use the total capability.

Table 1-4. Status of Candidate Experiment Definition for Manned Space Stations

FPE NO.	TITLE	MODULE CANDIDATES	ADDITIONS, REVISIONS OR DELETIONS AUTHORIZED SINCE 15 SEPTEMBER 1969
5.1	Grazing Incidence X-Ray Telescope	X	None
5.2A	Stellar Astronomy	X	Deleted figure sensor.
5.3A	Solar Astronomy	X	Added 3 Zirin Cameras effective 15 Dec. 69.
5.4	UV Stellar Survey	—	None
5.5	High Energy Stellar Astronomy	X	None
5.6	Space Physics Airlock Experiments	—	None
5.7	Plasma Physics and Environmental Perturbations	X	Expanded to include (4) additional experiments 15 Oct. 69.
5.8	Cosmic Ray Lab	X	None
5.9	Small Vertebrates (Bio D)	X	None
5.10	Plant Specimens (Bio E)	X	None
5.11	Earth Surveys	X	None
5.12	Remote Maneuvering Subsatellite	X	None
5.13	Biomedical and Behavioral Research	— *	Revision and expansion issued 26 Nov. 69.
(5.13C)	Manned Centrifuge	X	None
5.14	Man/System Integration	— *	Revision and expansion issued 26 Nov. 69.
5.15	Life Support and Protective Systems	— *	Revision and expansion issued 26 Nov. 69.
5.16	Materials Science and Processing	X	None
5.17	Contamination Measurements	X	None
5.18	Exposure Experiments	X	None
5.19	Extended Space Structure Development	—	Revision and expansion issued 26 Nov. 69.
5.20	Fluid Physics in Microgravity	X	Requirement for 10^{-2}g experiment deleted Jan. 70.
5.21	Infrared Stellar Survey	—	None
5.22	Component Test and Sensor Calibration	X	None
5.23 **	Primates (Bio A)	X	Added 15 Oct. 69. Requirements updated 6 Feb.70.
5.24	Manned Space Flight Engineering & Ops.	—	Revision and expansion issued 26 Nov. 69.
5.25	Microbiology (Bio C)	—	None
5.26	Invertebrates (Bio F)	—	None
5.27	Physics and Chemistry Lab	X	FPE 5.27 added 15 Oct. 69.

* To be examined for compatibility with common modules during Task IV.

** Was titled "Advanced Spacecraft System Tests." This category of experiments deleted by 15 Sept. issue.

The method used to project growth or variation in each experiment FPE included the following steps:

a. Projection or extrapolations from past developments.

b. Review of various experiment program documents, scientific group projections, and selected technical papers.

c. Consultation with local specialists.

Table 1-5 lists the chief documents that were reviewed to identify specific growth or variation that may occur in each of the FPEs.

Table 1-5. References Reviewed for Experiment Growth

1. NASA SP-213	A Long Range Program in Space Astronomy, Position Paper of the Astronomy Missions Board, July 1969
2. NASA SP-196	NASA Science and Technology Advisory Committee for Manned Space Flight, Proceedings of Winter Study on Uses of Manned Space Flight (1975-2985), Volume II-Appendix, Dec. 1968
3. NASA	Experiment Program for Extended Earth Orbital Missions, September 1969 (Yellow Book)
4. ED-2002-795	Advanced Astronomy Mission Concepts, ATM Follow-on Study by Martin Marietta Company, April 1969
5. MDC G0549	Earth Orbital Experiment Program and Requirements Study by McDonnell Douglas Astronautics Company, April 1970 (Progress Report)
6. DAC 58141	Orbital Astronomy Support Facility Study, by McDonnell Douglas Corporation, June 1968
7.	Useful Applications of Earth Oriented Satellites, by National Academy of Sciences for NASA, 1969
8. A/7285	Report of the Committee on the Peaceful Uses of Outer Space, United Nations General Assembly, 1968
9. 8900	Optical Technology Apollo Extension System Phase A Study (OTES) by Perkin Elmer, October 1967
10.	Space Processing and Manufacturing Meeting, NASA/MSFC, Huntsville, October 1967
11.	Orbiting Research Lab Experiment Program, Volume B, by IBM, February 1966

Table 1-5. References Reviewed for Experiment Growth (Continued)

12. XM-TN-130	Technical Notes on FPE 5.5 High Energy Astronomy, by J. Matteson, UCSD, for GD/Convair, January 1970
13. 70-9443-1	Study of a Large Telescope, ITEK, May 1970
14.	"Physics of the Earth in Space", Woods Hole Summer Study, 1968, Woods Hole, Massachusetts
15.	ORL Experiment Program; IBM Federal Systems Division, February, 1966

In addition to these efforts, recommendations for growth considerations and experiment implementation requirements were received at times during the study from various NASA sources.

The following sections summarize the results of this analysis of potential growth or variation, together with the effect of growth on module subsystems and interfaces, a recommendation for the growth that should be provided for in module design, and the effects on module commonality.

1.3.1 EXPERIMENT GROWTH PROJECTIONS BY DISCIPLINE. Following is briefly summarized the potential growth or variation in each experiment FPE for the various disciplines, together with the effects on module capabilities. These are recapped in Table 1-6.

1.3.1.1 Astronomy. Growth projections for the astronomy FPEs are based on review of NASA AMB Report SP-213 (Reference 1) and NASA SATAC Report SP-196 (Reference 2) in addition to other documents listed in Table 1-5. Information was also informally received from NASA sources such as the potential need for polarity measurements for FPE 5.2A Stellar, and the improvement in data correlation made possible by a boresighted grouping of the FPE 5.3A Solar Telescopes.

The potential need for FPE 5.2A Stellar primary mirror operations at the 70°F manufacturing temperature resulted from a recent study of this telescope, as did the projected weight increase in this mirror (Reference 13). Mirror operation at 70°F may require an additional 1 to 2 kW electrical power, which has been verified as feasible to provide as an experiment peculiar set of solar arrays.

The magnetograph weight, data, and power values were estimated to make provisions for the magnetograph specified but without these parameters in the Blue Book for FPE 5.3A Solar.

Table 1-6. Summary of Experiment Growth Projections

Discipline	FPE No	Title	Projected Growth or Variation	Special Capabilities	Growth or Variation Parameters							
					Weight-lbs		Volume-ft^3		Data - Mbps/MHz		Avg Power-kw	
					BB	G	BB	G	BB	G	BB	G
Astronomy	5.1	X-Ray	Locate stellar sources to 1 sec	Point to 1 sec								
			Permit use of 3 nested mirror unit		3300	3600	35	43				
			Additional sensors, data rates						0.10	0.50	0.25	0.30
	5.2A	Stellar	Increased weight of primary mirror		1700	1000						
			Observations on sunlit side of orbit						1.0	2.0		
			Capability for polarity measurement	Rotate 90 - sunside								
			Potential need to maintain mirror @ 70°F.								0	1-2.0(1)
			Additional sensors (photometer polarimeter)		0	100	0	2	0	1	0	0.2
	5.3A	Solar	Photo heliograph weight increase		3200	4000						
			Provisions for magnetograph		0	200	0	12	0	1	-	0.08
			Vidicon replacement of sensors		0	+180	0	+6	Digital	3 @ 1.3 MH_z	0	+0.6
			Boresight point - target telescopes	Single Module								
	5.5	High Energy	Gamma ray detector size increase (50%)		5000	7500	-	30			-	+.26
Space Physics	5.7	Plasma	Provide for experiments without RMS	Growth to RMS								
	5.8	Cosmic Ray Lab	Limit to Astrophysics only	±45° View from horizon								
			Revise geometry to nominal 15 ft									
			Delete Hydrogen target & refrigeration		500	-					2.5	-
			Provide for dual magnet	(deletes torque)	5,000	3,000						
			Provide for Total Absorption Detector		15,000	24,000						
Biology	5.9 5.10	Vertebrates Plants	Provisions for FPE 5.25 microbiology and FPE 5.26 invertebrates		4419	6241	496	706	(2) TV	(3) TV	1.09	1.85
			Provide shuttle compatible centrifuge									
Earth Appl.	5.11	Earth Surveys	Potential requirement for ±60° conical pointing of sensors									
Aero Med.	5.13C	Centrifuge	Provide shuttle compatible centrifuge									
Matls Sc.	5.16	Matls Sc & Proc	Provisions for on-board analytical equipment, processing furnace		820	5120	52	842				

Notes: (1) Provide as experiment peculiar solar panel power supply.

The three vidicon cameras for FPE 5.3A Solar are projected to replace the three digital sensors.

1.3.1.2 Space Physics. Projections in growth and variations for space physics FPEs resulted chiefly from combined efforts of local specialists and responsible NASA personnel due to problems encountered in implementing the FPE 5.7 Plasma and FPE 5.8 Cosmic Ray experiments.

The initial implementation of FPE 5.7 Plasma envisioned suitcase experiments carried into the FPE 5.12 RMS Hangar, which in turn housed six RMS used for a growth version of radio occultation experiments, as well as for plasma physics. The revised version for implementing these experiments is to provide a plasma physics lab that provides measurement capability without the use of RMS, but provides space and support to RMS operations when they become necessary in later stages of experiments, for both FPE 5.7 Plasma Physics and the radio occultation experiment of FPE 5.12.

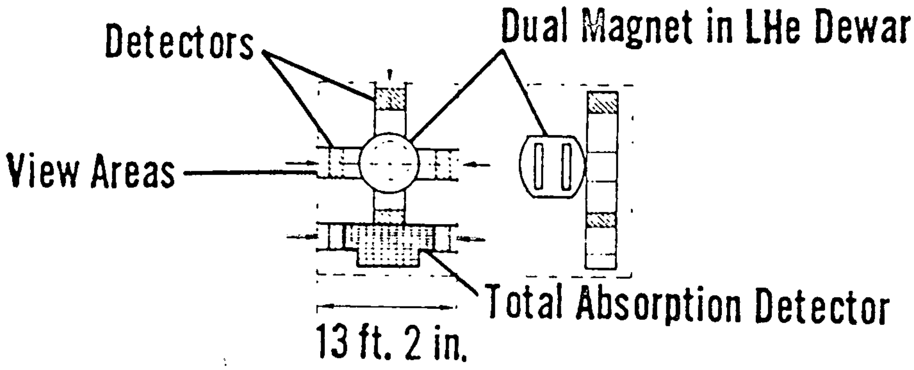
The FPE 5.8 Cosmic Ray laboratory definition resulted in many implementation problems during initial module design phases. One problem was that the experiment objectives and geometry require a 22 foot diameter cylinder, which is not compatible with the shuttle cargo bay. Another was that the interaction between the laboratory magnet and the earth magnetic field produced a significant torque effect. As a result of these and other problems, concerted effort was put forth by NASA and other specialists to re-define the experiment for shuttle compatibility and simplified implementation that would permit accommodation in a laboratory attached to the space station. While these problems were not all resolved by the time of completion of the growth analysis task, the principal revisions were predictable with reasonable confidence (Ref. XM-TN-160 Vol. V, May 1970):

a. Limiting the near-term experiment to Astrophysics only which permits deletion of the hydrogen target, acceptability of a 15 foot diameter geometry and increase in allowable "window" thickness.

b. Use of a dual magnet to prevent the torque-creating interaction with earth fields.

c. Selection of cryogenic resupply in lieu of refrigeration (optional in Blue Book).

Continuing consultation with specialists assigned to support the experiment module study resulted in the adoption of a proposed new geometry for this experiment, plus the addition of a total absorption detector to replace the ionization spectrograph called out in the Blue Book:



The feasibility of accommodating both the current Blue Book and the projected or redefined growth version of this FPE has been verified, and conceptual designs of both versions are contained in Volume III. The higher weight requirements of the growth version is used for determining launch operations requirements.

Existence of the dual magnet has been used in baseline module concepts, the chief difference being the elimination of the gimbal mechanism between the attached laboratory and the sensor bay.

1.3.1.3 Biology. Growth projections made by local specialists include:

a. The biology laboratory module should contain the necessary provisions to accommodate two biology FPEs as potential growth items that are not currently included in the module baseline experiments:

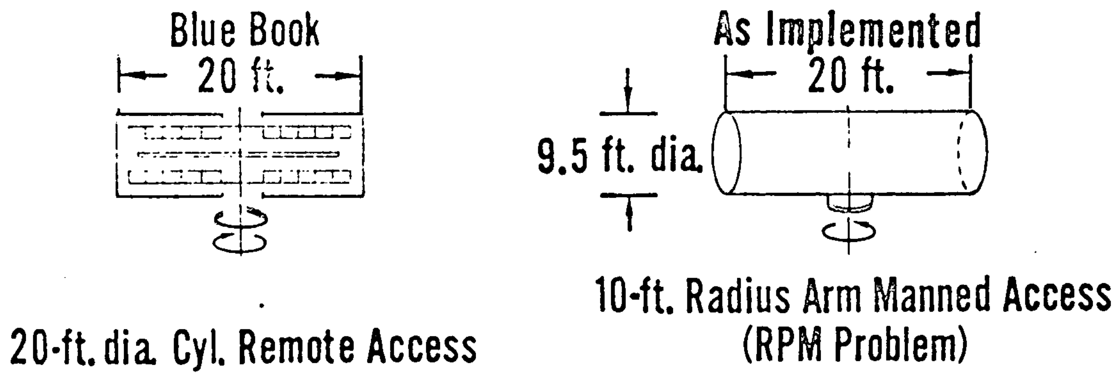
   FPE 5.25, Microbiology (Bio C)

   FPE 5.26, Invertebrates (Bio F)

b. The biology centrifuge, as currently defined in the Blue Book, has 20-foot diameter counter-rotating heads, which cannot be housed in a module that is compatible with the 15-foot diameter shuttle cargo bay. The concept offered for shuttle compatibility is a 9.5 by 20-foot cylinder rotated about an axis normal to the cylinder axis.

c. Provisions for manned access to the experiments during the elevated-g exposure is included for improved experimental conditions, although the remotely actuated equipment in the Blue Book could be substituted.

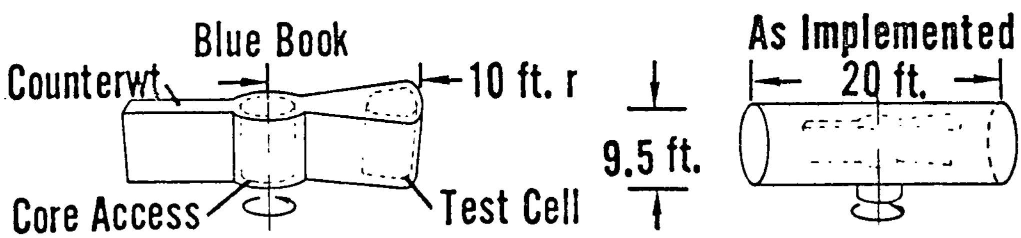
   A potential problem exists for manned attendance in this particular concept with the current dimensions and g loads which require 17 rpm for 1 g at 10 feet — a condition that may exceed man's tolerance. Alternative solutions lie in increasing cylinder length or reducing experiment g requirements.



1.3.1.4 Earth Applications. Earth applications include the experiments in FPE 5.11 Earth Surveys. The chief sources of information for projecting growth were investigations by local technical and scientific personnel.

Principal growth projections in this FPE consist of the potential need for sensor pointing capability of from 45° to 60° about the nadir to increase coverage and permit oblique viewing. The capability to accommodate this growth is discussed in Volume III.

1.3.1.5 Aerospace Medicine. The manned centrifuge contained in FPE 5.13, Biomedical, presents the same problem with shuttle compatibility as the biology lab centrifuge, since the preferred housing would be a 20-foot-diameter cylinder. For shuttle compatibility, the rotating cylinder concept is considered a potential solution.



1.3.1.6 Materials Science. This discipline contains only FPE 5.16 Materials Science and Processing. The main sources of information in this area were various technical papers presented at the Space Processing and Manufacturing Meeting (Reference 10) and discussions with local technical personnel.

Primary growth projected is the addition of laboratory equipment to permit greater capabilities for on-board experiment evaluation and provisions for a furnace. The lab equipment previously identified for FPE 5.27 Physics and Chemistry Lab, was used as a basis for the equipment size, weight and power predictions.

1.3.1.7 Advanced Technology. The FPEs contained within Advanced Technology are:

a. FPE 5.17 — Contamination

b. FPE 5.18 — Exposure Experiments

c. FPE 5.20 — Fluid Physics in Microgravity

d. FPE 5.22 — Component Test and Sensor Calibration

The chief sources of growth information in these areas were local technical personnel.

No growth was predicted for these experiments. Each is considered sufficiently typical of the experiments to be conducted to not warrant any increase at this time, in the requirements specified in the Blue Book.

1.3.2 EFFECT ON MODULE SIZING. The final experiment FPE provisions in each of the common modules are shown in Figures 1-2 through 1-4 for module launch weight, pressurized volume, and average electrical power rating, respectively.

Using the projected growth in experiment weights, module launch weights shown are compatible with the shuttle capability although several of the modules, weighing over 25,000 pounds, will require self-circularization following shuttle insertion into a 100 n. mi. by 270 n. mi. elliptical orbit. Increased weight due to growth has no significant effect on the module design.

The experiment volume provisions, Figure 1-3, show the Materials Science, FPE 5.16 5.16, and the Biology, FPE 5.9/5.10/5.23, experiments using the total volume available. For the other FPEs a growth potential or flexibility is suggested by excess volume capacity.

The common module average electrical power ratings (Figure 1-4) are adequate to accommodate additional experiment power requirements, after the increase in CM-1 power by 200 watts to provide growth for additional sensors.

1.3.3 EFFECT ON COMMON MODULE ASSIGNMENTS. The final common module assignments for the experiment FPE were modified as a result of growth provisions. The changes were:

a. FPE 5.3A Advanced Solar Astronomy accommodated in a single CM-1 free-flying module (was two CM-1 modules)

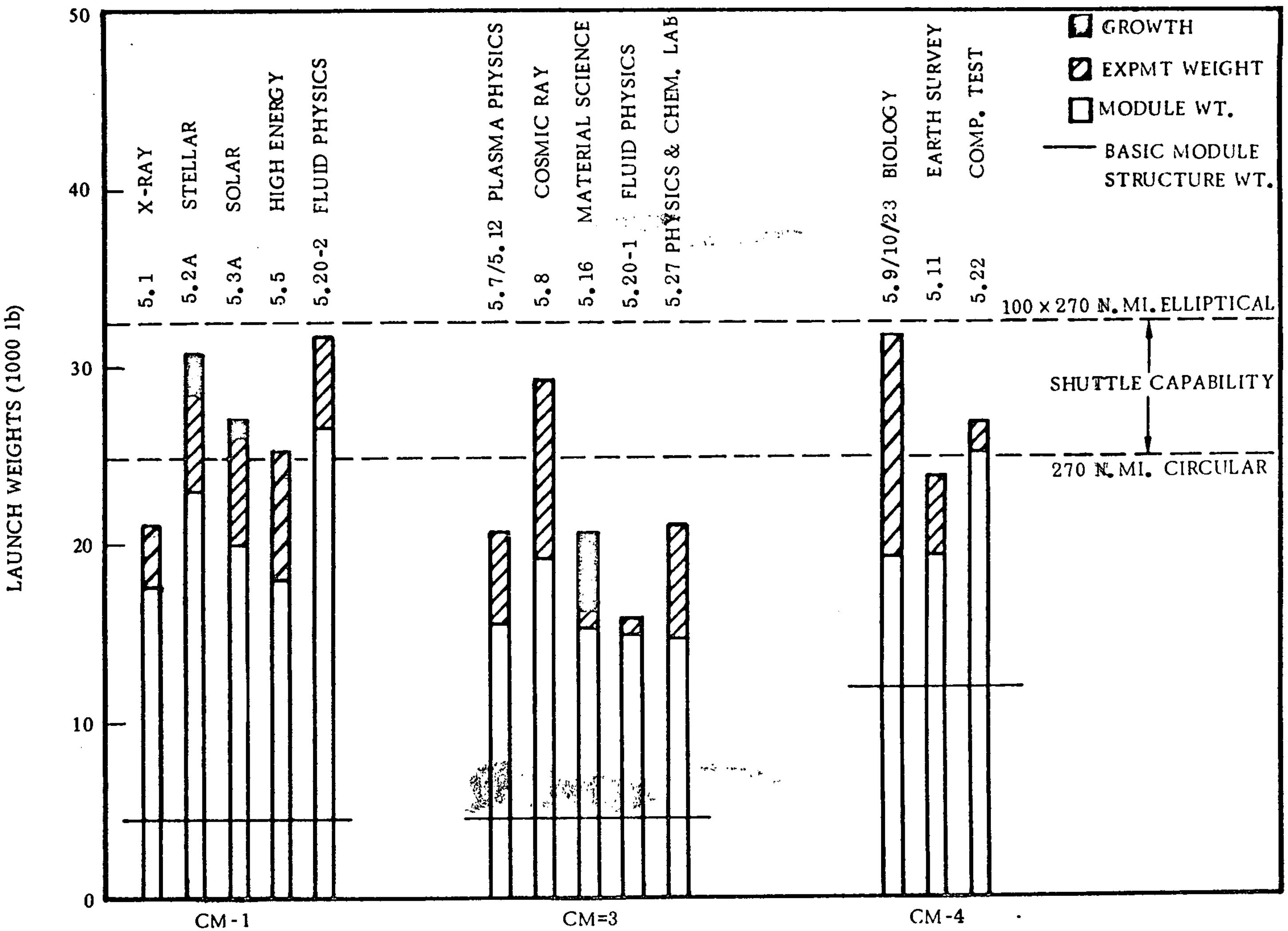


Figure 1-2. Experiment Provisions vs. Module Launch Weight

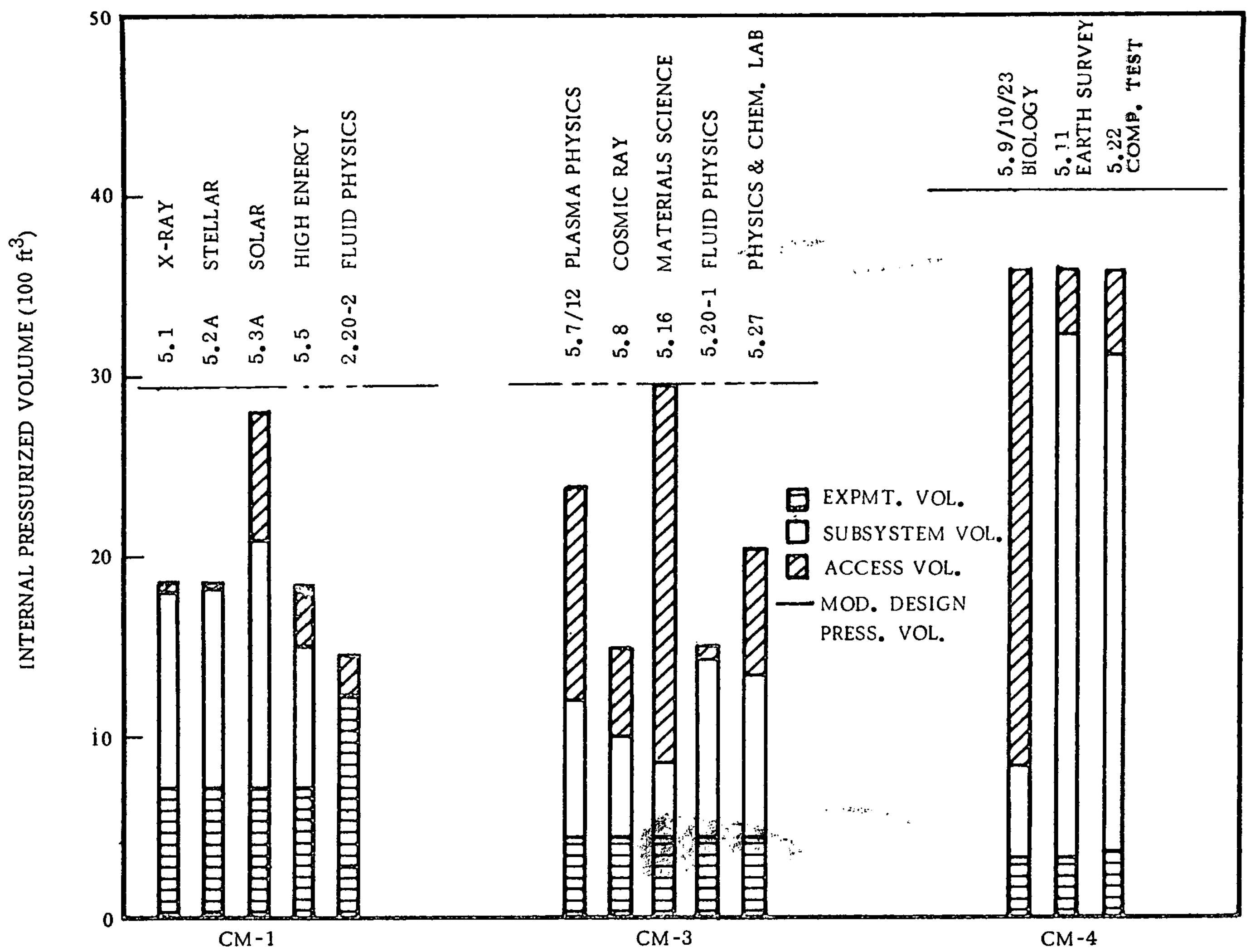


Figure 1-3. Experiment Provisions vs. Module Pressurized Volume

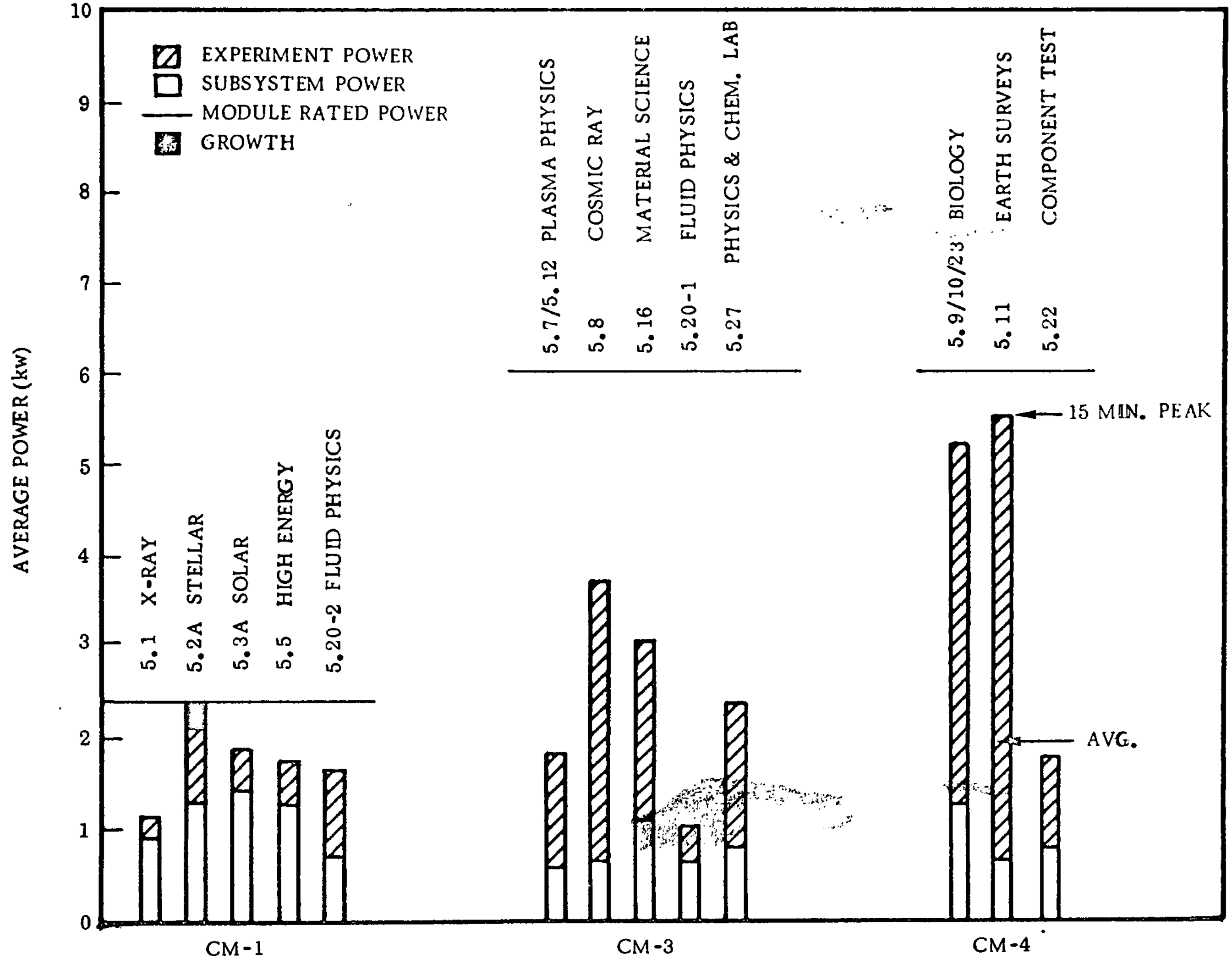


Figure 1-4. Experiment Provisions vs. Module Average Power Rating

b. FPE 5.7 Plasma Physics Lab includes FPE 5.12 RMS and is assigned to a CM-3 attached module (was CM-4 module).

c. FPE 5.8 Cosmic Ray Lab assigned to a single CM-3 attached module (was two CM-3 modules).

d. FPE 5.9/5.10/5.23 Biology reassigned to a CM-4 attached module (was CM-3 modules).

A total of 13 common modules are needed: five CM-1, five CM-3, and three CM-4 modules, respectively.

SECTION 2

EXPERIMENT REQUIREMENTS ON MODULES

The governing criteria for development of module concepts are the requirements imposed by the experiments on module design and operations. These requirements are grouped into four general categories.

a. Facility type support -- including electrical power, data transmission, equipment weight and mounting structure.

b. Crew support -- experiment operations and servicing.

c. Environmental control -- including thermal, atmospheric, acceleration and vibration isolation.

d. Orientation -- direction, accuracy and stability.

Determination of module design and operations requirements fall into four areas of analysis:

a. Experiment requirements on module subsystems.

b. Operating mode selection -- attached or free-flying.

c. Experiment time profiles/duty cycles.

d. Role of man in the experiment program.

2.1 REQUIREMENTS ON MODULE SUBSYSTEMS

Basic module subsystem requirements were defined through examination of the Blue Book (June 1970 revision) definitions of the experiment equipment and program requirements. These requirements are summarized in Table 2-1. In some instances growth analysis, projected experiment revision, or other requirements have been used in lieu of Blue Book values; these instances are as summarized in Table 2-2; and described in detail in section 1.3, Experiment Growth Analysis.

FPE 5.20 (Fluid Physics) has been divided into subgroups in Table 2-1 due to major differences in experiment requirements.

a. 5.20-1 includes experiments with acceleration limits of 10^{-3} and 10^{-4} g.

b. 5.20-2 includes a group of non-cryogenic experiments at controlled acceleration levels from 10^{-3} to 10^{-6}g.

Table 2-1. Experiments Requirements Summary

Parameter	X-Ray	Stellar	Solar	High Energy	Plasma Physics	Cosmic Ray	Vertebrates	Plant	Earth Surveys	RMS	Centrifuge	Material Science	Contamination	Exposure	Fluid Physics				Comp. Test	Primates	Phy & Chem
	5.1	5.2A	5.3A	5.5	5.7	5.8	5.9	5.10	5.11	5.12	5.13C	5.16	5.17	5.18	5.20-1	5.20-2	5.20-3	5.20-4	5.22	5.23	5.27
Orientation	Stellar	Stellar	Solar	Stellar	-	Zenith	-	-	Earth	-	-	-	-	Earth	-	-	-	-	Earth(1)	-	-
Pointing																					
Accuracy (± sec)	120	10	2.5	15	-	(9)	-	-	1080	-	-	-	-	-	-	-	-	-	30	-	-
Stability (sec/exposure)	1.0	0.005	0.01	1.0	-	-	-	-	108	-	-	-	-	-	-	-	-	-	7.2	-	-
Acceleration Constraints (g)	-	-	-	-	-	-	10^{-3}	10^{-5}	-	-	-	10^{-3}	-	-	10^{-4}	(Sustained accel. at 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6})			10^{-2}	10^{-3}	10^{-6}
Experiment Equipment																					
Weight (pounds)	3300	(10) 8685	(10) 6875	7800	1800	34180	5747	2599	4600	3200	1720	(10) 5580(4)	850	400	785	5141	3460	5252	1650	4500	6220
Data (Also see Table 2-3)																					
Digital Rate (kbps)	8	8000	5000	10	80	10	10	10	26,400	-	25	1	63	8.4	1	5.78	6	6	20	200	1
Analog Bandwidth (kHz)	-	-	-	-	10	-	-	-	3600	-	-	.001	-	0.1	-	-	-	-	-	-	-
TV Channels	1	1	1 3 @ 1.3 MHz	1	1	1	2	1	1		1	2	2	-	1	6 (8)	1	2	1	1	1
Film Required	-	Yes	Yes	(Emulsions)	Yes	(Emulsions)	Yes	Yes	Yes	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Electrical Power - Average (kW)	0.19	0.74	0.50	0.51	1.28	3.1	1.0	0.35	1.04	-	0.25	2.0	0.4	0.143	0.4	1.0	1.4	0.17	1.0	2.6	1.6
- Peak (kW)	0.36	1.25 (10)	0.85	0.65	1.9	4.4	1.75	0.35	6.9	-	0.25	5.0	0.5	0.26	1.1	1.4	4.0	1.2	1.8	3.3	2.3
Operating Environment																					
Pressure (psia)	0	0	0	0	0	14.7	14.7	14.7	14.7	-	14.7	14.7	0	0	14.7	0-14.7	0	0	0 14.7	14.7	14.7
Temperature (°F)	(5)(6)	(6)	(6)	(5)(6)	-		70	70	70	-	70	70(7)	Space	Space	70	70	-	-	(5)	70	70(7)
Temperature Tolerance (°F)	-	-	-	-	-	(5)	±5	±5	±5	-	±5	±5	-	-	±5	±5	-	-	-	±5	±5
Operating Metabolic Load (Btu/hr)	-	-	-	-	-	-	700(2)	700(2)	-	-	500(3)	-	-	-	-	-	-	-	-	700	-
Cryogenic Supply Required (LB/MO)	125	-	-	-	-	250	-	-	20	-	-	10	-	-	-	-	-	250	980	-	133
Contamination Sensitive	Yes	Yes	Yes	Yes	-	-	-	-	Yes	-	-	-	Req'd	Yes	-	-	-	-	Yes	-	-
Radiation Sensitive (Below Personnel Level)	Yes	-	Yes	Yes	-	Yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

NOTES:
(1) Two sensor experiments require view of earth for short periods (15 min).
(2) EC/LS system for specimens is provided with experiment. Value shown is for scientist crew EC/LS.
(3) EC/LS system on centrifuge.
(4) Estimated weight of lab equipment.
(5) Contains sensors which are cryogenically cooled.
(6) Contains temperature critical sensors.
(7) Temperature control varies with each experiment.
(8) Reduced bandwidth is acceptable.
(9) Attitude known within ±2 deg.
(10) Growth projection incorporated.

Table 2-2. Experiment Revisions & Growth Items Incorporated into Experiment Requirements

FPE	Title	Change
5.2A	Stellar	Provide for observation on sunlit side of orbit, and capability for polarity measurement. Mirror weight increased from 1700 to 4000 lb.
5.3A	Solar	Boresight group of point-target instruments. Photoheliograph weight increased from 3200 lb to 4000 lb. Add 3 vidicon cameras, and provisions for 1 magnetograph.
5.7	Plasma Physics	Provide for centralized laboratory for experimentation, test conduction and data reduction.
5.8	Cosmic Ray	Provide growth version to include astrophysics experiments only, with dual magnet (no torque), and total absorption detector replacing ionization spectrograph.
5.9/10/23	Biology Lab.	Include growth provisions for FPE 5.25 (Microbiology) and FPE 5.26 (Invertebrates) Provide for shuttle compatible centrifuge with manned access.
5.13C	Centrifuge	Provide for shuttle compatible centrifuge.
5.16	Materials Science	Include growth provisions for analysis equipment and furnace.

c. 5.20-3 includes a group of cryogenic experiments at controlled acceleration levels from 10^{-3} to 10^{-6}g.

d. 5.20-4 includes one long term cryogenic storage experiment at controlled acceleration levels from 10^{-3} to 10^{-6}g.

Special requirements for each FPE as applicable are listed in Table 2-3. Section 4 of this volume contains the experiment logistics requirements, and experiment equipment weights are contained in Appendix I of this volume.

Pointing and stability requirements are tabulated by instrument in Table 2-4 for astronomy and other experiments with special pointing requirements. These requirements are based upon data contained in the Blue Book, in most cases. However, where the Blue-Book-stated values did not yield a compatible set of requirements for a given instrument, or where the requirements were not stated, new values were derived. These changes and additions are identified in the notes in

Table 2-3. Special Experiment Requirements

FPE	Title	Requirements
5.1	X-Ray	360 degrees rotation of entire telescope and sensor assembly for polarity measurements.
5.3A	Solar	Coronagraphs pointed at center of solar disk, other instruments trained on targets on solar disk.
5.5	High Energy	Separate pointing for X-ray and gamma instruments.
5.9	Vertebrates	Module atmosphere isolated from space station.
5.10	Plants	Isolate all cyclic phenomena: light, acceleration, etc.
5.20	Fluid Physics	Extended periods of sustained low (10^{-3} to 10^{-6}) g levels.
5.23	Primates	Decontamination capability, atmosphere isolated from space station.

Table 2-4 and are based on examination of experiment objectives and relationships between field of view versus pointing accuracy, and angular resolution versus stability.

The astronomy data requirements shown in Table 2-5 were derived from analysis of the instrument characteristics and the observation program as described in the Blue Book. The maximum data output rate column of this table shows the maximum data output that must be handled simultaneously -- in most instances output data is received sequentially from the instruments rather than in parallel.

FPE 5.3A, Solar Astronomy Spectrograph, specifies electronic imaging as an alternate mode to the photographic method. The data rates shown apply to this alternate mode. Film has been selected as primary mode since the required data rates exceed the projected state of the art in data transmission and recording.

2.2 EXPERIMENT OPERATING MODES

A key factor in module design is the selection of the operating mode that best meets experiment objectives. Three basic operating modes are available: (1) attached to the space station, (2) detached, free-flying, or (3) tethered. Modules designed to operate in the attached mode receive necessary power, data handling and transmission, atmospheric supply, and other support from the space station. Detached modules must be self-sustaining when in free-flight. They also must have orbital maneuvering flight capability. The attached mode is, therefore, preferable except where experiment environment or conditions dictate a free-flying mode.

Table 2-4. Pointing and Stability Requirements

FPP No.	TITLE	INSTRUMENTS	SIZE	RESOLUTION	FIELD OF VIEW	POINTING ACCURACY	POINTING STABILITY	OBSERVATIONS
5.1	X-Ray Astronomy	X-Ray Telescope	1000 cm^2 Area	≥1 Sec	2 Deg	±2 Min	±1 Min/Exposure; ±1 Sec/Sec	Stellar X-Ray Source
5.2A	Stellar Astronomy	UV-Visible Telescope	3-M Aperture	0.04 Sec	15 Min	±10 Sec	±0.005 Sec/Exposure	Stellar Objects
5.3A	Advanced Solar Astronomy	UV-Visible Telescope	1.5-M Aperture	0.1 Sec	1.1 Min	±2.5 Sec	±0.01 Sec/Exposure (1)	Solar Photospherid Features
		X-Ray Telescope	0.5-M Aperture	5.0 Sec	10 Min	±2.5 Sec	0.5 Sec/Exposure (7)	Solar Chromosphere & Photospheric Features
		XUV Spectroheliograph	0.25-M Aperture	1.0 Sec	32 Min	±2.5 Sec	±0.1 Sec/Exposure	
		1-6 Radii Coronagraph	0.02-M Aperture	10.0 Sec	±2.5 Deg	±15 Sec	±1 Sec/Exposure (4)	
		5-30 Radii Coronagraph	0.04-M Aperture	30.0 Sec	15 Deg	15 Sec	±1 Sec/Exposure	
5.[illegible]	High Energy Stellar Astronomy	X-Ray Telescope	0.5-M Aperture	≥1 Sec	15 Min	±15 Sec (2)	±5 Sec/Exposure; ±1 Sec/Sec	Stellar Sources
		X-Ray Spectrograph	24"×30" Aperture	30 Sec (3)	10 Min	10 Min	±3 Sec/Exposure	
		Gamma-Ray Spectrometer	~1-M×1-M Aperture	0.5 Deg (5)	30 Deg (5)	0.5 Deg	±0.5 Deg/Exposure	
		Spark Chamber	~0.5-M×0.5-M	0.5 Deg	30 Deg	±0.5 Deg	±3 Min/Exposure (6)	
5.11	Earth Surveys	Metric Camera	-		41×70 Deg	0.5 Deg	0.05 Deg/Sec	Terrain & Atmosphere
		Multispectral Camera		-	41 Deg	1.5 Deg	0.03 Deg/Sec	Terrain
		Multispectral Scanner		0.066 mrad	20 Deg	0.5 Deg	0.25 Deg/Sec	Terrain
		IR Interspectrometer		3 Deg	7.5 Deg	0.5 Deg	0.03 Deg/Sec	Atmosphere
		IR Atmospheric Sounder		12.5 Deg	12.5 Deg	1.0 Deg	0.2 Deg/Sec	Atmosphere
		IR Spectrometer/Radiometer		3.5mrad	0.2 Deg	0.3 Deg	1.0 Deg/Sec	Terrain & Atmosphere
		Microwave Scan Radiometer		1.5 Deg	100 Deg	1.0 Deg	0.03 Deg/Sec	Terrain
		Multifrequency Microwave Radiometer		-	120 Deg	0.5 Deg	0.05 Deg/Sec	Terrain & Atmosphere
		Radar Imager		-	8.6 Deg	0.5 Deg	0.05 Deg/Sec	Terrain
		Microwave Atmo. Sounder		5 Deg	60 Deg	±2.0 Deg	0.50 Deg/Sec	Atmosphere
		Active/Passive Microwave Radiometer		10 Deg	10 Deg	±0.5 Deg	1.0 Deg/Sec	Terrain
		Visible Wavelength Polarimeter		-	3 Deg	±0.5 Deg	0.2 Deg/Sec	Atmosphere
		UHF SFERICS		-	120 Deg	±2.0 Deg	0.5 Deg/Sec	Atmosphere
		Absorption Spectrometer		1.0 Deg	1.0 Deg	±0.5 Deg	0.5 Deg/Sec	Atmosphere
		Laser Altimeter		6×10^{-8} Sr	6×10^{-8} Sr	±0.5 Deg	0.05 Deg/Sec	Terrain
		Ultraviolet Imager Spectrometer		1.0 Deg	1.0 Deg	±0.5 Deg	0.05 Deg/Sec	Terrain
		Radar Altimeter Scatterometer		4×3 Deg	60×1 Deg	±0.5 Deg	1.0 Deg/Sec	Terrain
		Photo Emaging Camera		0.04 nrad	16 Deg	±0.5 Deg	0.05 Deg/Sec	Terrain
5.22	Component Test	LWIR Sensor		200 Ft.	±5 Deg	0.5 Min	0.002 Deg/Sec	Terrain

NOTES

(1) Blue Book states a value of 0.05 Sec. Revised to 1/10 angular resolution.

(2) Blue Book states a value of 15.0 Min. Not compatible with objective of precise location and resolution.

(3) Based on 10 × stability required. Value not stated in Blue Book.

(4) Based on 1/10 of angular resolution. Blue Book states a value of 4 Sec.

(5) Based on Spark Chamber Resolution and Field of View. Value not stated in Blue Book.

(6) Blue Book states a value of 0.5 Deg deadband. Stability revised to 1/10 angular resolution.

(7) Based on 1/10 of angular resolution. Blue Book states value of 0.05 Sec/Exposure.

Table 2-5. Astronomy FPE Data Requirements

FPE NO.	TITLE	SENSORS	TYPE**	IMAGE SIZE	BITS PER FRAME	FRAME RATE (FR/SEC.)	DATA RATE	MAXIMUM DATA OUTPUT RATES
5.1	X-Ray Astronomy	Polarimeter	1	None	8.1×10^6	1/2700	3×10^3 BPS	8×10^3 BPS Digital
		Crystal Spectrometer	3	None	6.0×10^7	1/30,000	2×10^3 BPS	
		Imaging Spectrometer	3	Unknown	1.6×10^7	1/2700	6×10^3 BPS	
		Solid State Detector	1	None	9×10^6	1/900	8×10^3 BPS	
		T.V. (Pointing Verification)	5	---	---	1	2.9×10^6 Hz	0.2×10^6 Hz Analog (Note 1)
5.2A	Stellar Astronomy	Field Image Video Device	3	70 × 70 mm	2.4×10^9	1/1200	8×10^6 BPS	8×10^6 BPS Digital (Plus Film)
		Field Image Plate Camera	4	225 × 225 mm	(Photo Plate)	1/40,000	---	
		Field Image Plate Camera	4	50 × 50 mm	(Photo Plate)	1/6000	---	
		Spectrograph Video Device	3	25 × 44 mm	2.4×10^9	1/1200	8×10^6 BPS	
		Spectrograph Film Recorder	4	25 × 44 mm	(Film Strip)	1/6000	---	
		T.V. (Pointing Verification)	5	---	---	1	2.9×10^6 Hz	0.2×10^6 Hz Analog (Note 1)
5.3A	Advanced Solar Astronomy	Spectrograph Range 1	4 *	28 × 100 mm	(3.91×10^8) *	1/10	(1×10^8) * BPS	Film
		Spectrograph Range 2	4 *	25 × 100 mm	(3.4×10^8) *	1/10	(1×10^8) * BPS	
		Spectrograph Range 3	4 *	9 × 142 mm	(1.7×10^8) *	1/10	(5×10^7) * BPS	
		H-α Vidicon	2	24 × 24 mm	(Analog)	1	.13 to 1.3×10^6 Hz	.39 to 3.9×10^6 Hz Analog
		White Light Vidicon	2	24 × 24 mm	(Analog)	1	.13 to 1.3×10^6 Hz	
		UV Vidicon	2	24 × 24 mm	(Analog)	1	.13 to 1.3×10^6 Hz	
		Magnetograph	1	None	1.2×10^8	1/120	1×10^6 BPS	1×10^6 BPS Digital
		T.V. (Pointing Verification)	5	---	---	1	2.9×10^6 Hz	0.2×10^6 Hz Analog (Note 1)
	(b)	Proportional Counters (X-ray)	1	None	1.2×10^5	1/600	200 BPS	5×10^6 BPS (Note 2)
		X-Ray Spectrometer	1	None	2.4×10^5	1/600	400 BPS	
		X-Ray Imaging System	2	35 × 35 mm	4.8×10^6	1	5×10^6 BPS (Note 2)	
		Spectroheliograph (XUV)	4	30 × 495 mm	(Film Strip)	1/60	---	Film
		Coronagraph (1-6 Radii)	4	18 × 24 mm	(Film)	5	---	
		Coronagraph (5-30 Radii)	4	18 × 24 mm	(Film)	5	---	
		T.V. (Pointing Verification	5	---	---	1	2.9×10^6 Hz	0.2×10^6 Hz Analog (Note 1)
5.5	High Energy Stellar Astronomy	X-Ray Imaging System	3	Unknown	---	---	2.2×10^3 BPS	10×10^3 BPS (Plus Emulsions)
		Bragg Spectrometer (X-Ray)	1	None	---	---	2.0×10^3 BPS	
		X-Ray Spectrograph	3	Unknown	---	---	2×10^3 BPS	
		Gamma-Ray Spectrometer	1	None	---	---	7.0×10^3 BPS	
		Gamma-Ray Spark Chamber	1, 4	None	---	---	$.7 \times 10^3$ BPS	
		T.V. (Pointing Verification	5	---	---	1	2.9×10^6 Hz	0.2×10^6 Hz Analog (Note 1)

**Sensor Type: (1) Counter
(2) Scanner - Continuous
(3) Scanner - Intermittent
(4) Photographic Recorder
(5) Continuous Scan - Intermittently Used

*Primary mode is photographic. Data rates shown are for alternate vidicon mode.

Notes: 1. TV is used for pointing verification only and does not operate continuously, 500.2 MHz is considered adequate.
2. Assumes 5:1 data compression aboard module.

2.2.1 SELECTION OF OPERATING MODES. Experiment program implementation must provide the environment necessary for successful experiment operations. In most cases, the environment required can be provided with a module that remains attached to the space station throughout the experiment program.

However, in the case of certain experiments, it is necessary to resort to a detached free-flying mode of operation to isolate the experiment operation from environmental conditions originated in the space station. In these cases, the module is returned to the station only for servicing of the experiment. Examples of environmental conditions which can interfere with experiment operations and may therefore require operation in a detached mode are:

a. Accelerations, crew or equipment induced, that prevent meeting the very low g level or stability requirements of some experiments.

b. Atmospheric contamination and radiation originating at the space station which may adversely affect astronomy instrument critical surfaces, sensors, or viewing columns.

c. Elevated g levels where experiment tolerances prohibit the use of a centrifuge to accelerate the experiment.

In addition to the attached and free-flying modules, some experiment equipment consists of a number of "carry-on" type instruments which are to be installed on or in the space station and one or more modules. These experiments do not require a separate module. They have been termed "suitcase" experiments and are implemented by assignment to the space station and to either attached or detached modules as appropriate.

Experiment environmental requirements that are not compatible with the space station projected environment are:

a. Acceleration -- Ambient. Space station acceleration levels are projected to be 10^{-5} g nominal with increases to 10^{-3} g during certain crew or station activities. This level is considered compatible with all experiments except two:

   1. Plant growth experiments in FPE 5.10 Plants (Bio E), which requires $\leq 10^{-5}$ g for 95% of the time and isolation from noise vibration and cyclic phenomena. Special isolation mechanisms can be provided to accomplish these experiments in the attached mode.

   2. The containerless casting experiments in FPE 5.16 Materials Science and Processing and the materials experiments in FPE 5.27 Physics and Chemistry Lab. Magnetic and/or electrostatic forces used in these experiments to restrain motion of the free floating molten masses may exceed acceptable levels resulting from local g disturbances and module/station

relative motion. These experiments may require a detached mode at a later date to accommodate growth in the experiment specimen sizes and weights.

The low "g" level requirements of other experiments can be accomplished by proper scheduling of experiments to avoid induced acceleration peaks. Effects of accelerations on astronomy experiment stability and pointing could probably be accommodated by properly designed telescope mounts for all except the very low stability levels required for two of the telescopes: FPE 5.2A Stellar Astronomy 3-meter telescope, and FPE 5.3A Solar Astronomy 1.5-meter telescope. The requirements of 0.005 $\widehat{sec}$/exp and 0.01 $\widehat{sec}$/exp, respectively, probably require a free-flying mode to avoid effects of peak accelerations from the station.

b. Acceleration -- Induced. Experiments that require accelerations above the space station ambient level of about 10^{-6} g or less fall into two categories, the first of which is compatible with the station ambient environment:

1. Experiments conducted on a centrifuge attached to the space station. These are FPE 5.9 Small Vertebrates -- 0.2 to 1 g experiments and FPE 5.10 Plants -- 0.2 to 1 g experiments. These will be conducted on the biology centrifuge. FPE 5.13C Centrifuge is used for conducting biomedical experiments with man as a subject.

2. Experiments whose conditions or tolerances prohibit the use of a centrifuge due to coriolis and other accelerations that exist in an attached centrifuge. These are FPE 5.20 Fluid Physics experiments which require accelerating of experiments at levels of 10^{-6}, 10^{-5}, 10^{-4}, and 10^{-3} g for specified periods of time. These experiments must be conducted in a detached mode, which provides the acceleration required within the specified experiment tolerances.

c. Stability. Space station projected pointing stability of 0.3 $\widehat{min}$/sec is acceptable for all experiments except FPE 5.2A Stellar Astronomy 3-meter telescope and FPE 5.3A Solar Astronomy 1.5-meter telescope. As previously discussed under a above, these two telescopes probably required detached mode of operation to avoid peak acceleration effects on stability.

d. Viewing. Space station orientation is currently projected as being either earth or inertially oriented. All experiments could be accommodated in the attached mode with either orientation. However, those experiments containing earth oriented remote sensing instruments are penalized if an inertial orientation is selected, and astronomy experiments are penalized by the complexity of instrument mounts if attached to a station with either orientation.

FPE 5.11 Earth Surveys, FPE 5.8 Cosmic Ray Lab, and FPE 5.22 Component Test Lab are selected for attached operation assuming either an earth-oriented station or a gimballed attachment to an inertially oriented station.

The stellar astronomy FPEs, 5.1 X-ray, 5.2A Stellar, and 5.5 High Energy Stellar, require relatively complex mountings to achieve efficient observation programs in the attached mode. FPE 5.3A Solar Astronomy viewing requirements impose special mounting problems, although not as complex as for stellar. These considerations suggest a detached mode of operation for these astronomy instruments to provide an efficient flexible observation program.

e. Contamination. The atmosphere immediately surrounding the space station will contain effluents that could potentially interfere with astronomy and other remote sensing observations. This interference could be temporary as in the case of condensation on lenses, or it could be long duration as in the case of ice crystals forming from continuous station atmosphere leakage. The potential for permanent damage to critical surfaces may also exist through chemical action of condensates, or erosion by engine exhausts.

These effects of contamination cannot be accurately predicted at this time. Therefore, it appears prudent to select a detached mode of operation for those astronomy instruments that are likely to be adversely affected by the predicted contaminant levels and composition. These are currently considered to be all of the astronomy instruments except the gamma-ray detectors in FPE 5.5 High Energy Astronomy.

f. Radiation. Radiation will be of two types -- natural and induced. Experiments that are sensitive to radiation will experience the same levels of natural radiation in either an attached or detached mode of operation, unless they are operated at a significantly different altitude than the space station. The need for operation of any of the experiments at different altitudes for reduced radiation levels has not been established. Therefore, natural radiation is currently not a driving requirement for operation in a free-flying mode. However, the possible use of a nuclear source of electrical energy aboard the space station suggests a detached mode of operation to isolate sensitive experiments from this source of radiation. These experiments are FPE 5.1 X-ray, FPE 5.5 High Energy, and the X-ray experiment in FPE 5.3A.

Operating mode selections for all FPEs are summarized in Table 2-6 along with the basis for mode selection. The four astronomy FPEs and the Fluid Physics sustained acceleration experiments are assigned to detached modules. Attached modules are selected for the remaining FPEs. The selection of the detached mode for the astronomy experiments is based more on a combination of factors than on any single experiment requirement.

2.3 EXPERIMENT TIME PROFILES

The experiment missions were analyzed to determine experiment operating time profiles, and servicing frequencies, and docking frequencies. A summary of these mission operations for each FPE is shown in Table 2-7.

Table 2-6. Selection of Operating Mode

FPE	Title	Experiment	Environmental Requirements: Accel. Ambient	Accel. Induced	Stability sec/sec.	Viewing	Contamination	Radiation	Basis for Selected Mode	Selected Mode of Operation
5.1	X-Ray	---	---	---	1.0	Sphere	Sensitive	Sensitive	Contamination & Radiation, viewing	Detached
5.2A	3-M Stellar	---	---	---	0.005	Sphere	Sensitive	---	Stability & Control, viewing, contam.	Detached
5.3A	Solar	1.5-M UV-Vis.	---	---	0.01	Solar	Sensitive	---	Stability & Control, contamination	Detached
		.5-M X-Ray	---	---	0.5		Sensitive	---	Contamination	Detached
		Spectro. Corona.	---	---	0.1		Sensitive	Sensitive	Contamination & Radiation, viewing	Detached
5.5	High Energy	X-Ray	---	---	1.0	Sphere	Sensitive	Sensitive	Contamination & Radiation, viewing	Detached
		Gamma	---	---	3 min/exp.		---	Sensitive	Radiation	Detached
5.7	Plasma	---	---	---	---	---	---	---	Experiment Operation	Attached
5.8	Cosmic Ray	Control	---	---	---	---	---	---	Station Compatible	Attached
		Sensors	---	---	---	Zenith	---	Sensitive	Station Compatible	Attached
5.9	Vertebrates (Bio D)	"0" g	$\leq 10^{-3}$ g	---	---	---	---	Sensitive	Station Compatible (1)	Attached
		Variable g	---	.2 to 1 g	---	---	---	Sensitive	Station Compatible (1)	Attached - Centrifuge
5.10	Plants (Bio E)	"0" g	$\leq 10^{-5}$ g	---	---	---	---	Sensitive	Station Compatible (1)	Attached - Isolated g
		Variable g	---	.2 to 1 g	---	---	---	Sensitive	Station Compatible (1)	Attached - Centrifuge
5.11	Earth Surveys	---	---	---	108.	Earth	Sensitive	---	Protect from Contamination	Attached
5.12	RMS	---	---	---	---	---	---	---	Experiment Operation (2)	Attached/Detached
5.13C	Centrifuge	---	---	0 to 7 g	---	---	---	---	Station Compatible	Attached - Centrifuge
5.16	Materials Processing	---	$\leq 10^{-3}$ g	---	---	---	---	---	Station Compatible	Attached
5.17	Contamination	---	---	---	---	---	Required	---	Contamination Required	Attached - *
5.18	Exposure	---	---	---	---	---	Sensitive	Sensitive	Contamination & Radiation	Detached - *
5.20	Fluid Physics	"0" g	$\leq 10^{-4}$ g	---	---	---	---	---	Station Compatible	Attached
	Fluid Physics	10^{-3} to 10^{-6} g	---	10^{-3} to 10^{-6} g	---	---	---	---	Acceleration Required	Detached - Propelled
5.22	Component Test	---	---		7.2	Earth	Sensitive	---	Protect From Contamination	Attached
5.23	Primates (Bio A)	---	---	---	---	---	---	---	Station Compatible	Attached
5.27	Physics & Chemistry	---	$\leq 10^{-4}$ g		---	---	---	---	Station Compatible	Attached
Space Station Ambient			10^{-3} to 10^{-5} g		18 sec.	Earth or Inertial Oriented	Source of Potential Gases & Solids	Power Generator		

*Suitcase experiments

(1) Assumed located at adequate distance from power generator.
(2) Housed in attached mode.

Table 2-7. Experiment Mission Times

FPE	Title	Mission Times: Calibrate/Set-Up Duration	Calibrate/Set-Up Frequency	Operate/Observe Duration	Operate/Observe Frequency	Operation	Exp. Repetitions/yr	Duty Cycle Min/Orb	Duty Cycle %
5.1	X-Ray	2-3 days	Once (initial)	--	--	Set up	--	90	100
		--	--	Continuous		View Tgt(1)	--	45(2)	50
		2-3 days	6/yr.	--	--	Service	--	90	100

(1) Target view time reduced by slew and sensor rotation into telescope focus.

(2) Deactivation during South Atlantic Anomaly - Typical - 10 min. during 4 successive orbits each 24 hr. period (or level of 600 protons Km^2 -sec.

(3) Simultaneous sensor operation: one sensor + pointing verification TV.

FPE	Title	Mission Times: Calibrate/Set-Up Duration	Calibrate/Set-Up Frequency	Operate/Observe Duration	Operate/Observe Frequency	Operation	Exp. Repetitions/yr	Duty Cycle Min/Orb	Duty Cycle %
5.2A	Stellar	2 weeks	Once (initial)	--	--	Set up	--	90	100
		--	--	Continuous		Stellar Meas.	--	20(2)	40(2)
		2-3 days	6/yr.	--	--	Service	--	90	100

Note: (1) Simultaneous sensor operation: one sensor + pointing verification TV.

(2) Sunlet side viewing possible; will increase duty cycle to maximum of four 20 minute exposures per orbit.

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times: Calibrate/Set-Up Duration	Calibrate/Set-Up Frequency	Operate/Observe Duration	Operate/Observe Frequency	Operation	Exp. Repetitions/yr.	Duty Cycle Min/Orb	Duty Cycle %
5.3A	Solar	2 weeks	Once (initial)	--	--	Set up	--	90	100
		--	--			Solar meas.	--	45	50
		2-3 days	12/yr.	--	--	Service	--	90	100
	Note: Simultaneous sensor operation - worst case all sensors operate together, plus pointing vertification TV.								
5.5	Hi Energy	1 week	Once (initial)	--	--	Set up	--	90	100
	Nuclear	--	--	100 hrs. (2)	1/Tgt.	View Tgt.	--	45(1)	50
	Spark Chamber	--	--	10 hrs. (2)	1/Tgt.	View Tgt.	--	45(1)	50
	Spark Chamber	--	--	Varies (2)	When not viewing specific tgt.	Scan celestial sphere.	--	45(1)	50
	X-ray Detectory	--	--	Continuous	12/yr.	View x-ray sources.	--	45(1)	50
	All Sensors	2-3 days	12/yr.	--	--	Service	--	90	100

Notes:
(1) Deactivation during South Atlantic Anomaly - typical - 10 minutes during 4 successive orbits each 24 hr. period for level of 600 protons/Cm^2 -sec.

(2) Long viewing sequences may be interrupted.

(3) Simultaneous sensor operation: TV plus all sensors may be operated together except spectrometer or x-ray imaging which are mechanically exchanged at telescope focus. Detectors may not all point at same target simultaneously.

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times					Exp. Repetitions/yr	Duty Cycle	
		Calibrate/Set-Up		Operate/Observe		Operation		Min/Orb	%
		Duration	Frequency	Duration	Frequency				
5.7/12	Plasma Physics	3 weeks	Once (initial)	--	--	Set up	--	90	100
	-1 Plasma Wake	8 hr.	5/yr.	16 hr.	5/yr.	Wake meas.		45	50
	-2 Harmonic Wave	4 hr.	5/yr.	.5 hr.	5/yr.	Wave meas.		90	100
	-3 Wave Particle	4 hr.	5/yr.	1.0 hr.	5/yr.	Part. meas.		90	100
	-4 Accelerator	4 hr.	5/yr.	1.0 hr.	5.yr.	Auroral exl.		90	100
	-5 Plasma Jet	3 days	Once	30 days	Once	Jet meas.		90	100
	-6 Barium Cloud	4 hr.	5/yr.	1.0 hr.	5/yr.	Cloud meas.		90	100
	Note: Experiments conducted one at a time.								
5.8	Cosmic Ray								
	Facility	15 days	Once (initial)	--	--	Checkout	--	90	100
	Detectors			Continuous	--	Cosmic ray sensing	--	90 (1)	100
	Detectors	2-3 days	4/yr.	--	--	Service & reconfigure.	--	90	100
	Magnet	3-5	1/yr.	--	--	Dewar service.	--	90	100

(1) Reorient axis pointing towards zenith - 1/month reduces view time.

(2) Simultaneous detectors operating: worst case either detectors on longitudinal or radial axis. For either case magnet operates simultaneously.

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times					Exp. Repetitions/yr	Duty Cycle	
		Calibrate/Set-Up		Operate/Observe		Operation		Min/Orb	%
		Duration	Frequency	Duration	Frequency				
5.9	Vertebrates								
	Facility	4-5 day	1/yr	--	--	Checkout 0 G	1	90	100
	Facility	4-5 day	1/yr	--	--	Checkout Centrifuge	1		
	Experiment (1)	8 Hrs	1/yr	90 days	1/yr	0 G	1	90	100
		16 Hrs (2)	1/yr	90 days	1/yr	Art G	1		
	Experiment (2)	160 Hrs	1/yr	365 days	1/yr	0 G	1	90	100
	(1)	224 Hrs (2)	1/yr	365 days	1/yr	Art B	1		
	Experiment (3)	8 Hrs	2/90 days	30 days	2/90 day	0 G	1	90	100
		8 Hrs	2/90 days	30 days	2/90 day	Art G	1		
	Experiment (4)	14 Hrs	1/90 days	4-1/2 days	1/90 day	0 G	3	90	100
		14 Hrs	1/90 days	4-1/2 days	1/90 day	Art G	3		

Notes: (1) Total for 15 subexperiments in series - parallel

(2) Centrifuge set up assumed longer than 0 g setup when additional gages involved.

(3) Simultaneous experiments are: 1, 2 (partial), 3, 5; 2 (partial), 4, 8; 2 (partial), 6, 8; 2 (partial), 4, 5, 7.

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times					Exp. Repetitions/ yr	Duty Cycle	
		Calibrate/Set-Up		Operate/Observe		Operation		Min/Orb	%
		Duration	Frequency	Duration	Frequency				
5.9	Vertibrates								
	Experiment (5)	4-1/2 Hrs (Aug)	1/90 days	90 days	1/180 days	0 G	2	90	100
		9 Hrs (Aug)	1/90 days	90 days	1/180 days	Art G	2		
	Experiment (6)	8 Hrs	1/365 days	56 days	1/365 days	0 G	1	90	100
		16 Hrs (2)	1/365 days	56 days	1/365 days	Art G	1		
	Experiment (7)	8 Hrs	1/365 days	90 days	1/365 days	0 G	1	90	100
	Experiment (8)	1 Hr	1/365 days	180 days	1/365 days	0 G	1	90	100
		1 Hr	1/365 days	180 days	1/365 days	Art G	1		
	Facility	1 Hr	1/10 days	--	--	Centrifuge Maint.	36	90	100

Notes: (1) Total for 15 subexperiments in series -parallel

(2) Centrifuge set up assumed longer than 0 g setup when additional gages involved

(3) Simultaneous experiments are: [1, 2 (partial), 3, 5]
[2 (partial), 4, 8]
[2 (partial), 6, 8]
[2 (partial), 4, 5, 7]

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times					Exp. Repetitions/yr.	Duty Cycle	
		Calibrate/Set-Up		Operate/Observe		Operation		Min/Orb	%
		Duration	Frequency	Duration	Frequency				
5.10	Plants								
	Facility	4-5 days	1/yr	--	--	0 G	1	90	100
	Facility	4-5 days	1/yr	--	--	Centrifuge	1		
	Experiment (1)	8 Hrs	1/90 days	21 days	1/90 day	0 G	3	90	100
		16 Hrs (1)	1/90 days	21 days	1/90 day	Art G	3		
	Experiment (2)	8 Hrs	1/90 days	14 days	1/90 day	0 G	3	90	100
		16 Hrs (1)	1/90 days	14 days	1/90 day	Art G	3		
	Experiment (3)	4 Hrs	1/90 days	21 days	1/90 days	0 G	3	90	100
		8 Hrs (1)	1/90 days	21 days	1/90 days	Art G	3		
	Experiment (4)	8 Hrs	1/yr	270 days	1/yr	0 G	1	90	100
		16 Hrs (1)	1/yr	270 days	1/yr	Art G	1		
	Experiment (5)	8 Hrs	1/90 days	21 days	1/90 days	0 G	3	90	100
		16 Hrs (1)	1/90 days	21 days	1/90 days	Art G	3		
	Experiment (6)	8 Hrs	1/90 days	21 days	1/90 days	0 G	3	90	100
		8 Hrs	1/90 days	21 days	1/90 days	Art G	3		

Notes:

(1) Artificial G experiment setup assumed longer than 0 "G" setup when more cages involved.

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times					Exp. Repetitions/yr.	Duty Cycle	
		Calibrate/Set-Up		Operate/Observe		Operation		Min/Orb	%
		Duration	Frequency	Duration	Frequency				
5.10	Plants								
	Experiment (7)	8 Hrs	1/90 days	28 days	1/90 days	0 G	3	90	100
	Facility	1 Hr	1/10 days	--	--	Centrifuge Maint.	36	90	100

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times					Exp. Repetitions/yr	Duty Cycle	
		Calibrate/Set-Up		Operate/Observe		Operation		Min/Orb	%
		Duration	Frequency	Duration	Frequency				
5.11	Earth Surveys								
	Facility	4-6 days	1/yr	--	--	Lab Checkout	1	90	100
	Sensors	--	--	15 min (1)	1/90 min	Earth Sensing	5575	15	17
	Sensors	10 min	4/day	--	--	Calibrate Microwave Sensor	1440	10	11

Notes: All sensors operate simultaneously.

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times					Exp. Repetitions/ 180 days	Duty Cycle	
		Calibrate/Set-Up		Operate/Observe		Operation		Min/Orb	%
		Duration	Frequency	Duration	Frequency				
5.16	Materials Science						(1)		
	Facility	2-4 days	Once Initial	--	--	Checkout	once	90	100
	Experiment (1)	2-4 days (3)	5/month	2 Hr	5/month	Prep. Specimens	6	90	100
	Experiment (2)	14 Hrs (3)	3/month	6 Hr	3/month	Prep. Specimens	6	90	100
	Experiment (3)	10 Hrs (3)	4/month	2 Hr	4/month	Prep. Specimens	6	90	100
	Experiment (4)	12 Hrs (3)	8/month	50 Hr	8/month	Prep. Specimens	6	90	100
	Experiment (5)	12 Hrs (3)	4/month	4 Hr	4/month	Prep. Specimens	6	90	100
	Experiment (6)	18 Hrs (3)	6/month	1 Hr	6/month	Prep. Specimens	6	90	100

Notes:
(1) Worst case period shown. Experiment program ranges from 12 tests per month for 180 days to 30 tests/month for 180 days as shown.
(2) Simultaneous experiment operation as follows: 1 experiment per day except 3C & 4C simultaneously 4 times/month, with 1 day separation minimum, power required only during operation period.
(3) Includes set up and termination time.

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times: Calibrate/Set-Up Duration	Frequency	Operate/Observe Duration	Frequency	Operation	Exp. Repetitions	Duty Cycle Min/Orb	%
5.20	Fluid Physics.								
	Laboratory								
	Attached								
	Free Flying								
	Experiment (1)								
	Experiment (2)								
	Experiment (3)								
	Experiment (4)								
	Experiment (5)	Reference Tables 3-23 and 3-24 of Section 3 for times and conditions							
	Experiment (6)								
	Experiment (7)								
	Experiment (8)								
	Experiment (9)								
	Experiment (10)								
	Experiment (11)								
	Experiment (12)								
	Equipment								

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times: Calibrate/Set-Up Duration	Calibrate/Set-Up Frequency	Operate/Observe Duration	Operate/Observe Frequency	Operation	Exp. Repetitions	Duty Cycle Min/Orb	Duty Cycle %
5.22	Component Test								
	Lab							90	100
	Experiment 1-1	4 Hrs	once	3 Hrs	2/day	Test	30	90	100
	1-2	4 Hrs	once	3000 Hrs	once	Test	once	90	100
	Experiment 2	7 Hrs	1/9 days	1 Hr	1/day	Test	150	90	100
	Experiment 3	1 Hr	1/day	5 Hrs	1/day	Test	50	90	100
	Experiment 4	4 Hrs	1/5 day	1.5 Hrs	6/day	Test	50	90	100
	Experiment 5	8 Hrs	1/6 day	4 Hrs	2/day	Test	20	90	100
	Experiment 6	0.8 Hrs	3/day	0.8 Hrs	10/day	Test	75	90	100
	Experiment 7	3 Hrs	2/day	0.4 Hrs	20/day	Test	50	90	100
	Experiment 8	2 Hrs	2/day	4 Hrs	2/day	Test	6	90	100
	Experiment 9	5 Hrs	1/day	3 Hrs	3/day	Test	6	90	100
	Experiment 10	1 Hr	1/day	1 Hr	1/day(1)	Test	96	15(1)	17

Notes:

(1) Requires earth pointing and truth site(s)

(2) Simultaneous experiments as follows: Experiments are conducted singly except for Exp. 1-2 which operates concurrently with Exp. 2 thru 7, and Exp. 10 which operates concurrently with Exps. 1,2, & 3.
1, 2 & 3.

5.23	Primates								
	Experiment 1			12 mos.	once	Test	1	90	100
	Experiment 2			2 mos.	once	Test	1	90	100

Table 2-7. Experiment Mission Times (Continued)

FPE	Title	Mission Times					Exp. Repetitions	Duty Cycle	
		Calibrate/Set-Up		Operate/Observe		Operation		Min/Orb	%
		Duration	Frequency	Duration	Frequency				
5.27	Physics & Chemistry	(1)							
	Laboratory	2-4 days	once	--	--	Checkout	-	90	100
	Experiment (1)	14 Hrs	2/yr	90 Hr	2/yr	Prep Specimens	-	90	100
	Experiment (2)	14 Hrs	2/yr	90 Hr	2/yr	Test	-	90	100
	Experiment (3)	7 Hrs	2/yr	54 Hrs	2/yr	Test	-	90	100
	Experiment (4)	4 Hrs	2/yr	24 Hr	2/yr	Test	-	90	100
	Experiment (5)	5 Hrs	2/yr	4	2/yr	Test @ Sustained "G"			
	Experiment (6)	18 Hrs	2/yr	4	2/yr	Test @ Sustained "G"			

Notes:

(1) Includes reconfiguration time.

(2) Experiments are independent. One or more may be run at a time depending on the available crew, facility, or evaluation equipment.

These time lines are used to develop requirements for time-dependent functions such as data rates and power profiles.

Based on analysis of experiment servicing and logistics requirements, and the need for sustained "g" module return for refueling, module docking frequency was established as shown in Table 2-8.

2.4 ROLE OF MAN

The experiment module concepts and operations techniques capitalize on man's appropriate participation in research, experiment operation, data management, assembly, deployment, checkout, maintenance, repair, alignment, calibration, retrofit, and replacement. Table 2-9 summarizes the crew requirements and specific duties related to each experiment FPE.

Table 2-10 describes typical service cycle tasks for free-flying astronomy modules. Only the service crew such as module technicians or scientist/astronauts are shown. Flight control crewmen would also be required to perform functions related to module maneuvering to and from the stationkeeping location. About 20 hours is the minimum experiment lost time which would be possible if the typical module were serviced on a three-shift basis. A routine, single shift, service cycle is depicted in Figure 2-1 for Tasks 6 through 12. Prior or subsequent tasks are performed by flight controllers and do not require the module crewmen. The service crew works singly or together to accomplish service functions in less than two working days. Each service crewman is assumed to be available for experiment work 8-10 hours per day, six days per week. The total experiment down time for the routine cycle is about 30 to 35 hours. Tasks are listed in Table 2-10.

Astronomy modules are serviced at 30 or 60 day intervals. Using a maximum of four astronomy modules operating concurrently, with two serviced every 30 days and two every 60 days, gives a total equivalent module service frequency of three per month. Allowing additional time for repairs, contingencies, and logistics preparations, two skilled crewmen would be adequate to accomplish the worst case astronomy module servicing load.

Attached modules are available for service at any time. Different skills are required for experiment servicing in attached modules, however, due to module commonality, servicing could probably be accomplished with the same basic skills as used for detached modules. Flight control/dynamics skills will be required for the operation of FPE 5.12 Remote Maneuvering Subsatellites operating from an attached module.

Skill requirements for each FPE are summarized in Table 2-11. Since several modules may be operating at any one time, cross training should be accomplished whenever possible to reduce the total crew resource requirements.

Table 2-8. Module Docking Frequency – Free-Flying Modules

FPE NO.	Title	Baseline Docking Frequency (docks/day)	Experiment-Related Docked Operations				
			Cryog. Exp. Maint.	Replace Film	Replenish Test Fluid	Change/ Adjust Exp. Equip.	Deploy/ Retrieve Exp. Samples
5.1	X-ray Astronomy	1/60 days	X				X**
5.2A	Stellar Astronomy	1/60 days		X			X**
5.3A	Solar Astronomy	1/30 days		X			X**
5.5	High-energy Stellar	1/30 days	X	X			X**
5.20-2	Fluid Physics	40/95 days*		X	X	X	
5.20-3	Fluid Physics	25/45 days*		X			
5.20-4	Fluid Physics	10/290 days*			X		

*Includes docking for module propellant resupply

**Samples for FPE 5.18 Exposure experiments – nominal 1/60 days.

Table 2-9. Summary of Crew Requirements — Experiment Modules

FPE NO.	TITLE	Type of Experiment		MAX. NO. OF CREW MEMBERS AT ANY ONE TIME	NORMAL OPERATING MODE		NOMINAL DURATION & FREQUENCY OF MANNING	REMARKS/DUTIES
		Man Conducted	Man Serviced		Attached	Detached		
5.1	X-Ray Astronomy		X	2		X	2-3 Days - every 60 days.	Routine equip. maint., refuel, resupply cryogenics, update sensors (1/year).
5.2A	3-Meter Telescope		X	2		X	2-3 Days - every 60 days.	Refuel, update sensors (1/year).
5.3A	Solar Astronomy		X	2		X	2-3 Days - every 60 days.	Replace film, refuel, update sensors, change gratings (1/year).
5.5	Hi-Energy Astronomy		X	2		X	2-3 Days - every 30 days.	Routine maint., refuel, resupply cryogenics, update sensors, replace emulsions.
5.7	Plasma Physics	X		2	X		5-10 Days per experiment × 5 times/yr.	Operate RMS and sensors, monitor data, calibrate and service instrumentation.
5.8	Cosmic Ray		X	2	X		1 Man continuous 8 hrs/day; 2 man setup 4 hrs/90 days.	Monitor data 8 hrs/day. Revise experiment. Service dewar, change emulsions (1/3 days).
5.9 5.10	Space Biology	X		2	X		2 Men continuous for 8 hrs/day.	Attend specimens, conduct & monitor experiment, and load/unload biocentrifuge.
5.11	Earth Surveys	X		2	X		2 Men continuous for 8 hrs/day.	Operate sensors, monitor data, calib. & service instr.
5.12	RMS Hangar (see 5.7)	X		2	X		(Same operation as in 5.7)	(Same man) Deploy/retrieve, service RMS, waste disposal.
5.13C	Centrifuge	X		2	X		2 Men	Operate centrifuge, monitor subject, act as subject.
5.16	Matls. Process Lab	X		2	X		2 Men continuous for 8 hrs/day.	Prepare, conduct, monitor experiment, analyze specimens and attend to free-flying modules.
5.17	Contamination		X	1 + 1	Suitcase X		2 Men (1 + 1 EVA) for 4 days every 60 days.	Measure samples, replace, monitor automated instr.
5.18	Exposure		X	1 + 1		Suitcase X	2 Men (1 + 1 EVA) " " "	Measure samples, replace, monitor automated instr.
5.20	Fluid Physics	X		2	X	X	2 Men continuous for 8 hrs/day.	Prepare & conduct experiment, attend to free-flying module, film replacement.
5.22	Comp. Test/Sensor	X		2	X		1 to 2 Men continuous 8 hrs/day.	Set up and conduct experiment, maintain test equipment.
5.23	Primates (Bio A)	X		2	X		(Same as 5.9 and 5.10)	Attend specimens, conduct experiments.
5.27	Physics & Chem.	X		2	X	X	2 Men continuous for 8 hrs/day.	Set up and conduct experiments, attend to free-flying module (5.20) when used for 5.27 experiments.

Table 2-10. Astronomy Module Servicing Cycle (Typical)

Task No.	Task Description	No. of Service Crew	Control Mode**	Time Allocated (hr)*	Elapsed Time (hr)*
1.	Secure Experiment Equipment	0	R	0.25	0.25
2.	Ready Module Subsystems for Return	0	R	0.25	0.50
3.	Orient Module and Apply Transfer ΔV Impulse	0	R	0.25	0.75
4.	Transfer Space Station Vicinity and Apply Re-circulation ΔV Impulse	0	R	1.6	2.35
5.	Rendezvous With Space Station and Dock	0	R	0.4	2.75
6.	Pressurize Service Tunnel and Module and Leak Test	1	R	2.0	4.75
7.	Open Hatch and Inspect Module	2	M	0.5	5.25
8.	Service Experiments*	2	M	6.0	11.25
9.	Service Module Subsystems*	2	M	2.0	13.25
10.	Inspect Module	2	M	0.5	13.75
11.	Close Hatch and Depressurize+ Module & Service Tunnel	2	M	2.0	15.75
12.	Checkout Experiments and Module Subsystems	1	R	1.0	16.75
13.	Ready Module Subsystems for Launch	0	R	0.5	17.25
14.	Launch Module and Clear Space Station Buffer Zone	0	R	0.15	17.42
15.	Orient Module and Apply Transfer ΔV Impulse	0	R	0.25	17.67
16.	Transfer to Stationkeeping Position and Apply Re-circularization ΔV	0	R	1.6	19.27

Table 2-10. Astronomy Module Servicing Cycle (Typical) (Continued)

Task No.	Task Description	No. of Service Crew	Control Mode**	Time Allocated (hr)*	Elapsed Time (hr)*
17.	Acquire Pointing Reference	0	R	0.25	19.50
18.	Orient Module	0	R	0.25	19.75
19.	Ready Module Subsystems for Experiments	0	R	0.25	20.00
20.	Ready Experiment Equipment	0	R	0.5	20.50
21.	Resume Observation Program	0	R	0.5	21.00

*Servicing times will vary with individual modules; typical values are shown for replenishment of expendables, adjustments and calibration, and do not include repair time.

+Pump-down to ~1.0 psia.

**Control Modes: R = Orbital remote, M = Manual

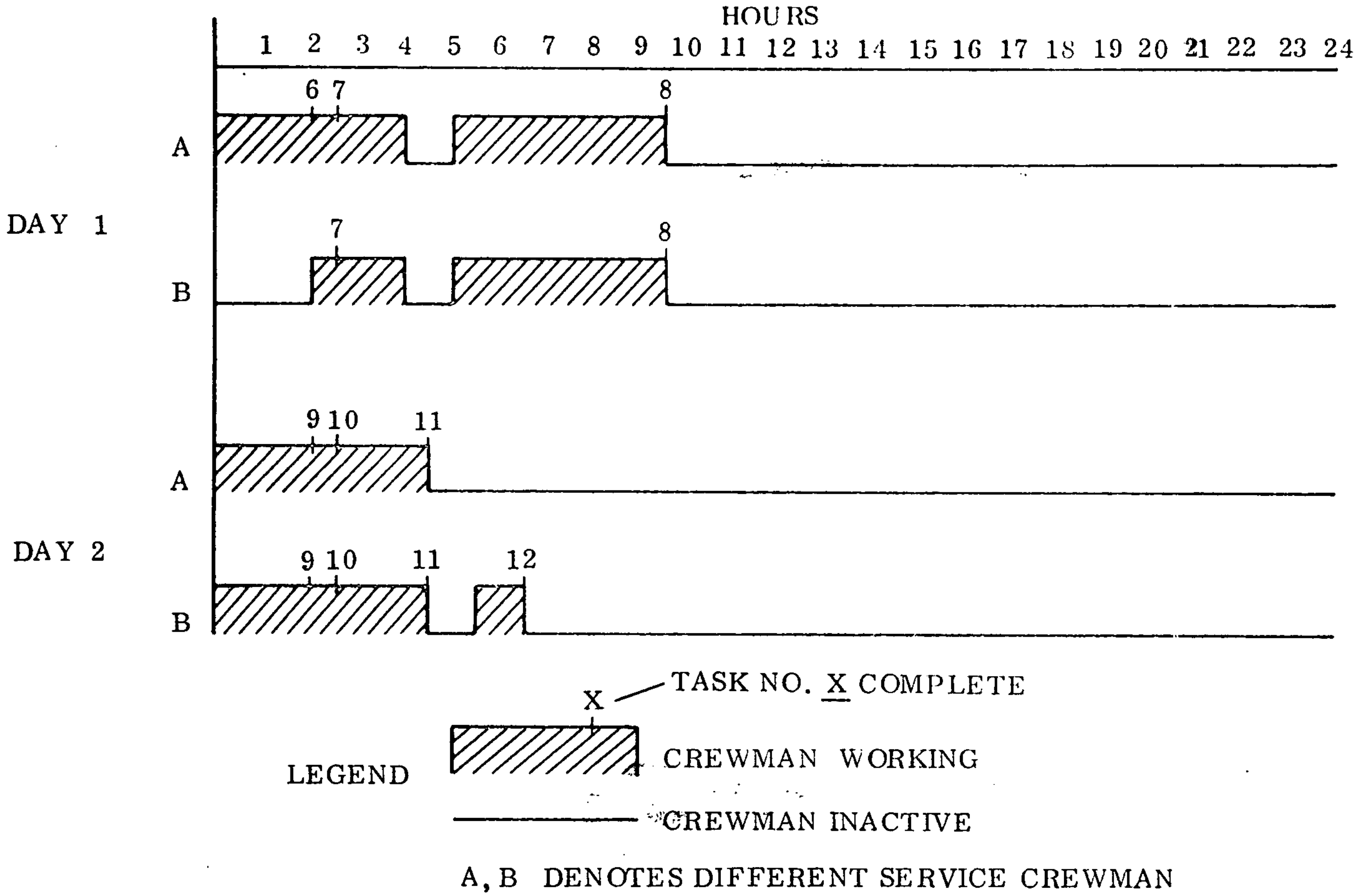


Figure 2-1. Astronomy Module Single Shift Service Timeline (Typical)

Table 2-11. Experiment Crew Skills Summary

FPE	TITLE	EXPERIMENT CREW SKILLS+										
		Astronomer	Physicist	Physiologist	Earth Scientist	Metallurgist	Technician	Sys./Test Engr.	Electrical Engr.	Optical/Photo Tech.	Electro/Mech. Tech.	Biology Lab Tech.
5.1	X-Ray									X*	X*	
5.2A	Stellar	X								X*	X*	
5.3A	Solar	X								X*	X*	
5.5	High Energy									X*	X*	
5.7/12	Plasma Physics		X				X					
5.8	Cosmic Ray		X						X			
5.9	Vertebrates			X								X
5.10	Plants			X								X
5.11	Earth Resources				X					X		
5.13C	Centrifuge			X			X					
5.16	Materials Science					X	X					
5.17	Contamination						X					
5.18	Exposure						X					
5.20	Fluid Physics						X			X		
5.22	Component Test						X			X		
5.23	Primates			X								X
5.27	Physics & Chemistry					X		X		X	X	

+ Ground Control
+ Not including flight control/dynamics crewmen for module control.
* Crew required for service and operation backup except for high resolution solar astronomy.

SECTION 3

MISSION OPERATIONS

The experiment program is defined as being conducted in conjunction with a space station in low earth orbit. The nominal orbit of the space station has been ground ruled at 270 n.mi. altitude and 55 degrees inclination.

Module operating requirements are based on the experiment modules being a part of the total space station system (see Figure 3-1) and, as such, deriving significant support from the other elements and being constrained to be compatible with these support elements. Modules are delivered to orbit by the earth-to-orbit shuttle or, expendable launch vehicles. Attached modules dock to the space station and remain docked for their normal mission life.

Free-flying modules dock to the station for initial activation/calibration, free-fly for experiment operations, and periodically return to the station for servicing. During the free-flying mode, experiment and module operations are controlled by the space station, and experiment data and module subsystem status are transmitted back to the station for processing, action, and retransmittal to ground.

Modules are also to be capable of being serviced while in the free-flying mode by the shuttle or other manned service vehicles.

Experiment modules designed to implement the experiment program must therefore be compatible with two major mission operations related to the space station:

a. Launch and rendezvous with the space station, using either the space shuttle or expendable launch vehicles.

b. Operating co-orbitally with the space station in either an attached or free flying mode.

Performance and operational aspects of these requirements are presented in the following paragraphs. Interface requirements with launch vehicles and space station are presented in Section 4.

3.1. LAUNCH AND DISPOSAL OPERATIONS

Launch vehicle capabilities and requirements were examined in three phases:

a. Initial constraints for formulation of module design in the form of weights, envelope time, and circularization, rendezvous and docking requirements.

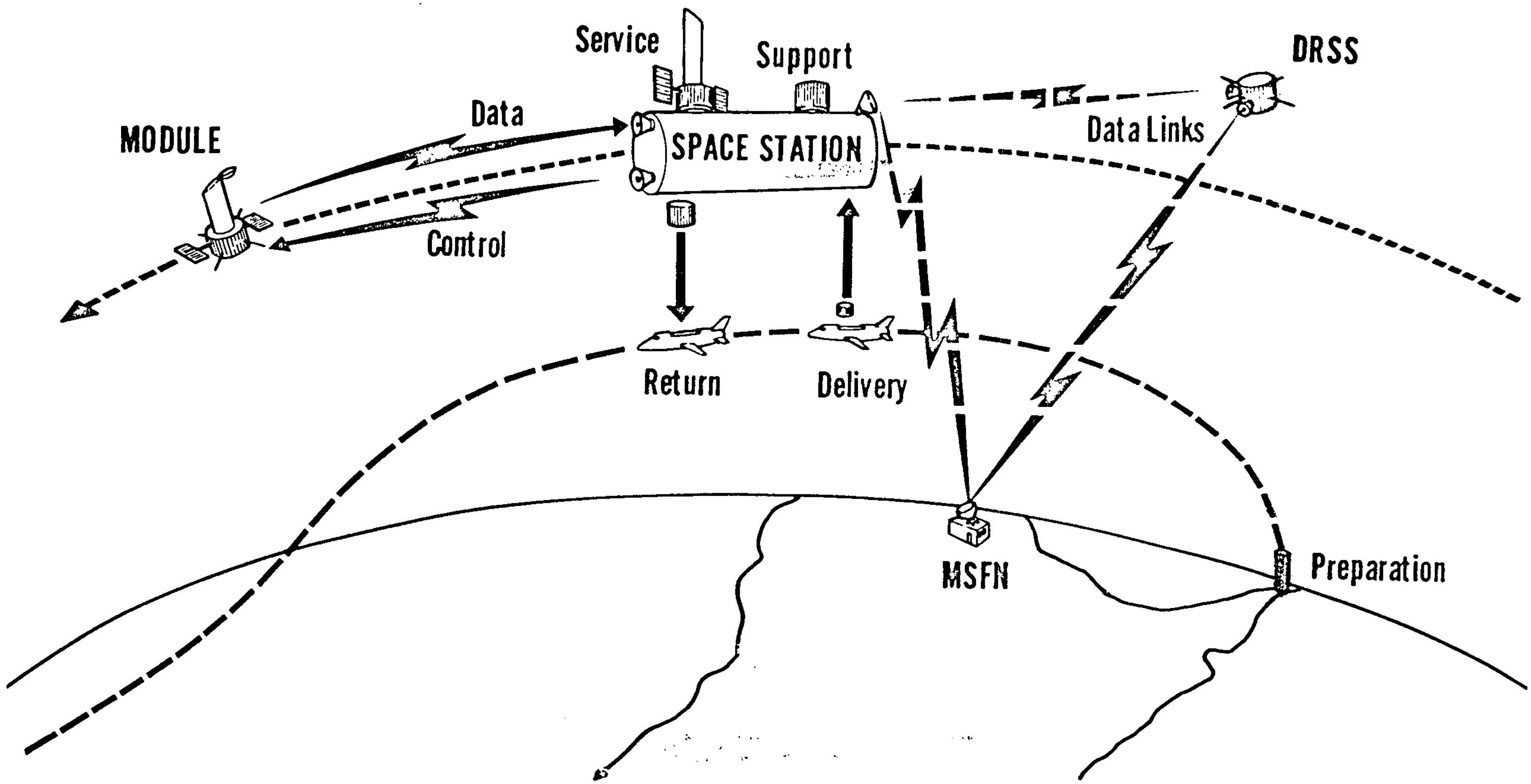


Figure 3-1. Experiment Module Operations

b. Examination of the sensitivity of module design to launch vehicle capabilities and recovery and disposal functions.

c. Selection of a delivery mode and launch vehicle set for study and planning purposes following completion of module designs.

3.1.1 CONSTRAINTS AND REQUIREMENTS. Study ground rules require that modules be compatible with launch by both space shuttle and expendable vehicles. This ground rule provides flexibility since module development is decoupled from any particular program. Whenever possible, fundamental module characteristics, such as basic structure or operations, should be insensitive to the type of launch vehicle finally selected.

As a design goal module subsystems power-up requirements during launch should be kept to a minimum. Functions requiring stored power during the pre-launch, ascent and docking period are shown in Table 3-1.

Table 3-1. Module Functions Requiring Stored Power - Prelaunch through Docking

	Allocation	
Module Function	Shuttle Launch	Expendable Launch
Internal Power Checks	X	X
Status Monitoring	X	X
Status Transmission to Ground		X
Status Transmission to Shuttle	X	
Guidance Update	X	X
Separate		X
Deploy	X	
Transmit to Station/Receive Commands	X	X
Orient	X	X
Apply Circularize ΔV (as Reqd)	X	X
Apply Rend. & Dock ΔV	X	X
Dock	X	X

Some experiment unique functions may also be required during the initial delivery phases. Life support power and monitoring for specimens included in module cages, thermal control for telescopes, and cryogenic vent control are examples of typical experiment functions. For study purposes, functions of this type were assumed to be experiment supplied.

a. Space Shuttle. Shuttle launch vehicle payload capability is ground ruled at 25,000 pounds delivered close to the space station. Delivery is assumed to be to a stand-off position in circular orbit at the space station altitude of 270 n.mi. altitude for the baseline case. The effect of introducing hard docking capability is discussed in Section 3.2.6. Rendezvous and docking of attached and detached experiment modules to the space station is then accomplished with propulsion integral to the module. The ΔV budget for this operation is estimated at 85 fps, including a contingency docking allowance.

   The other basic shuttle delivery mode for modules exceeding 25,000 pounds is to a 100 x 270 n.mi. elliptical orbit at 55 degrees. The module undocks from the shuttle, uses its RCS to circularize the orbit and then free-flies to the space station and docks. The additional ΔV required for circularization is approximately 300 fps. The shuttle payload capability for elliptical orbit delivery is estimated at 32,000 pounds.

   A typical mission profile for the shuttle delivery mode shown in Figure 3-2 indicates that up to 24 hours may be required for the shuttle to properly phase its orbit and for the experiment module to dock with the space station. Module or experiment functions are therefore required while in the cargo bay, attached to the shuttle or in transit to the space station for maximum periods of approximately 24 hours after liftoff. An additional time period of 24 hours is allocated for pre-launch pad checkout of shuttle and payload.

b. Expendable Launch Vehicles. Expendable launch vehicle constraints and requirements on module design are dependent on the launch vehicle envelope, performance capabilities, and the circularization, rendezvous and docking technique. Delivery time for expendable launch vehicles should not exceed shuttle delivery time.

   Insertion of the module into circular orbit for rendezvous with the space station can be either direct insertion or by use of a transfer ellipse. The transfer ellipse provides a greater payload capability and is selected when module weight estimates indicate the greater payload is needed.

   Circularization of the module at apogee of the insertion ellipse can be accomplished by either the module or launch vehicle upper stage (Transtage on Titan vehicles). However, since all modules are required to have free-flying

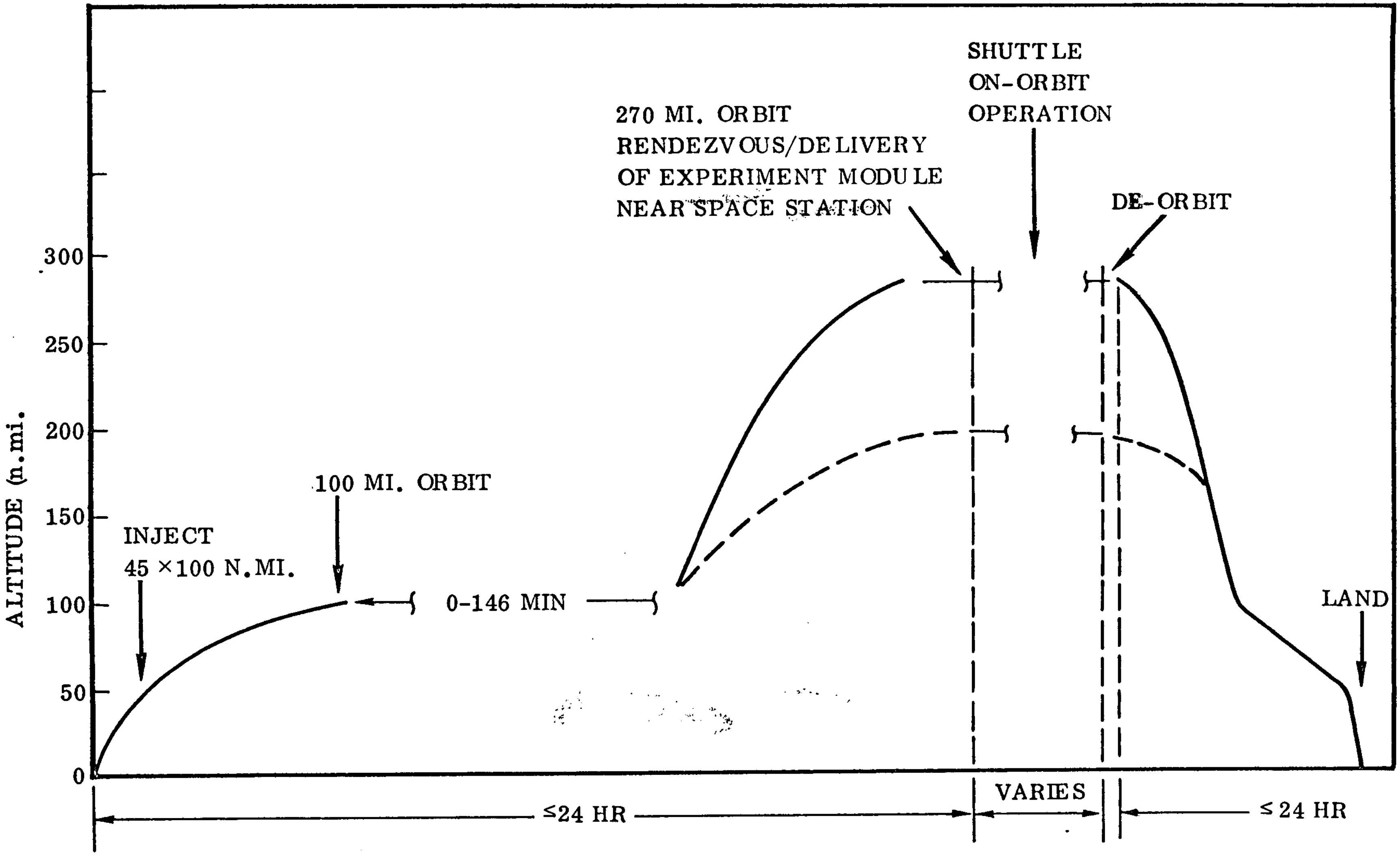


Figure 3-2. Typical Shuttle Delivery Mission Profile

capabilities for the rendezvous and docking phase following orbit circularization for the expendable launch vehicle case, it is more economical to increase the propellant tankage to provide circularization capability, using module RCS with performance requirement estimated at 300 fps for this circularization.

Expendable launch vehicle capabilities for total payload to elliptical and circular orbits, 55° inclination, less allowances for jettisonable fairings and payload support are estimated in Table 3-2.

Table 3-2. Expendable Launch Vehicle Payload Capability

Launch Vehicle	Approximate Payload Capability (lb)			Reference
	100 × 270 × 55° Elliptical	100 × 55° Circular	270 × 55° Circular	
T-IIIC	20,000	24,000	12,000	3-1.1
T-IIIF	28,000	33,000	18,000	3-1.1
SIB	34,000	37,000	24,000	3-1.1 3-1.2

These estimates are based on:

a. The Titan IIIC and the Titan IIIF (both without transtage) payload is that weight above Stage II less 800 pounds of payload structure, which remains on Stage II;

b. On both the Titan IIIC and the Titan IIIF, the nosecone/payload shroud equal to 10,000 pounds is jettisoned during boost;

c. The Saturn IB (unmanned payload weight is that weight above the Instrumentation Unit (IU) less 800 pounds of additional payload support structure. The nose cone/payload shroud, jettisoned during boost, is equal to 10,000 pounds.

d. No range safety constraints were assumed for allowable launch azimuth headings for the expendable vehicles.

The limits on payload diameter and length for a launch probability of 95% are:

L/V	D = 13 ft	D = 15 ft	D = 18 ft
TIIIC	L = 76 ft	L = 53 ft	L = 28 ft
TIIIF	L = 69 ft	L = 46 ft	L = 23 ft

3.1.2 EXPERIMENT MODULE ASSIGNMENT. Assignment of FPEs to experiment modules is discussed in some detail in Volume III of this report. The subject is introduced at this point to provide the necessary background for the discussions of experiment module operations.

The number of common module types for minimum program cost is three. These three types of common modules are:

a. CM-1 – this is the only free-flying common module type; all astronomy FPEs and the Fluid Physics sustained g experiments (FPE 5.20) are housed in this module.

b. CM-3 – is an attached module; it houses FPEs assigned to the attached mode that can be housed in a single pressurizable compartment.

c. CM-4 – is an attached module which houses FPEs assigned to the attached mode that require more space than is available in the CM-3 module.

Thirteen common modules are necessary to implement the total experiment module program as shown in Figure 3-3. Five CM-1, five CM-3, and three CM-4 modules are required. Experiments and experiment peculiar equipment and structure are shaded in this figure.

In addition to the common modules there are five major experiment-peculiar hardware items necessary to complete the experiment program: two centrifuges, two fluid physics (FPE 5.20) experiment tanks, and a propulsion slice. These hardware items are shown in Figure 3-4.

Both the biomedical (FPE 5.13C) and the biological (FPEs 5.9/10/23) centrifuges require a 10-foot-radius arm. To meet space shuttle cargo bay restrictions these centrifuges are encased in small-diameter cylinders with the whole assembly rotatable on external bearings. They are attached to the end of a common module or to the space station while on-orbit. Longitudinal mounting of the centrifuge within the shuttle cargo bay allows for simultaneous launch with the related common module. Retraction mechanisms position the centrifuges after they are on-orbit.

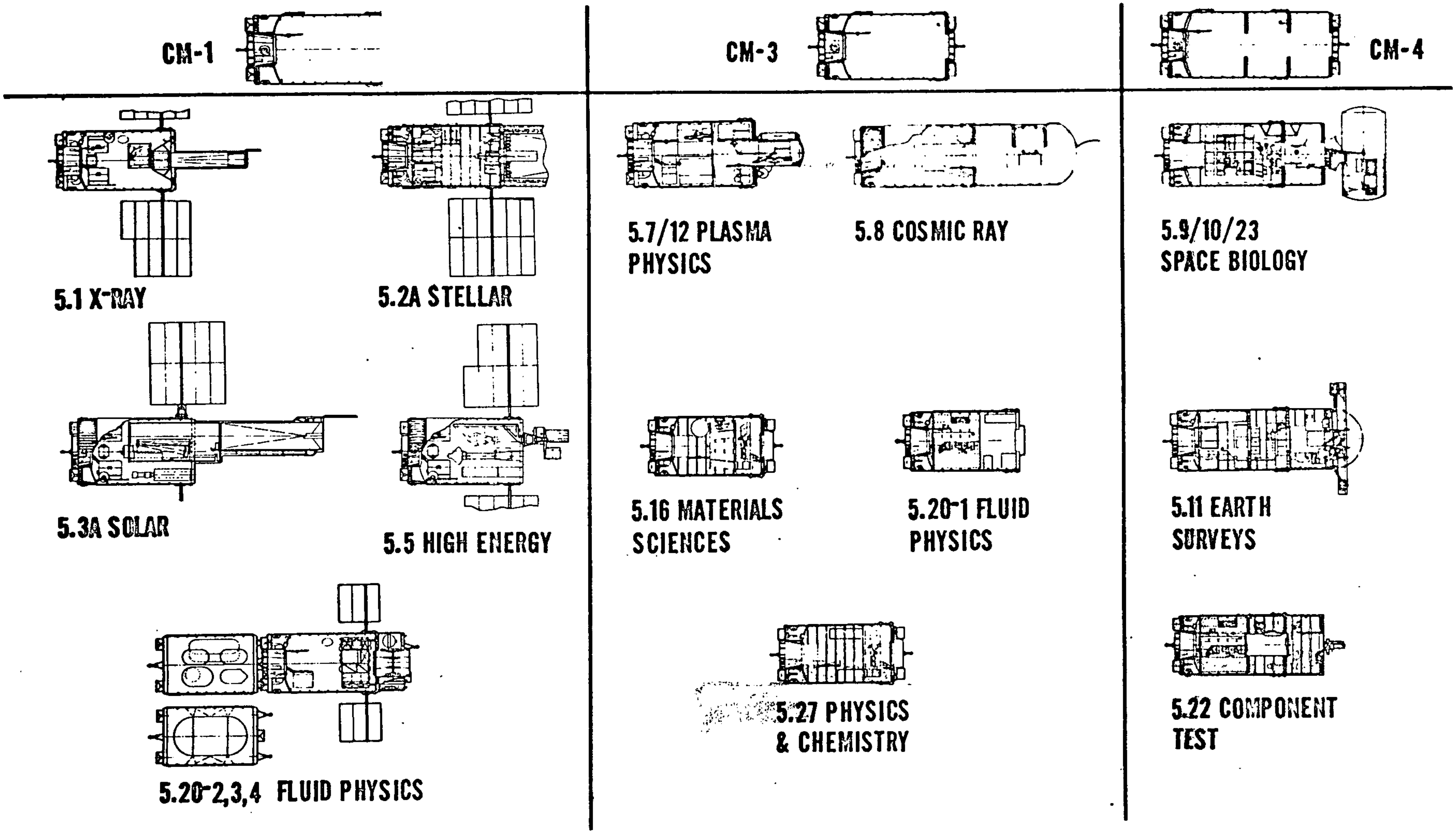
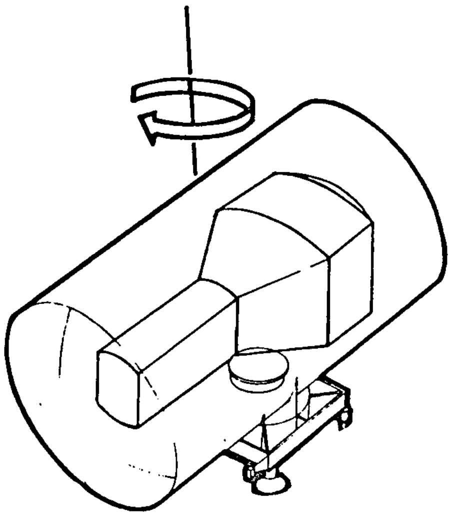


Figure 3-3. Experiment Module Assignments

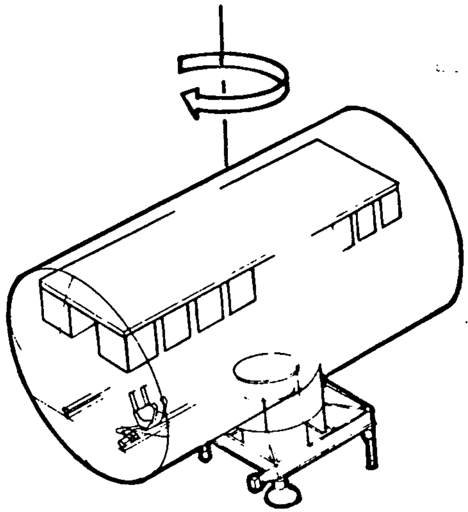
BIOMEDICAL CENTRIFUGE CONCEPT



9.5 ft. dia. by 20 ft. long

wt. = 6,800 lb.

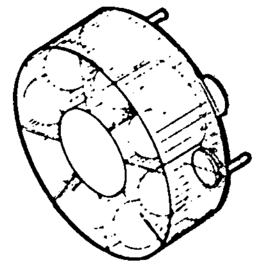
BIOLOGICAL CENTRIFUGE CONCEPT



9.5 ft. dia. by 20 ft. long

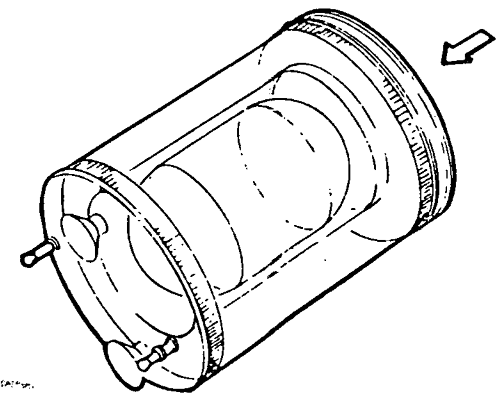
wt. = 7,000 lb.

FLUID PHYSICS TANKS (2) & PROPULSION



14 ft. dia. by 6 ft. long

Propulsion Slice wt. = 4,680 lb. dry



14 ft. dia. by 25 ft. long

wt. = 9,600 lb. max.

Figure 3-4. Major Experiment Peculiar Hardware

The propulsion slice is attached to the experiment bulkhead of the FPE 5.20 (Fluid Physics) free-flying CM-1 module to provide thrust for the sustained low-g acceleration tests.

Experiment tanks are attached to the opposite (from the propulsion slice) end of the fluid physics free-flying CM-1 module. These units only contain the fluid tanks, enclosing structure and docking ports. Each tank remains attached to the CM-1 module through a series of tests where experiments are replaced and the propulsion slice refueled while on-orbit.

Grouping and module assignment of experiment module program FPEs are summarized in Table 3-3. Two of the FPEs, FPE 5.17 (Contamination) and FPE 5.18 (Exposure), do not fall into the categories discussed in the preceding paragraphs. They are small experiments, called "suitcase experiments," which can be easily carried onboard a module or the space station. The requirements for these experiments are such that they can be carried piggy-back on experiment modules assigned to other FPEs, or they can be attached to the space station. Dedicated experiment modules are, therefore, not assigned to these FPEs.

3.1.3 MODULE DESIGN SENSITIVITY TO LAUNCH VEHICLES. Shuttle and expendable launch vehicle delivery capabilities are compared to payload weight and length characteristics in Figures 3-5 and 3-6. Modules are designed for compatibility with launch on both shuttles and expendable vehicles and assume shuttle stand-off delivery (see Section 3.2.6 for effect of hard-dock capability). Weights include additional structure necessary for higher expendable launch vehicle accelerations (approximately 600 pounds of structure required for 6 g vs. 3 g for shuttle) and shuttle cargo bay interface fittings. Experiment modules are contained within jettisonable payload shrouds when launched on expendable vehicles. Therefore both expendable launch vehicles and shuttle launches provide protected payload environments. Payload penalties for shrouds and interstage structure were estimated and deducted from expendable launch vehicle performance capability.

The shuttle payload is 25,000 pounds to 270 n.mi. circular orbit at 55 degrees. It is estimated that the payload capability is approximately 32,000 pounds to 100 × 270 n.mi. elliptical orbit at 55 degrees. Review of Figure 3-5 shows that elliptical delivery is needed for five or six modules. Module payload weights shown in Figure 3-5 include 2560 pounds of propellant. About 1500 pounds of propellant can be off-loaded prior to launch when circular delivery is selected.

Payload compatibility with shuttle length constraints is also shown. The shuttle cargo bay length is ground ruled at 60 feet. All modules will fit inside the shuttle cargo bay although payload deployment devices or operations might cause interference with the FPE 5.2A Stellar and FPE 5.9/10/23 Space Biology modules.

Table 3-3. FPE Module Assignment

FPE	TITLE	Assignment			
		CM-1	CM-3	CM-4	Experiment Peculiar
5.1	X-Ray	X			
5.2A	Stellar	X			
5.3A	Solar	X			
5.5	High Energy	X			
5.7/12	Plasma Physics		X		
5.8	Cosmic Ray		X		
5.9/10/23	Space Biology			X	Biological Centrifuge
5.11	Earth Surveys			X	
5.13C	Centrifuge				Biomedical Centrifuge
5.16	Materials Sci.		X		
5.17	Contamination				Suitcase Experiment
5.18	Exposure				Suitcase Experiment
5.20-1	Fluid Physics		X		
5.20-2, -3, -4	Fluid Physics	X			One Propulsion Slice, two Experiment Tanks
5.22	Component Test			X	
5.27	Phy. & Chem. Lab		X		

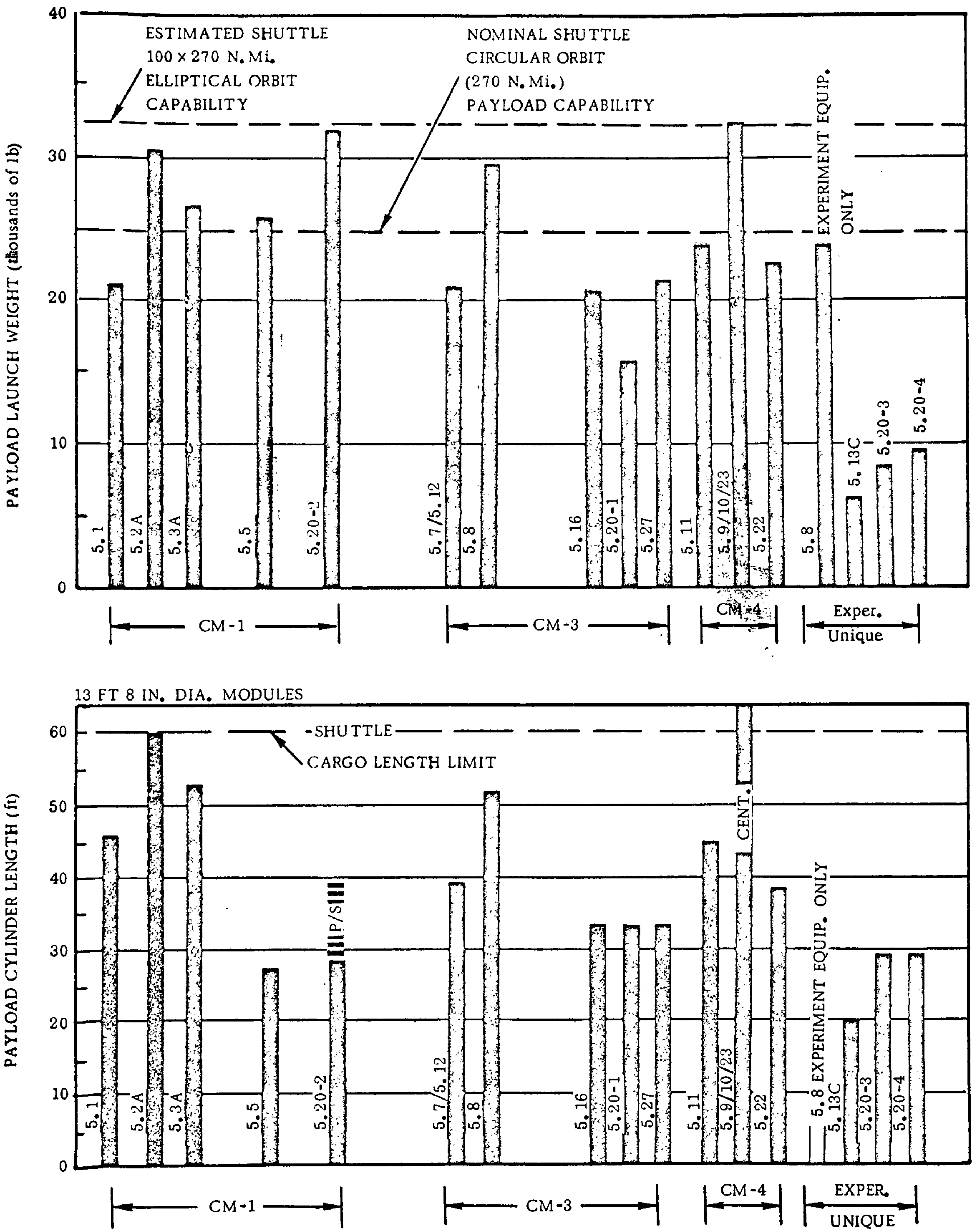


Figure 3-5. Shuttle Payload Sensitivity

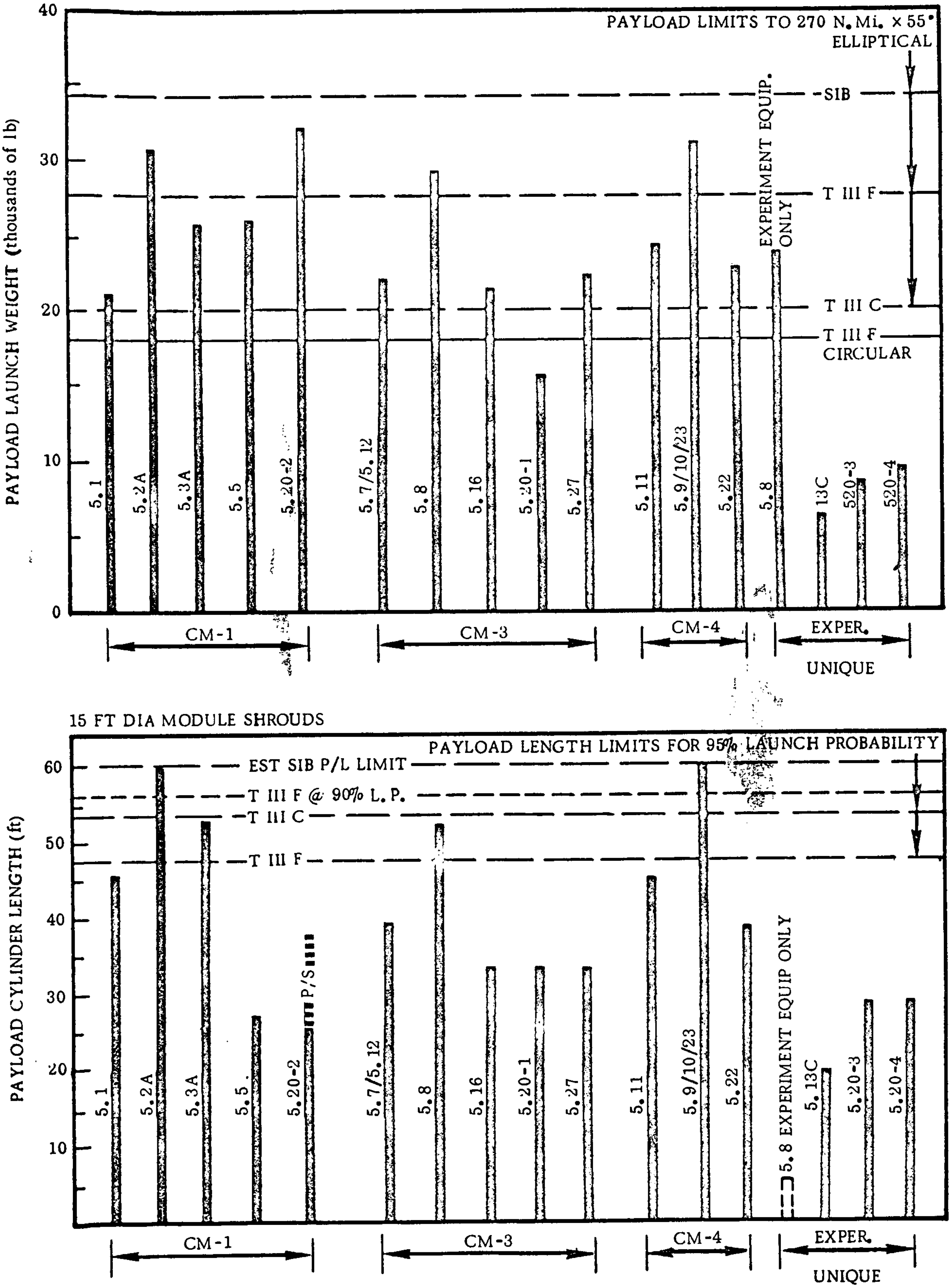


Figure 3-6. Expendable L/V Payload Sensitivity

Review of Figure 3-6 shows that all experiment module payloads can be carried by either Titan IIIF or Saturn IB expendable launch vehicles. Several payloads are also candidates for lighter payload T-IIIC launch vehicles, again with some of the modules requiring elliptical orbit delivery to allow use of the smaller launch vehicle. Circular orbit capability to 270 n.mi. is approximately 11,000 pounds for T-IIIC, 18,000 pounds for Titan IIIF and 23,000 pounds for Saturn IB, respectively, based on the same references. The Intermediate-20 launch vehicle was also considered, but has a payload capacity far in excess of module predicted weights.

The cylindrical length for bulbous payloads on Titan III vehicles is quite sensitive to payload diameter as shown in Figures 3-7 (Reference 3-1.1). Assuming a 15-foot diameter payload shroud, cylindrical lengths of all T-IIIF launched modules permit at least a 95% launch probability ability with the exception of FPE 5.3A Solar Astronomy. Reduction in payload shroud diameter from 15 feet to 14 feet permits launch of FPE 5.3A at 95% probability. Increase of the payload launch shroud to 16 feet would reduce launch probability for FPE 5.1 X-Ray and FPE 5.11A Earth Surveys to less than 90%. The payload minimum allowable cylinder length for bulbous payloads on T-III requires that the length to diameter ratio (L/D) exceed 1:1. All experiment modules meet this criteria.

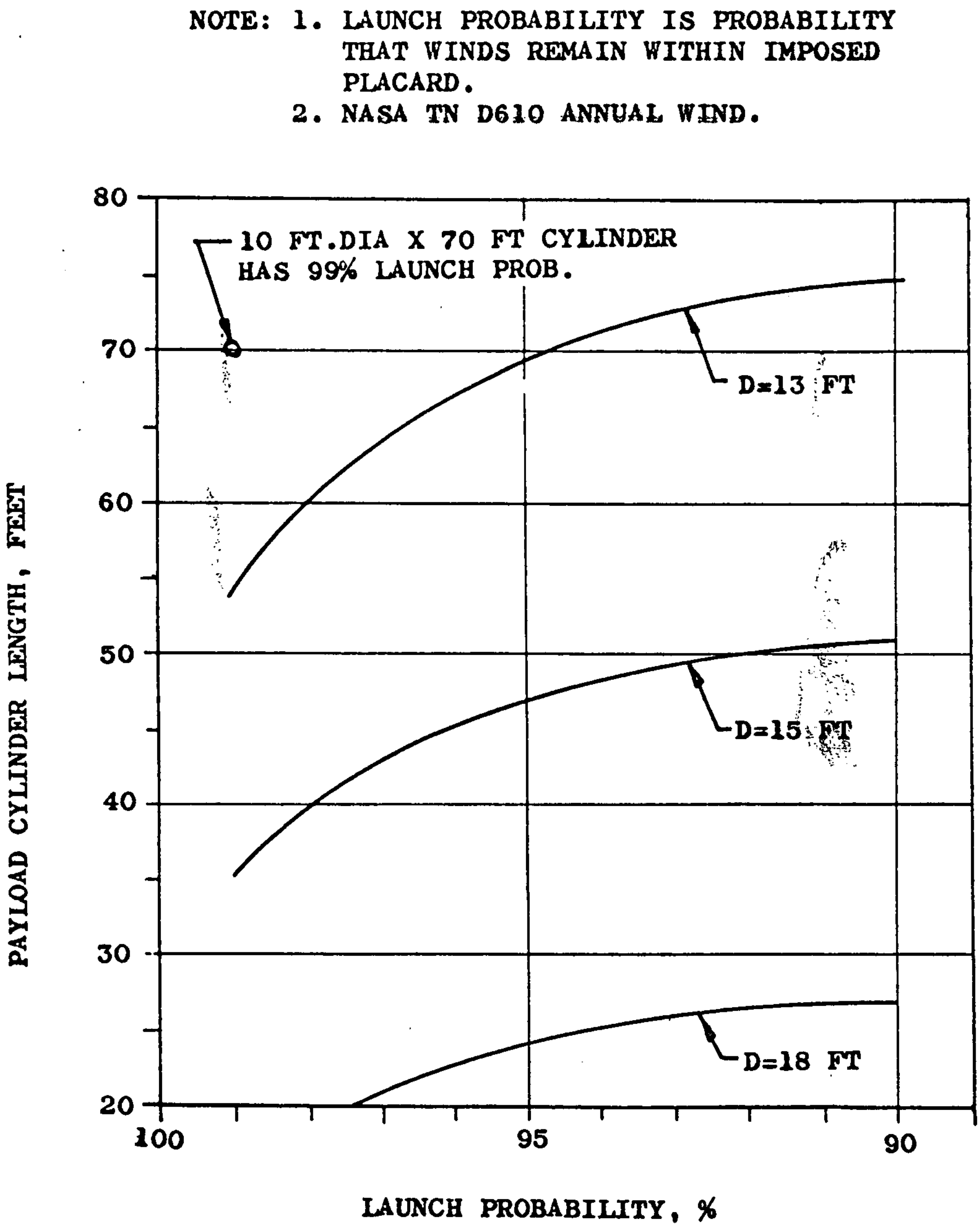
Experiment module lengths are compatible with launch on a Saturn IB vehicle. Reference 3-1.2 indicates that payload cylindrical lengths of 60 feet can be accommodated.

3.1.4 PAYLOAD DELIVERY REQUIREMENTS. Table 3-4 summarizes the requirements for payload delivery in terms of length and weight of experiment modules and experiment unique payloads. Both shuttle and expendable launch vehicles deliver the payloads to the required 270 n.mi., 55 degree orbit using selected circular or elliptical delivery modes summarized in Table 3-4 and described in the following paragraphs.

Circularized and transfer ellipse delivery orbits are selected for the module and experiment unique payload weights derived during the study and documented in Volume III and Table 3-4. Module weights include 2560 pounds of propellant. The propellant can be offloaded approximately 1500 pounds for modules delivered to circular orbit. In the case of Fluid Physics FPE 5.20-2 an additional 6800 pounds of propulsion slice propellant can be offloaded if necessary to meet payload constraints. The propulsion slice is experiment unique and provides special thrusters and equipment for sustained, low-g experiments. Table 3-4 indicates the specific payloads that would be offloaded.

The FPE 5.11A Earth Surveys module is selected for elliptical orbit insertion because of potential growth in weight.

The FPE 5.9/10/23 Space Biology module weighs about 1 percent more than elliptical orbit capability of the shuttle. However, the weight includes a full complement of specimens and cages totalling 2600 pounds. Typical Blue Book schedules show that



(Source ED-2002-795)

Figure 3-7. Titan IIIF Bulbous Payload Launch Probability

Table 3-4. Summary of Payload Delivery Requirements

FPE	Title	Payload Type: Module	Payload Type: Experiment Unique	Payload Length (1) (ft)	Payload Length (1) (inches)	Payload (lb x 1000) (7)	Shuttle Delivery: 270 n.mi. 55° Circular Orbit	Shuttle Delivery: 100 x 270 n.mi. 55° Elliptical Orbit (6)	Expendable Launch Vehicle Delivery: 270 n.mi. 55° Circular Orbit	Expendable Launch Vehicle Delivery: 100 x 270 n.mi. 55° Elliptical Orbit (6)
5.1	X-Ray	x		45	9	21.0	x			x
5.2A	Stellar	x		60	0	30.6		x		x[12]
5.3A	Solar	x		53	11	26.8		x		x
5.5	High Energy	x		27	0	26.1		x		x
5.7/5.12	Plasma Physics	x		38	11	20.8	x[9]			x
5.8	Cosmic Ray	x		51	11	29.8		x		x[12]
5.8	Cosmic Ray		x	6	8[2]	24.0[5]	x		x	
5.9/10/23	Space Biology	x		59	5[3]	32.4[3][11]		x		x[12]
5.11A	Earth Surveys	x		45	1	24.1	x[9]			x
5.13C	Centrifuge		x	20	0	6.8	x		x	
5.16	Materials Science	x		31	5	20.6	x[9]			x
5.20-1	Fluid Physics	x		31	5	15.9	x[9]		x	
5.20-2	Fluid Physics	x		37	11	31.9	x[8]			x[12]
5.20-3	Fluid Physics		x	27	10[4]	7.8[4]	x		x	
5.20-4	Fluid Physics		x	27	10[4]	9.6[4]	x		x	
5.22	Component Test	x		38	4	23.0[10]	x[9]			x
5.27	Physics and Chemistry	x		31	5	21.3	x[9]			x

Notes
(1) Length to end of extended docking probe(s).
(2) Experiment equipment without packaging.
(3) Includes Bio-centrifuge.
(4) Experiment tanks-wet.
(5) Detector may be divided into packages as small as 350 lb.
(6) Experiment module provides circularization ΔV.
(7) Includes 2560 lb propellant.
(8) Propulsion slice off-loaded up to 6800 lb propellant.
(9) Module may be off-loaded up to 1500 lb propellant.
(10) Weight with 3950 lb experiment cryogenics & off-loaded.
(11) Experiment specimens and cages may be off-loaded up to 2600 lb.
(12) Alternate mode: delivery to interim circular orbit with subsequent transfer to 270 n.mi.

all experiments will not be conducted simultaneously. It is probable that a large fraction of the specimens would be delivered as logistics cargo and could be subtracted from the initial payload weight.

An alternate shuttle delivery mode involves a Hohmann transfer executed by the module from a low altitude. Experiment modules exceeding 25,000 pounds can be delivered to the 270 n.mi. × 55 degree orbit by using the experiment module RCS propulsion system to increase orbital altitude. The shuttle delivers the module to a lower, interim altitude orbit; for example, from Figure 3-8 a 31,000 pound experiment module can be delivered to a 200 n.mi. orbit. At this point the module then undocks from the orbiter and using its RCS propulsion executes a Hohmann transfer to the final 270 n.mi. orbit. Figure 3-8 shows that less than 1500 pounds of propellant is required to complete the transfer of the 31,000 pound module.

A 1500-pound limit was selected for the baseline as the maximum propellant available for transfer in order to leave sufficient propellant for rendezvous and docking, and contingencies. Propellant provided in the design as a result of Failure Modes and Effects Analysis was not considered as available for the transfer maneuvers.

If experiment module weight exceeds 32,500 pounds, the heavyweight module could be delivered on expendable launch vehicles or shuttles if additional propellant capacity was added as a kit to the baseline experiment module. If the module weight were not increased, an additional module propellant tank with 600 pounds of usable propellant (2100 pounds total) would provide the transfer capability shown in Figure 3-8. A module of up to approximately 35,000 pounds could be transferred to final orbit altitude by this mode.

Expendable launch vehicles also use two basic delivery modes. T-IIIC or T-IIIF vehicles deliver lightweight payloads to 270 n.mi. circular orbits. Heavier payloads are delivered by T-IIIF or SIB vehicles to a 100 x 270 n.mi. transfer ellipse and circularize at space station altitude using the module RCS in a manner similar to shuttle delivery.

Four experiment unique equipments have been identified as separately launched payloads. As shown in Table 3-4 these unique payloads are the large detector used in the growth version of FPE 5.8 - Cosmic Ray Physics, the manned Centrifuge - FPE 5.13C, and two fluid physics tanks containing cryogenic experiments designated FPE 5.20-3 and -4.

The growth version cosmic ray equipment is a segmented total absorption detector (TAD) weighing a total of 24,000 pounds separable into sections of approximately 350 pounds each. On-orbit assembly of this detector appears required since the

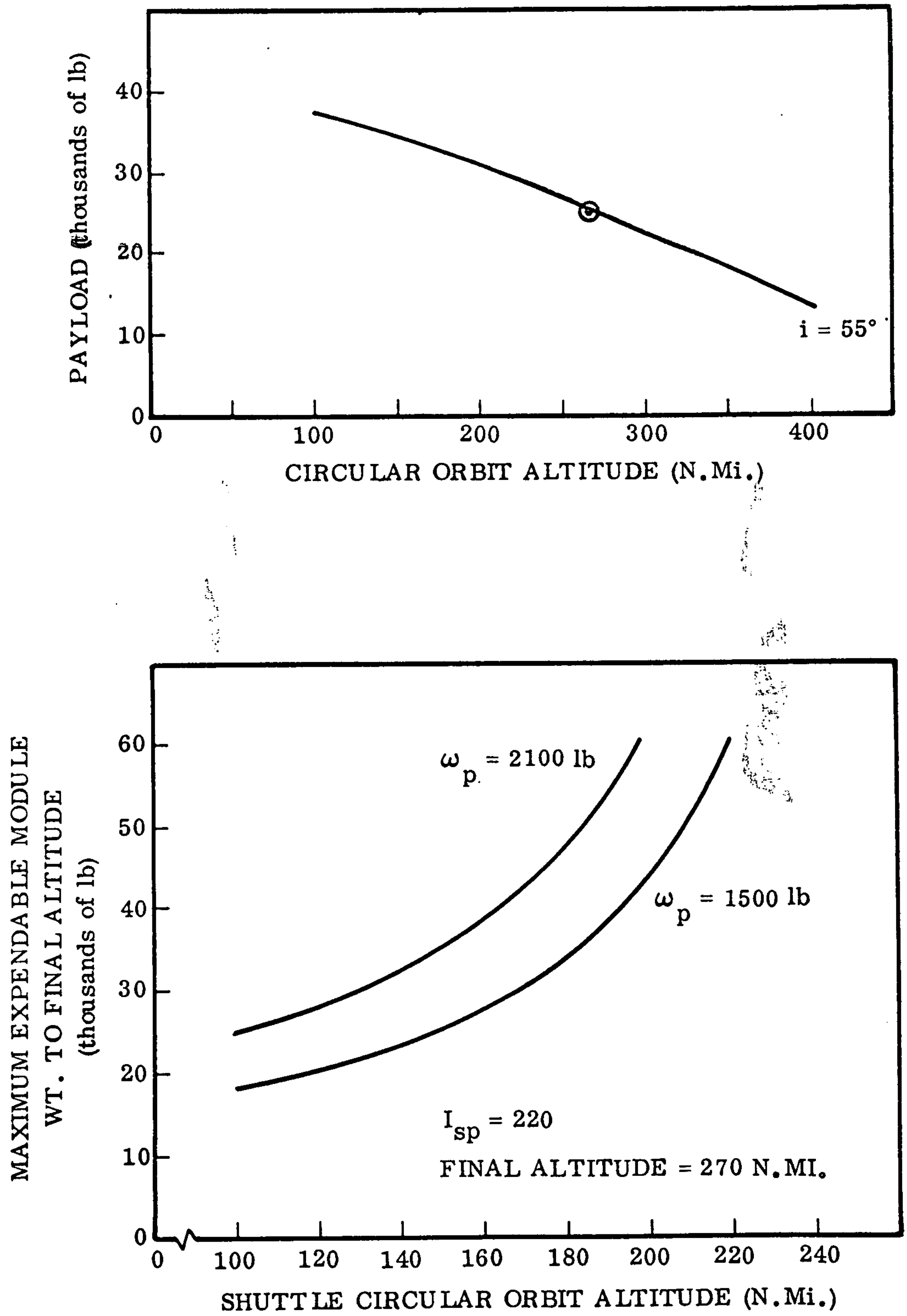


Figure 3-8. Payload Capability, 25k Space Shuttle

total module weight, if installed on the ground, would exceed all launch vehicle capabilities except the Intermediate 20. Shuttle delivery is assumed to be accomplished by the same means as standard shuttle logistics cargo. Expendable launch vehicle delivery could be accomplished by segmenting the TAD into two 12,000 pound units packaged for delivery by a module in a cargo transport role, or if the detector segment, housing and subsystems weight did not exceed 20,000 pounds, a Tital IIIF vehicle could perform a direct orbital insertion.

The manned centrifuge in the baseline program is delivered as a separate payload. The centrifuge is required to free-fly for expendable launch vehicles and the assumed stand-off shuttle delivery, and dock to the space station. A transporter could accomplish this function, but was not assumed since it may not be available to retrieve the centrifuge from the delivery vehicle. The shuttle would deliver the centrifuge to circular orbit in a similar manner to other payloads, or since the payload is light, an expendable launch vehicle would direct insert the centrifuge into circular orbit at 270 n.mi. The centrifuge would then execute docking maneuvers and be available for checkout and experiment operations.

The fluid physics experiment peculiar tanks are delivered to circular orbit with the shuttle or with expendable launch vehicle. The free-flying module which provides subsystems and the propulsion slice which houses propellant and engines for sustained low-g thrusting will be available from previous FPE 5.20 experimentation. The module and propulsion slice docks to the test tank, extracts it from the shuttle or expendable launch vehicle and returns to the space station for activation checkout and sustained low-g flights. At the conclusion of the 5.20-3 test phase, on-orbit exchange of test tanks is accomplished. Tanks for 5.20-3 are returned via the shuttle. The FPE 5.20-4 tank is delivered and utilized in a manner similar to 5.20-3.

Planning data for shuttle vehicles and for three classes of expendable launch vehicles necessary to support the experiment module program is given in Table 3-5. The Intermediate 20 launch vehicle was considered for experiment module payloads, but payload capability to 270 n.mi. of approximately 100,000 pounds (Reference 3-3) precludes selection for single module delivery. Multiple module delivery within payload cylindrical length constraints of about 60 feet appear feasible, but must be analyzed from a cost and experiment payload availability viewpoint.

As shown in Table 3-5, the Saturn IB launch vehicle provides a payload capability attractive for four modules. An alternate delivery method is feasible using T-IIIF through the addition of a 300 fps ΔV delivery kit to selected heavy weight experiment modules. The module could then be delivered to a 100 n.mi. circular orbit where it would separate from the Titan vehicle. The module RCS would provide the capability to transfer to the desired 270 n.mi. orbit and dock to the space station.

Table 3-5. Launch Vehicle Requirements – Experiment Payloads

Common Module			FPE	Title	Shuttle Requirements 25k Payload	Expendable L/V(3) Requirements		
1	3	4				T-IIIC 20K P/L	T-IIIF 28K P/L	S-IB 34K P/L
x			5.1	X-Ray	1		1	
x			5.2A	Stellar	1			1 (4)
x			5.3A	Solar	1		1	
x			5.5	High Energy	1		1	
	x		5.7/5.2	Plasma Physics	1		1	
	x		5.8	Cosmic Ray	1			1 (4)
Experiment Unique			5.8	Cosmic Ray	1 (E)		2 (E)	
		x	5.9/10/23	Space Biology	1(1)			1 (4)
		x	5.11A	Earth Surveys	1		1	
Experiment Unique			5.13C	Centrifuge	1 (E)	1 (E)		
	x		5.16	Materials Science	1		1	
	x		5.20-1	Fluid Physics	1	1		
x			-2(2)	Fluid Physics	1			1 (4)
Experiment Unique			-3(2)	Fluid Physics	1 (E)	1 (E)		
Experiment Unique			-4(2)	Fluid Physics	1 (E)	1 (E)		
		x	5.22	Components Test	1		1	
	x		5.27	Physics & Chemistry	1		1	
				TOTALS	13 Module 4 (E)	1 Module 3 (E)	8 Module 2 (E)	4 Module

LEGEND:

(E) Indicates experiment unique launch.

NOTES:

(1) Centrifuge is launched in combination with module.

(2) One propulsion slice is included. The same propulsion slice is used for the -2, -3, -4 experiment. The same CM1-1 module is also reused. Experiments are exchanged on-orbit.

(3) Based on extrapolated L/V performance data in References 3-1.1 and 3-1.2

(4) Alternate launch vehicle is TIIIF to interim altitude with module providing Δ V to final altitude.

3.1.5 DISPOSAL/RECOVERY OPERATIONS. Equipment to be returned to earth includes complete experiment modules as well as module components, experiment equipment, hard data and specimens. The requirements for equipment, data, etc., return logistics are similar to up logistics and are discussed in Section 4.2. Methods of return include the space shuttle as well as manned or unmanned re-entry vehicles such as Apollo or data capsules. Return cargo such as glass film plates or experiment specimens are packaged for the entry environment and secured in the return logistics vehicle. Special equipment such as packaging, acceleration monitoring or life support equipment, will be provided as experiment unique. An example of special requirements is the space biology discipline, which requires return of frozen or perhaps live specimens for subsequent analysis.

Module structure is ground ruled for a 10-year life and for compatibility with return to earth via the shuttle. The module recovery function sets design requirements on the experiment module which include retractable protuberances such as solar panels and bar magnets. The shuttle de-orbit or landing profile could also establish requirements for special recovery equipment such as for the FPE 5.2A Stellar Telescope.

In the event that the shuttle is not available or in an emergency situation, module RCS can be used for disposal. With one propellant tank not used, 415 fps ΔV would be available for de-orbit maneuvers. A landing footprint within an arbitrary 3,000 n.mi. × 2,500 n.mi. ocean disposal area could be achieved. A cursory examination of experiment and module equipment which might present special re-entry disposal problems is shown in Table 3-6. However, further analysis is required to determine if module design criteria are affected by disposal operations.

Table 3-6. Equipment Presenting Potential Disposal Problems

ITEM	QUANTITY/ MODULE *	SIZE	UNIT WT. (LBS)
Mirror (Fused Silica)	1	10 ft. dia.	4,000
CMG Rotor	2	20 in. dia.	40
Inertia Wheel	3	20 in. dia.	55
Bar Magnet	10	8 ft. long	80
Thruster & Catalyst	32	—	15
Furnace	1	4 ft. dia.	1,000
Total Absorption Detector	1	40 in. × 40 in. × 80 in.	24,000

*All items are not carried by single module.

3.2 ON-ORBIT OPERATIONS

Experiment modules are based at the space station in the baseline experiment module program. Attached modules are permanently docked to the space station, and free-flying modules periodically return to the space station for servicing. Atmospheric drag and orbital mechanics influences on module on-orbit performance requirements are analyzed in this section, and candidate schemes for accomplishing the necessary on-orbit operations are discussed.

Module on-orbit operating criteria are established by analysis of:

a. On-orbit functional requirements and the assignment of these requirements to the module, to the space station, or to other system elements.

b. Performance requirements and stationkeeping schemes for deploying and maintaining free-flying modules operating in the near vicinity of the space station.

c. Performance requirements for growth missions to higher orbits.

d. Performance requirements and operation schemes for experiments requiring sustained low g levels over extended periods (i.e., FPE 5.20 Fluid Physics).

Free-flying modules are deployed in the space station orbit (circular at 270 n.mi. altitude at an inclination of 55 degrees) in the baseline experiment module program. Baseline module designs have integral propulsion systems for accomplishing on-orbit operations. However, an analysis of auxiliary spacecraft or transporters (i.e., space tug vehicles) to provide module on-orbit propulsion is presented in this section.

3.2.1 MODULE FUNCTIONAL REQUIREMENTS. Experiment and mission requirements and study ground rules were analyzed to determine: (1) operating functions and requirements, and (2) to allocate functions and requirements to either the experiment modules or to other program elements.

Operating functions and requirements were allocated to the following elements of the experiment module program:

a. Experiments/experiment modules

b. Space station

c. Launch vehicle

d. Ground support

Table 3-7. Baseline Operational Requirements Allocation

Operation	Operational Requirement Allocation			
	Experiment Module	Space Station	Launch Vehicle	Ground Support
Boost	TM status	Receive booster position update. prepare to take over control of module.	Provide guidance & navigation, propulsion & TM status.	Track booster position and relay to space station, receive booster and module TM.
Launch Vehicle/Experimental Module Separation & Experimental Module Coast	Provide attitude control. TM status.	Take over module control. receive module TM, track module and activate module subsystems.	Release module. separate module from booster. retro or return booster.	Track booster, back up reception of module TM.
Orbit Circularization (As Required)	Provide attitude and thrust vector control and propulsion for ΔV, TM status.	Provide command and control & guidance and navigation to the module. receive TM. track module.	—	Track booster.
Rendezvous & Docking for stand-off shuttle docking. and for expendable launch vehicle case. (See Section 3.2.6.)	Provide attitude and thrust vector control and propulsion for ΔV. TM status.	Generate range and range rate and module tracking data. provide command & control and guidance & navigation to module receive module TM.	—	—
Module Relocation at Space Station	Same as above.	Same as above.	—	—
Attached Module Experiment	Send experiment data to space station.	Provide stability control. receive experiment data.	—	—
Free Flight (deployment, experimentation, station-keeping and return)	Provide stability. attitude and thrust vector control and propulsion for ΔV. TM experiment data and module status.	Track module, provide command and control and guidance & navigation to module receive TM from module.	—	—

PRECEDING PAGE BLANK NOT FILMED

30-day intervals. The module is returned to the space station at nominal 60-day intervals for servicing, and is initially docked at the space station. Velocity requirements over the 60-day servicing cycle are then:

Mission Phase	ΔV (fps)
Undock	10
Deployment	15
Stationkeeping (4 times)	4
Return	15
Dock	20
Total	64 fps

3.2.2 ORBIT MAINTENANCE AND STATIONKEEPING. A body in low earth orbit experiences orbit decay due to aerodynamic drag. This drag is a function of atmospheric density and the ballistic coefficient of the body. A body experiencing drag follows a path of lower radius and higher angular velocity relative to a drag-free body, and will soon pass and precede the drag-free body in orbit. Stationkeeping (or orbit maintenance) consists then of applying a ΔV to the drag body to execute a Hohmann transfer to its original, or higher, orbit and circularizes at the new altitude as shown in Figure 3-10. Three basic stationkeeping methods are shown:

a. Transferring to an orbit sufficiently high to cause the module to encircle the space station by passing behind and below the station.

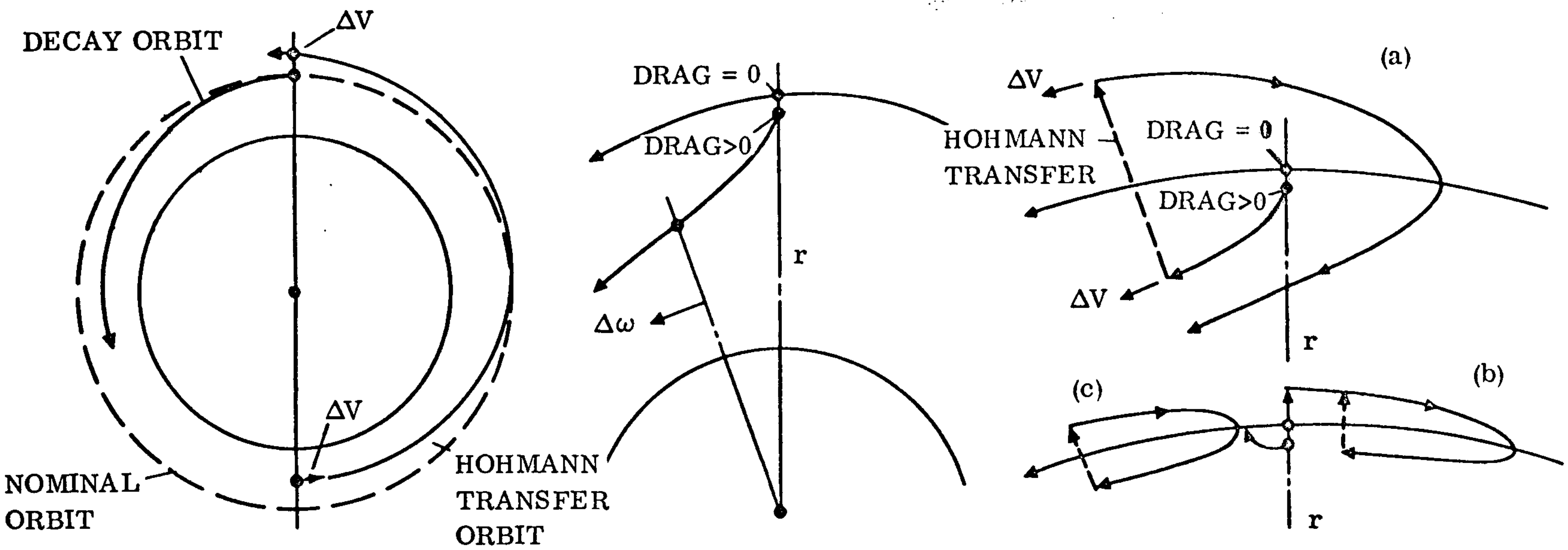
b. Conducting stationkeeping behind the station by boosting the module to a higher altitude behind the station.

c. Conducting stationkeeping ahead of the station by transferring the module ahead of the station position where its orbit will decay and increase the module to space station range.

In each case, the average altitude of the decay transfer loop is the same as that of the station and the module orbit during the decay is approximately a parabola relative to the drag-free space station; ΔV requirements are about equal. The length of the parabolic loop is limited by range capability of the communications systems.

3.2.2.1 Selection of Stationkeeping Method. Encircling the station provides the longest periods between ΔV for a given communications distance, but presents the station and other modules as potential occulting bodies to astronomy modules. Stationkeeping behind or in front of the station appear to be about equal, except for potential contamination, which appears to be least in front of the station.

PRECEDING PAGE BLANK NOT FILMED



ORBIT DECAY DUE TO AERO DRAG

RELATIVE MOTION OF DECAY WITH DRAG

STATIONKEEPING METHODS
a. Encircle Station
b. Behind Station
c. Ahead of Station

Figure 3-10. Orbital Motion and Stationkeeping

For the baseline experiment module program, all free-flying modules are maintained in proximity to the space station. Selection of the stationkeeping method for astronomy modules then considers factors which are primarily experiment oriented:

a. The module flight path should avoid occultation by the space station or by other modules.

b. Observation times should be maximized. ΔV applications for stationkeeping disrupt observations due to the need to (1) orient the telescopes with the thrust axis, (2) accomplish the orbit transfer, (3) reorient the module, and (4) reacquire the target.

c. Contamination in the vicinity of the space station will result when light-scattering particles are in the telescope viewing column. These particles may degrade experiment observations. Astronomy modules should also be kept away from areas where the optical surfaces could be exposed to RCS exhausts from the station, from modules or from logistic craft approaching the station.

Module designs are not particularly sensitive to which of the three stationkeeping methods are used. Selection of the method has therefore been based primarily on experiment or operations considerations. It is subject to review when a more complete definition of total space station operations (tracking, navigation, traffic control, communications, etc.) is available.

The selected method for stationkeeping astronomy modules maintains the modules in a loop which precedes the space station in orbit. This method reduces potential for: (1) occulting by the station, and (2) for viewing degradation due to contaminants which might exist in a trail behind the station.

Stationkeeping scheme is shown in Figure 3-11. The vertical scale is greatly exaggerated. Loop dimensions for a typical module ($\beta \cong 16$) during a period of average atmospheric density are about 500 by 1 n.mi. The limiting factor in this range selection is the communication range created by extended intervals between orbit maintenance operations. For the average module ballistic coefficient and average atmospheric density, orbit maintenance operations conducted in 30-day cycles will result in less than 1% lost observation time. This 30-day cycle will result in a communication range from module to station of about 500 n.mi., which requires five watts transmitted power for the baseline data rates. These parameters have been selected for module baseline design.

Detached laboratory modules are operated in a similar manner in the vicinity of the station within boundaries of traffic control, distance from astronomy modules, and communications range.

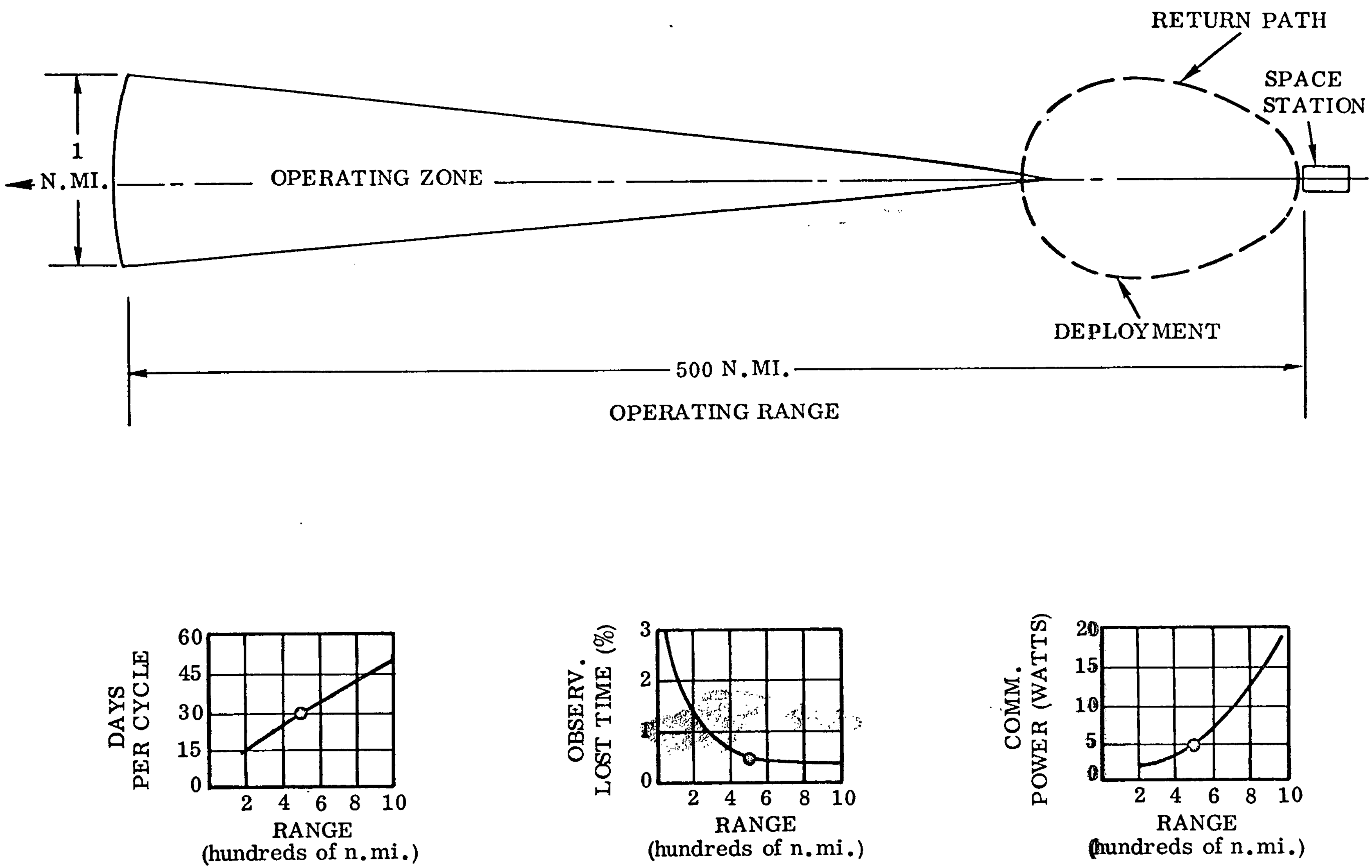


Figure 3-11. Detached Module Operating Range

3.2.2.2 Stationkeeping Performance Requirements

a. Module Drag Offset.

Module performance required to offset drag is dependent on the density of the atmosphere and the module ballistic coefficient. Perhaps the simplest useful model atmosphere is a spherically symmetric air mass having an exponential density variation with altitude and rotating as if rigidly attached to the earth. The nominal density at a given altitude is a strong function of solar activity which varies on a solar cycle with a period of about 11 years. Perturbations in density include a strong diurnal bulge effect due to daily solar heating, and smaller perturbations due to many lesser effects.

Several popular model atmosphere density curves are shown in Figure 3-12 for reference. The COSPAR International Reference Atmosphere for 1965 (CIRA '65) is a reference atmosphere which is given in ten different models; Model 1 is typical of a very low level of solar activity, Model 5 of a moderate level, and Model 10 of a very high level of solar activity. The CIRA '65 Model 5 atmosphere was used in the calculations presented in this section. This model gives average maximum expected values of atmospheric drag which correspond to the actual values for early 1969 and as expected for 1980.

Density values derived from NASA Model Atmosphere are also shown in Figure 3-12 (Reference 3-2.1). These values are given for four different conditions, i.e., nominal, $+2\sigma$, geomagnetic storm, and severe geomagnetic storm. Predicted worst-case values for the years 1975 and 1980 are shown. It is apparent that the CIRA '65 Model 10 atmosphere is representative of the worst cases to be expected in 1980.

Module ballistic coefficient (β) is defined as $\beta = \frac{W}{C_D A}$ where W is the vehicle weight in lb, C_D is the dimensionless drag coefficient, and A is the reference area in ft^2. In the β system the drag equation becomes

$$\frac{D}{m} = \frac{1}{2} \rho V^2 \frac{C_D A}{m} = \frac{g}{2} \frac{C_D A}{W} \rho V^2 = \frac{g}{2\beta} \rho V^2$$

so that drag deceleration $\left(\frac{D}{m}\right)$ is inversely proportional to β.

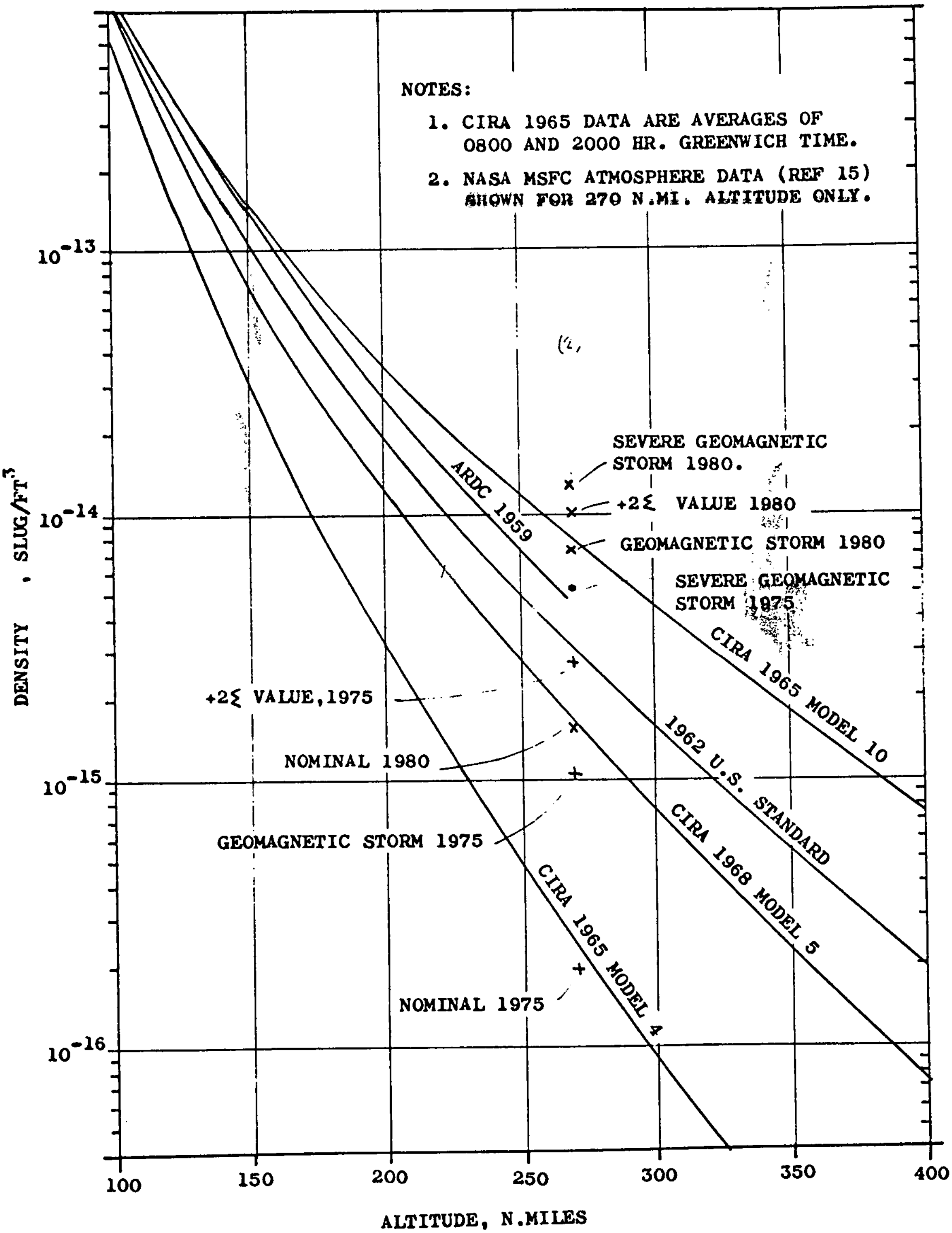


Figure 3-12. Atmospheric Density Models

Drag deceleration is plotted in Figure 3-13 versus orbital altitude for a $\beta = 16.1\ lb/ft^2$. Drag deceleration for β values other than 16.1 are computed from:

$$\frac{D}{m} = \left(\frac{D}{m}\right)_{\beta = 16.1} \left(\frac{16.1}{\beta}\right)$$

where $\left(\frac{D}{m}\right)_{\beta = 16.1}$ is the drag deceleration from Figure 3-13 and β is the value of the spacecraft ballistic coefficient.

An average ballistic coefficient (arithmetic mean of minimum and maximum values) is typically in the 15 to 20 pounds per sq. ft. range for the astronomy modules. At space station altitudes, approximately 0.33 fps ΔV per day is required for years of highest atmospheric density (CIRA Model 10), about 0.1 fps for mean density (CIRA Model 5) and about 0.002 fps for least density (CIRA Model 1) as shown in Figure 3-14. The propellant requirement is about 3 to 4 pounds per fps ΔV for these modules (at an I_{sp} = 220 sec.). About 1 pound is used per day for the worst case at space station altitudes. Experiment modules maintain stationkeeping orbits using RCS thrusters integral to the module.

Stationkeeping ΔV requirements diminish rapidly with increasing altitude. However. for modules required to operate higher than the station but below altitudes of about 350 to 400 n.mi., the effect of altitude decay should be investigated to determine the maximum on-orbit stay time and the effect on relative orbital precession rates.

Module altitude loss or sink rate is shown in Figure 3-15 for the case where no stationkeeping ΔV is applied. Approximate module sink rates for other ballistic coefficient values can be calculated for typical experiment module conditions using the following equation:

$$\frac{\Delta r}{t} = \frac{2\ D/m}{\omega}$$

where Δr = altitude change

t = time

D/m = drag deceleration

ω = orbital rate

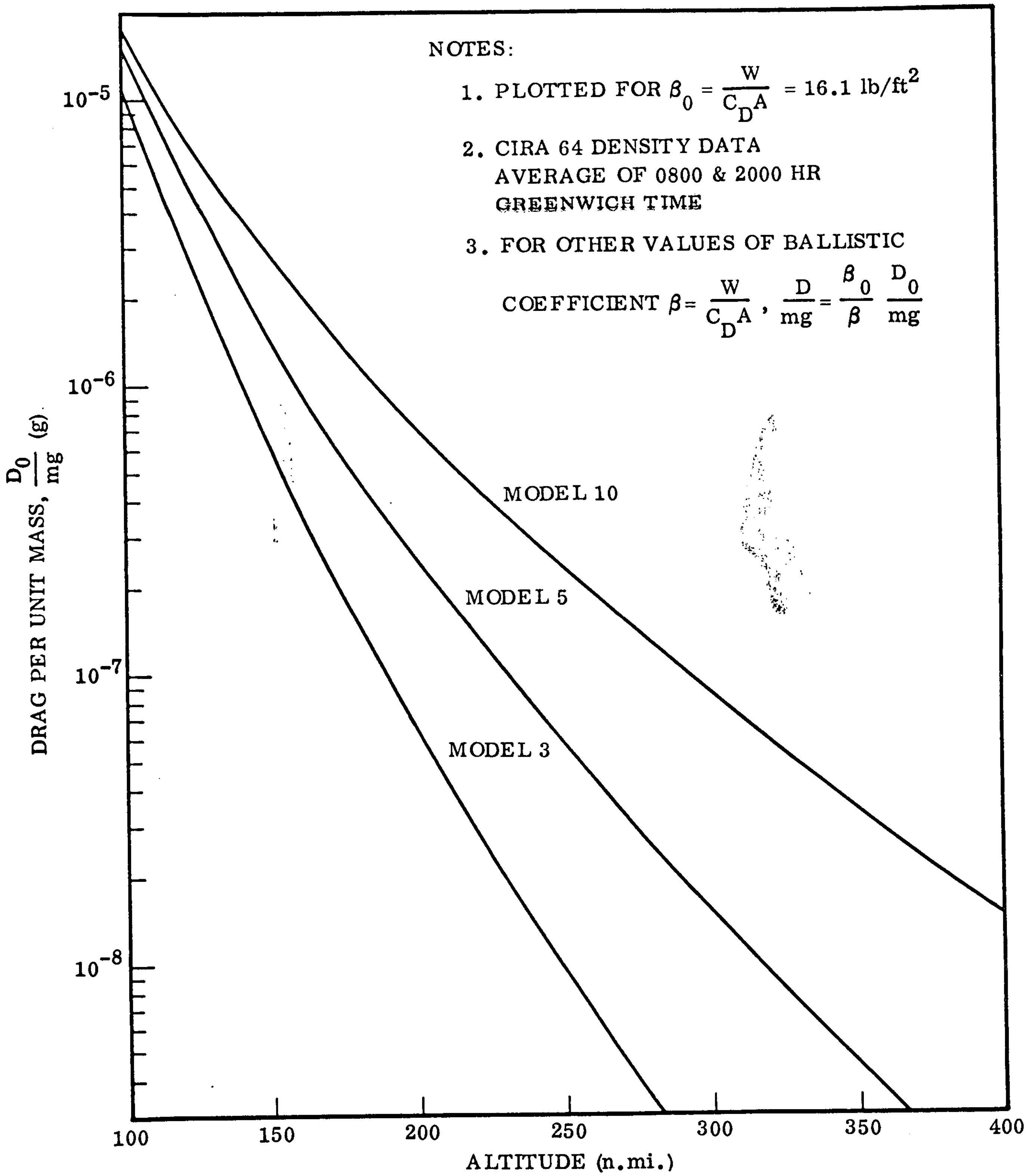


Figure 3-13. Aerodynamic Drag Acceleration

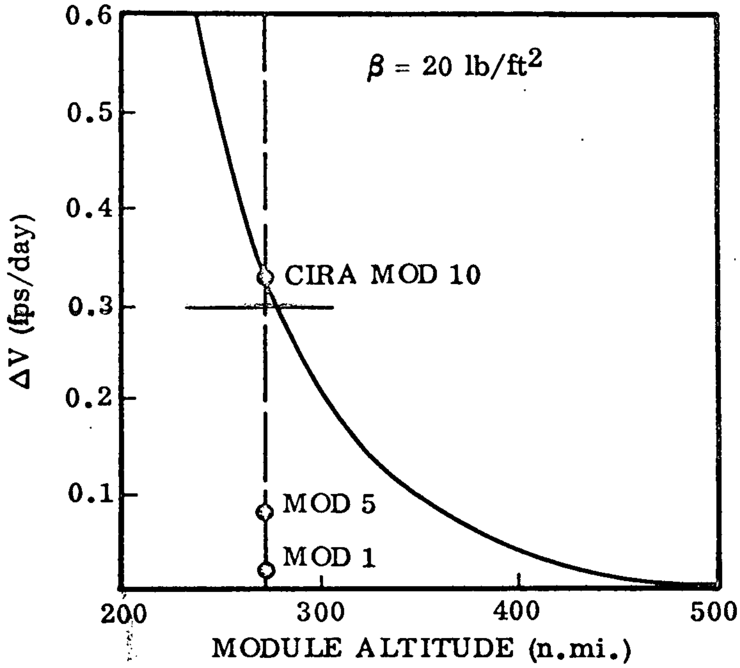


Figure 3-14. Stationkeeping Velocity Requirements

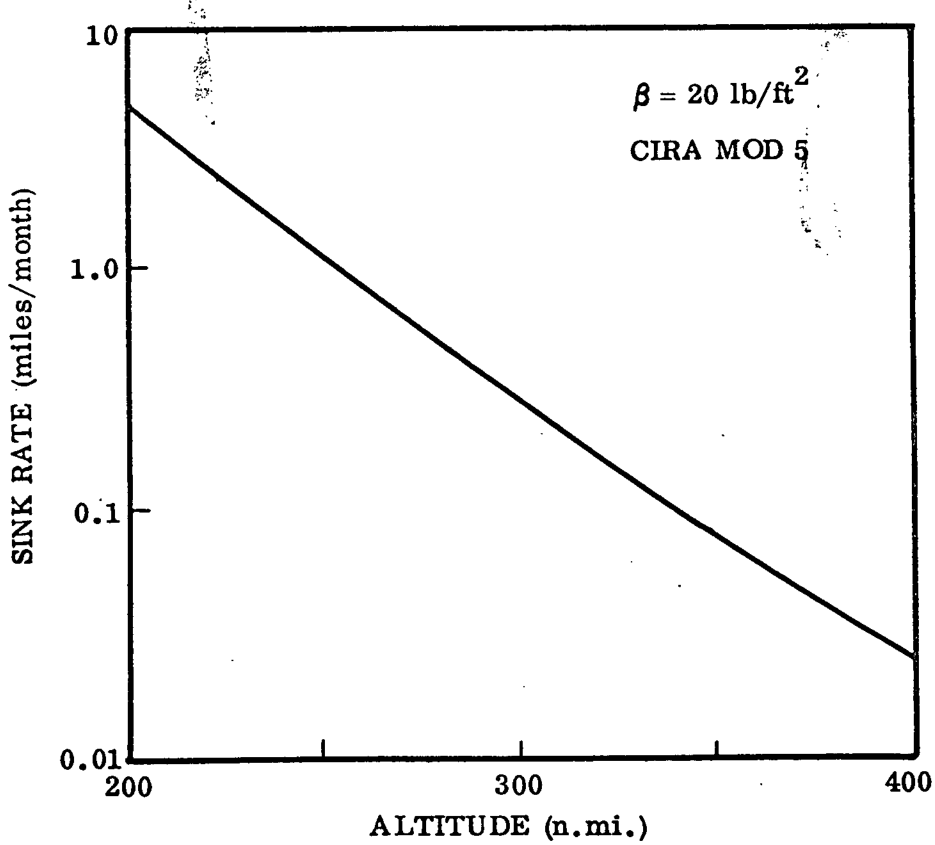


Figure 3-15. Module Sink Rate

Separation (ΔS) between an experiment module and the drag-free space station is approximated with the following equation.

$$\Delta S = \frac{3}{2} \frac{D}{m} t^2$$

Both of these equations are the first, and most significant, terms of a series of terms (see Reference 3-2.2 for the full equations). They are reasonable approximations of the true values for normal experiment module β values, baseline orbital altitudes and permissible experiment module/space station separations.

The velocity increment to execute the stationkeeping Hohmann transfer is:

$$\Delta V_{sk} \cong 0.55 \times 10^{-3} \; \Delta r$$

Substituting the equation for Δr and Δs and the drag deceleration inverse relationship with β results in the equation for the stationkeeping velocity increment as a function of β and the length of the stationkeeping orbit. (Note that the length of the stationkeeping orbit, ΔS, is traversed twice as the module follows a parabolic path relative to the space station.)

$$\Delta V_{sk} = 37.2 \sqrt{\frac{\Delta S}{\beta} \left(\frac{D}{m}\right)_{\beta = 16.1}}$$

where

ΔV_{sk} = the stationkeeping velocity increment (both perigee and apogee velocity increments) in ft/sec

ΔS = length of stationkeeping orbit in ft

β = experiment module ballistic coefficient in lb/ft^2

$\left(\frac{D}{m}\right)_{\beta = 16.1}$ = drag deceleration (from Figure 3-10) in g

b. Stationkeeping Cycles

Stationkeeping is accomplished by an application of the Hohmann transfer ΔV to recover the lost module altitude, and thereby keep the module within close proximity of the space station. Typical astronomy module ΔV requirements are summarized in Table 3-8. Module ballistic coefficients (β) are the arithmetic mean of module minimum and maximum β values. The number of days between service cycles (60 or 30 days) is established by the planned experiment servicing

Table 3-8. Typical Astronomy Module Service Cycle ΔV Requirements

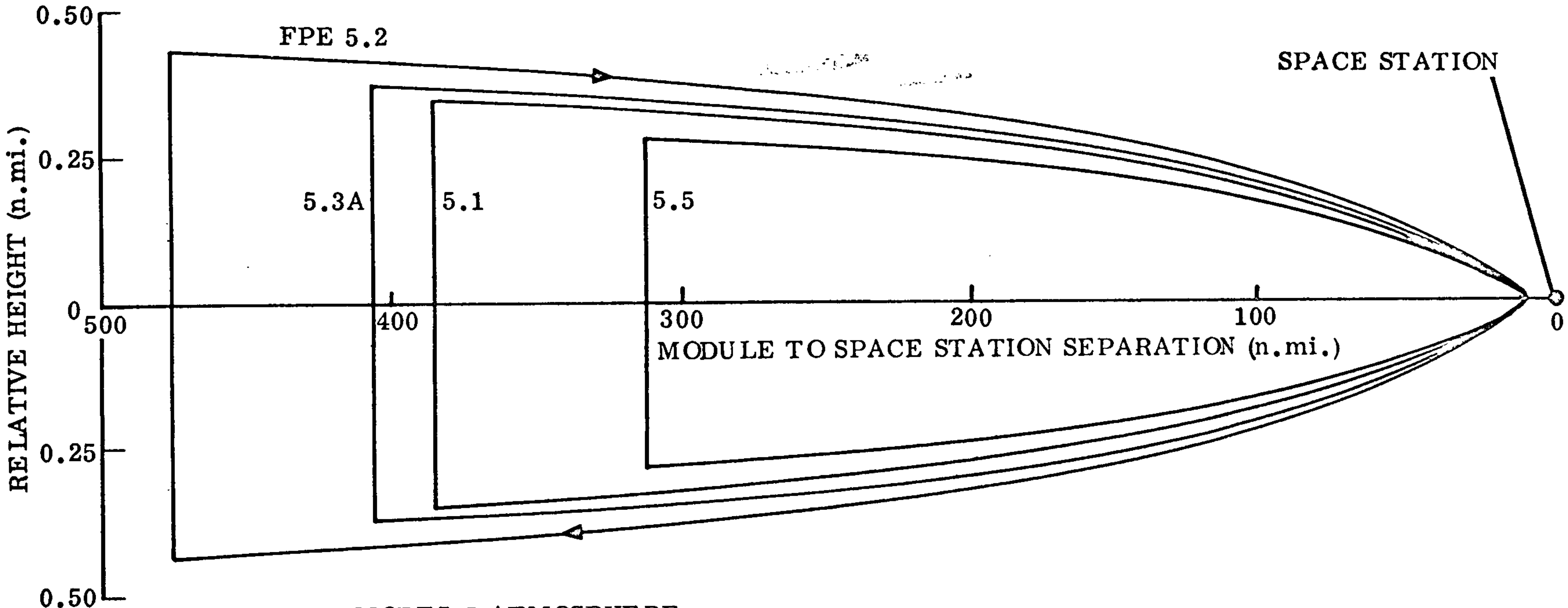
PARAMETER	FPE 5.1 X-RAY	5.2 STELLAR	5.3A SOLAR	5.5 HIGH ENERGY
Experiment Module β (lb/ft^2)	20	16	19	25
Number of Days Per Service Cycle	60	60	30	60
Maximum Number of Days Per Stationkeeping Cycle	35	31.4	34.2	39.2
Number of Stationkeeping Cycles Per Service Cycle	2	2	2	2
ΔV Per Stationkeeping Cycle (fps)	2.2	2.8	2.4	1.8
Undocking ΔV	10.0 fps	10.0 fps	10.0 fps	10.0 fps
Deployment ΔV	8.6	8.6	8.6	8.6
Out-of-Plane ΔV	6.0	6.0	6.0	6.0
Stationkeeping ΔV Per Service Cycle	4.4	5.6	2.4	3.6
Return ΔV	8.6	8.6	8.6	8.6
Out-of-Plane ΔV	6.0	6.0	6.0	6.0
Docking ΔV	20.0	20.0	20.0	20.0
Total ΔV Per Service Cycle	63.6 fps	64.8 fps	61.6 fps	62.8 fps

and adjustment schedule. Maximum stationkeeping cycle periods vary from 31.4 days (FPE 5.2 - Stellar) to 39.2 days (FPE 5.5 - High Energy) where the range from the space station to the experiment module is limited to 500 n.mi. and the apex of the stationkeeping orbit is 10 n.mi. ahead of the space station. An average (CIRA Model 5) atmosphere was used to calculate the stationkeeping cycle. Space station to module ranges will typically be less than 500 n.mi. to force the stationkeeping cycle period to be an even sub-multiple of the servicing cycle. Either one or two stationkeeping cycles are accomplished during each servicing cycle for these modules. Stationkeeping orbits for these free-flying astronomy modules are sketched in Figure 3-16. Note that the vertical scale is greatly expanded. The Hohmann transfer ΔV to maintain the stationkeeping orbit varies from 1.8 to 2.8 fps per stationkeeping cycle.

Typical velocity increment requirements per service cycle are tabulated in the lower portion of Table 3-8. A ΔV allowance of 10 fps is assigned for undocking of the experiment module from the space station. The scheme for deploying the modules to the apex of the parabolic stationkeeping orbit 10 n.mi. ahead of the space station is shown in Figure 3-17. Following undocking, a velocity increment opposing the module velocity is applying causing the module to enter an elliptic orbit with a shorter period. Once each orbit the module returns to the apogee of its orbit which corresponds to the space station circular orbit altitude. When a velocity increment equal but opposite in direction to the original ΔV is applied at the apogee, the module re-enters the original orbit; but now the experiment module is deployed ahead of the space station as a result of the difference in orbital rates. Two ΔV applications of 4.3 fps each (for a total of 8.6 fps) are necessary to separate the module and the space station by 10 n.mi. after one orbital period.

The out-of-plane ΔV is applied with the deployment ΔV (and again on return) to displace the module orbit relative to the space station orbit and reduce module-to-module occulation. Modules are also separated laterally as well as in the orbital plane by this scheme to ease the traffic control problem. Stationkeeping ΔV per service cycle is the product of the number of stationkeeping cycles per service cycle and the ΔV per stationkeeping cycle. Module return is the reverse of the deployment maneuver, and an out-of-plane ΔV equal but in the opposite direction to that applied during deployment is applied with the return ΔV to bring the module orbit back to that of the space station. A ΔV of 20 fps is allowed for the docking maneuver. The total ΔV per service cycle varies from 61.6 fps for FPE 5.3A Solar to 64.8 fps for FPE 5.2 Stellar.

Module accelerations experienced during applications of stationkeeping velocity increments are 10^{-3}g or lower. This is within the limits of the solar panels in the extended position. Solar panels are not retracted for stationkeeping ΔV applications.



- MODEL 5 ATMOSPHERE
- 30-DAY STATIONKEEPING CYCLE

Figure 3-16. Astronomy Module Stationkeeping Orbits

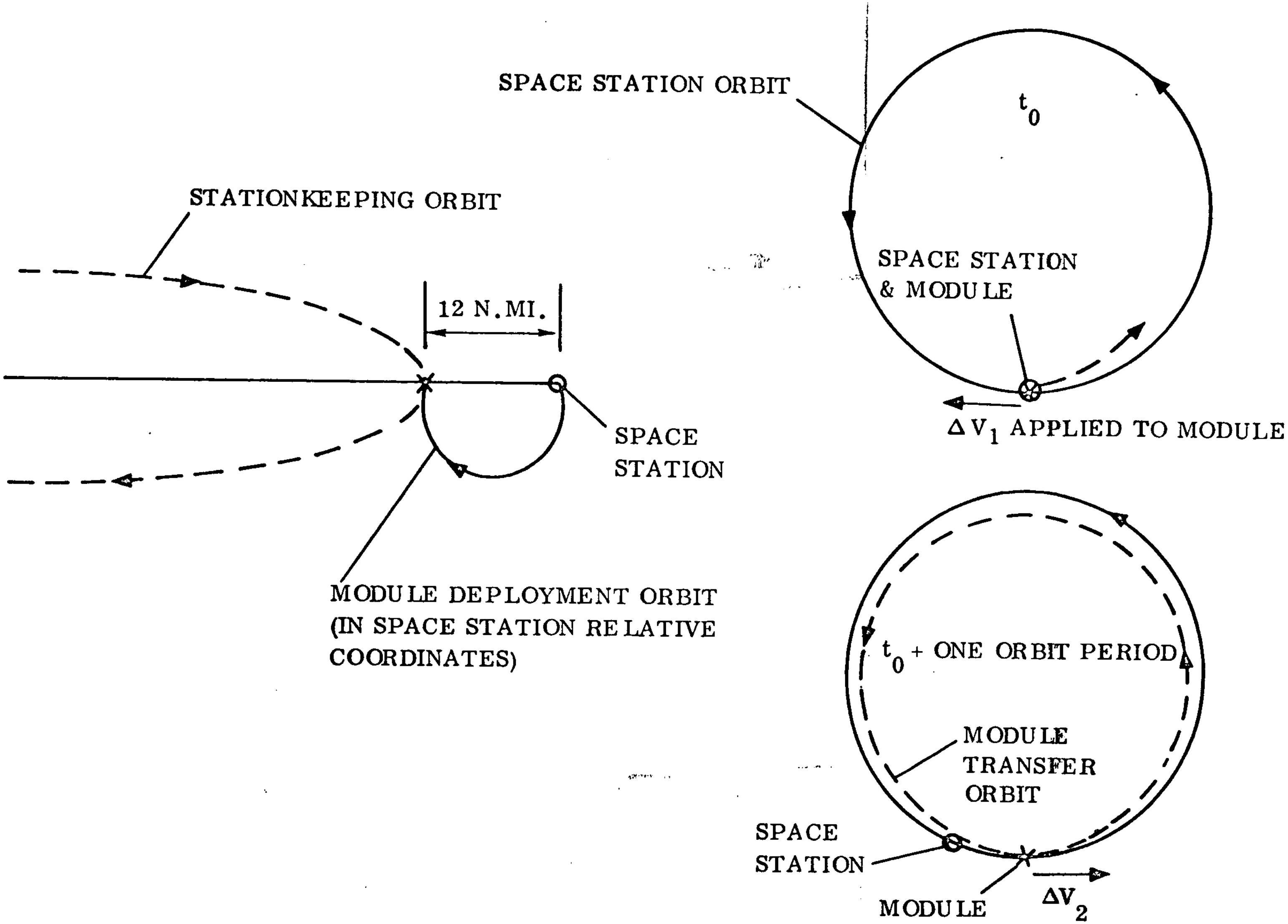


Figure 3-17. Deployment of Free-Flying Modules to Stationkeeping Orbits

The amount of time lost to observations as a result of stationkeeping maneuvers is a direct function of the frequency at which stationkeeping ΔV must be applied. It therefore is very desirable to maximize the interval between stationkeeping ΔV applications. The frequency of stationkeeping ΔV applications is determined by the allowable module to space station distance. Communication system capability is the primary limiting factor. For the module baseline communication system limits of 500 n.mi. the stationkeeping cycle time will vary from about 16 days to 96 days for a module $\beta = 20$ lb/ft^2 at the extreme atmospheric conditions (atmosphere Models 1 and 10 of Figure 3-10). The average stationkeeping cycle time (Model 5 atmosphere) is 35.2 days.

When the possible variations in module β are considered, stationkeeping cycle time variations are considerably greater since β values can vary by about 10 to 1 depending upon the orientation of the experiment module cylinder section and the orientation of the solar panels to the relative wind.

Stationkeeping cycle time is a strong function of allowable space station to module range. This relationship is plotted in Figure 3-18. Cycle time under average atmospheric conditions (Model 5 atmosphere) is reduced from about 35 to 15 days when the stationkeeping orbit is reduced from 500 to 100 n.mi.

Losses in experiment observation time are about four hours for the worst case stationkeeping cycle for module orientation, thrusting, orbital transfer, re-acquisition of the observation target, stabilization of sensors and initiation of observation. Total available observation time per stationkeeping cycle is about 99.5% for the 500 n.mi. range case (cycle time of 35 days) and 98.9% at 100 n.mi. range (cycle time of 15 days).

3.2.3 ON-ORBIT TRANSPORTATION. Experiment modules must be either self-propelled or be transported while on-orbit to:

a. Deliver the module from the launch vehicle to the space station.

b. Relocate experiment modules from one space station docking port to another.

c. Deliver modules to free-flight orbits and return modules to the space station.

d. Provide station keeping velocity increments for maintenance of free-flight orbits.

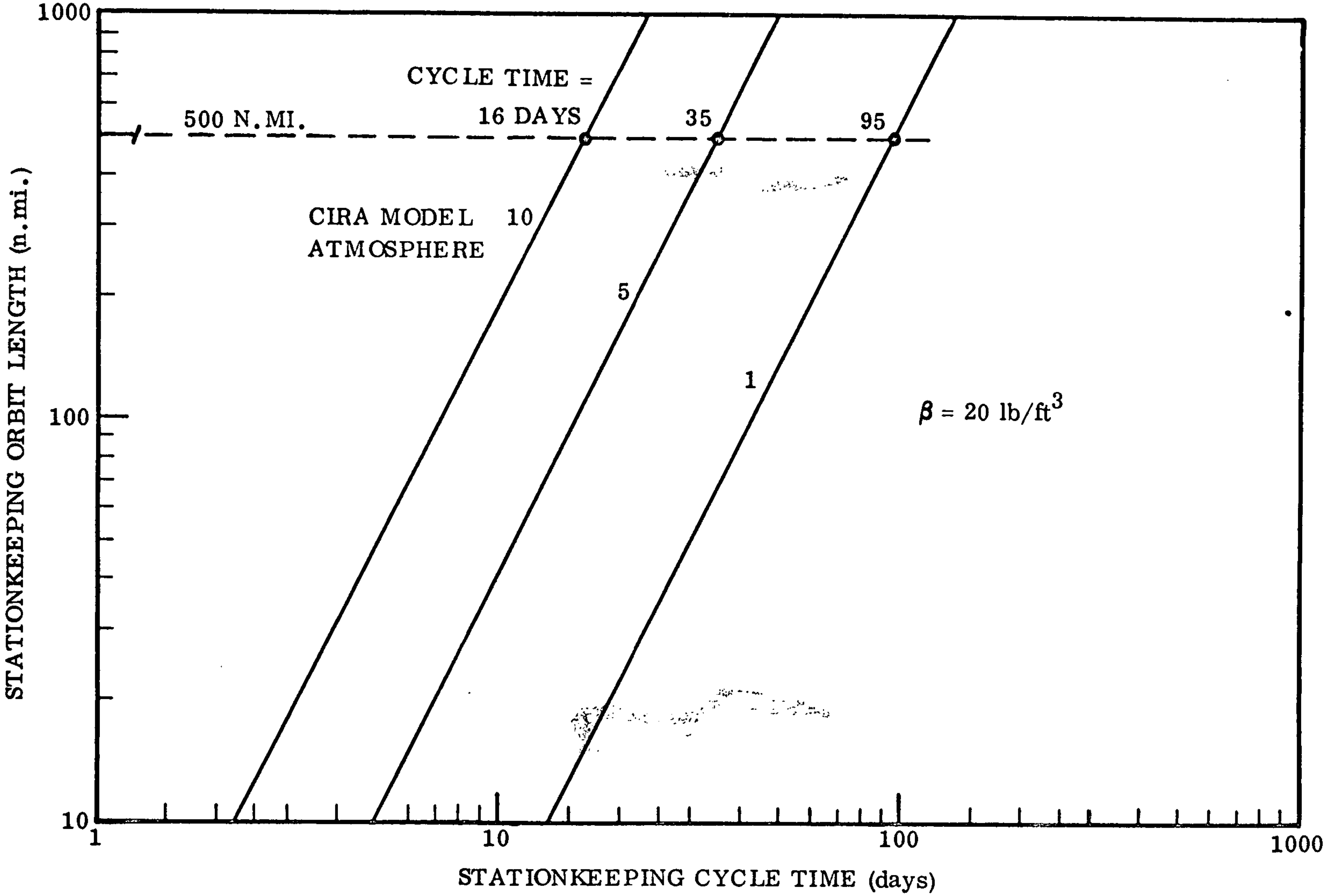


Figure 3-18. Stationkeeping Cycle Time

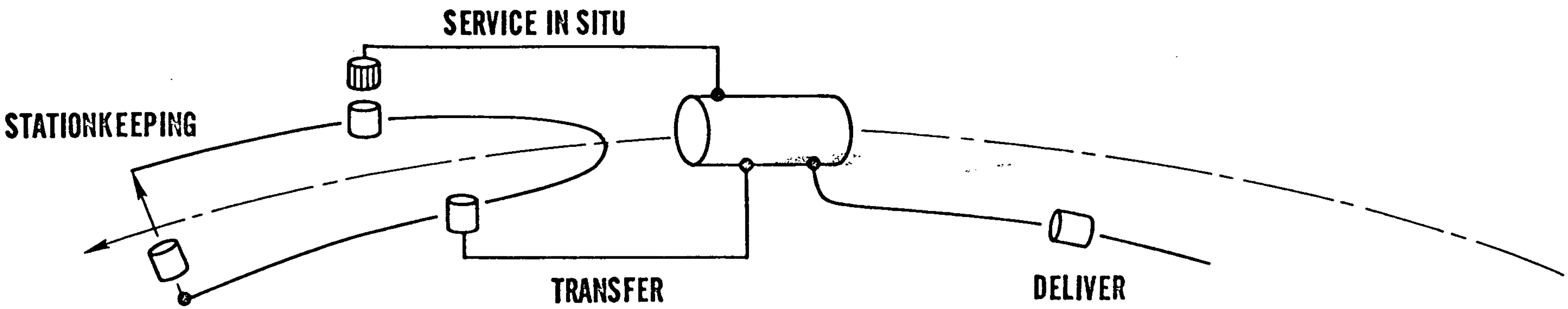
Experiment module baseline designs have propulsive capability integral to the modules. To evaluate the effectiveness of these designs, modules with integral propulsion were compared with modules with no, or limited, propulsive capability.

The modules with reduced propulsion capability require auxiliary vehicles (i.e., space tug type spacecraft or transporters) for on-orbit module transportation. Transportation concepts (integral module propulsion and transporters) comparisons were accomplished on the basis of cost, experiment growth potential, impact on space station, funding, flexibility and technical risk, and study results are presented in this section.

3.2.3.1 Summary of Results. Both manned and unmanned transporters with storable and cryogenic propulsion systems were evaluated. A CM-1 common module was used as a transporter with a storable (N_2H_4) propulsion system. The manned version of this transporter requires additional life support equipment. The cryogenic (LO_2 & LH_2) transporter was patterned after a growth version of Centaur. Manned capability was added by incorporating a CM-1 module as a crew compartment. These transporters were selected because: (1) they are representative of the types of transporters which may be developed, and (2) are vehicles which could be developed at the minimum additional cost. CM-1 transporter development costs are largely accounted for when the CM-1 module is developed for the experiment program, and the cryogenic transporter development costs are less since the transporter is an evolution of the existing Centaur vehicle.

A cost comparison of the experiment module program with unmanned and manned CM-1 transporters is shown in Table 3-9. Similar cost information for the cryogenic transporter is presented in the text - program costs with a cryogenic transporter are generally higher. Costs are presented as cost increments referenced to the baseline transportation concept of propulsion integral to the experiment modules. Cost increments for the module subsystem development and production are combined under "subsystem deletions"; additional costs for module docking ports are tabulated under "interface hardware"; transporter development and production costs are listed in the adjacent column. Ten year operations' costs include the cost of boosting transporters to orbit and on-orbit propellant costs; in the case of the manned transporter servicing

Table 3-9. Transporter Trade Study



TYPE MODULE	COST ITEM	Δ COST FROM MODULE PROPULSION ($M)	
		MANNED TRANSPORTER	UNMANNED TRANSPORTER
FREE-FLYING	MODULE SUBSYSTEMS	− 11.2	− 11.2
	DOCKING ATTACHMENTS	+ 16.4	+ 16.4
	TRANSPORTER RDT&E, PROD.	+102.0	+ 44.7
	10-YR. OPER (CREW & PROP.)	+ 30.5	+ 61.3
	TOTAL	+137.7	+111.2
ATTACHED	MODULE SUBSYSTEMS	− 76.2	− 76.2
	DOCKING ATTACHMENTS	+ 7.0	+ 7.0
	TRANSPORTER RDT&E & PROD.	+ 88.4	+ 31.1
	10-YR. OPER (CREW & PROP.)	+ 16.5	+ 15.5
	TOTAL	+ 35.7	− 22.6

the free-flying modules, costs associated with in-situ servicing of the modules are also included in the 10-year operations' column.

Experiment modules subsystem costs are decreased by sizable margins; particularly for the attached modules where the reaction control system, stability and control system, guidance and navigation hardware and a portion of the communications equipment are deleted resulting in a $76.2M decrease in subsystem costs. All other cost increments are positive (referenced to the baseline integral propulsion concept) resulting in a net cost increase of $111.2M when an unmanned transporter is used only with the free-flying modules and a net cost decrease of $22.6M when an unmanned transporter is used only with the attached modules. $22.6M is approximately 1% of the total program cost. If an unmanned transporter were used with both the free-flying and attached modules, the program cost increment would be the sum of the two values (+$111.2M & -$22.6M) for a net program cost of $88.2M.

Net program costs are higher when a manned transporter is used with the experiment modules; cost increase by $137.7M with the free-flying modules and $35.7M with the attached modules. The increased net costs largely result from the increase in transporter development and production costs.

Study conclusions for the use of a transporter as part of the experiment module program are:

a. There is no conclusive cost advantage to the use of a transporter for experiment module operations.

b. Transporter use may be advantageous for noncosted factors:

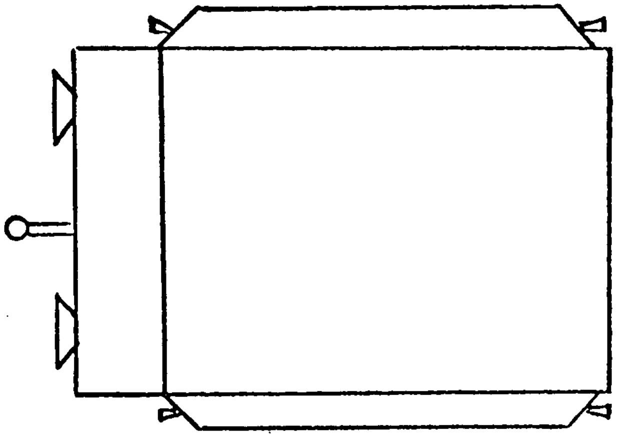
  1. Reduction in contamination through in-situ servicing.

  2. Growth missions to other orbits.

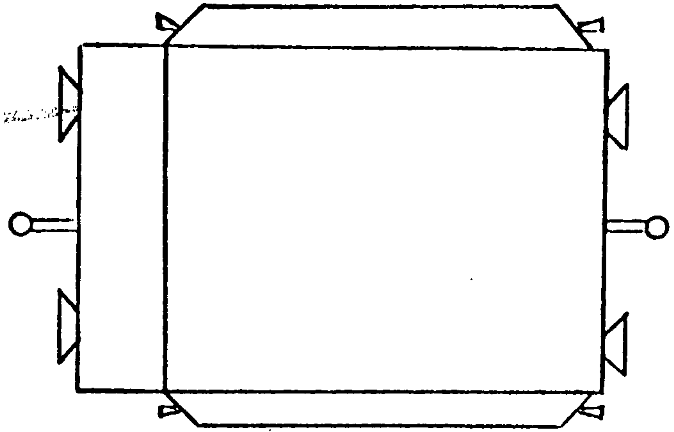
c. Maximum program flexibility is achieved with modules capable of operations' independent of a transporter.

3.2.3.2 Transporter Concepts and Transportation Requirements. The approach followed in this study was to first identify candidate transporter concepts. Next, maneuver and velocity increment requirements were defined. The use of the transporter with free-flying astronomy modules and with attached modules was then evaluated separately. This was followed by evaluation of the candidate transportation concepts for the total experiment module program and the study conclusions and recommendations.

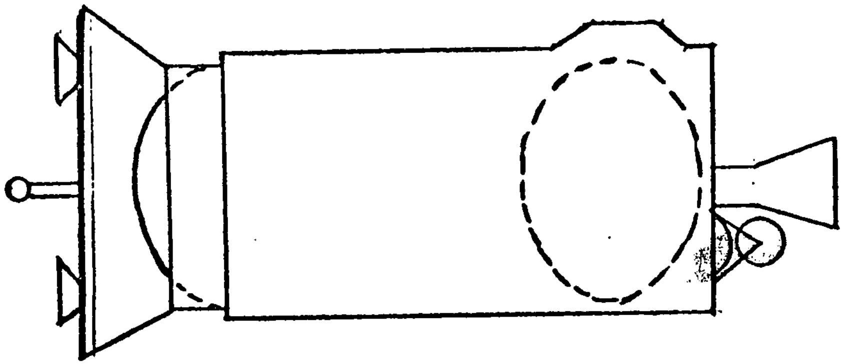
The candidate transportation concepts are sketched in Figure 3-19. Propulsion is integral to the experiment modules in the baseline concept. This is consistent with the current module conceptual designs. Both manned and unmanned versions of



BASELINE — INTEGRAL
PROPULSION



CM-1 TRANSPORTER
(MANNED / UNMANNED)



CRYOGENIC TRANSPORTER
(MANNED / UNMANNED)

Figure 3-19. Transportation Alternatives transporters with storable and cryogenic propulsion systems were evaluated. The transporter with storable propellants is an adaptation of the CM-1 module; additional life support equipment is included in the manned version of this module. Propellant is N_2H_4 with an I_{sp} = 220 sec. This transporter minimizes additional development costs assuming prior funding of the experiment module program. The cryogenic transporter is a growth version of Centaur. Propellants are liquid hydrogen and oxygen with an I_{sp} of 454 sec. In the manned version a CM-1 module is used as the crew compartment.

Transportation requirements for the baseline (propulsion integral to the experiment module) concepts are identified with the aid of Figure 3-20. The shuttle or an expendable booster delivers the experiment module to a 100 × 270 n.mi. orbit. The experiment module then supplies the velocity increment necessary to circularize the orbit at 270 n.mi. altitude. The integral propulsion is also used for the rendezvous and docking with the space station, module relocation at the space station, module deployment to their free-fly orbit, stationkeeping, and to return free-flying experiment modules to the space station. Free-flying modules are deployed at the apex of their free flight parabola which is approximately 12 n.mi. ahead of the space station. Stationkeeping velocity increments are applied to keep the module-to-space station range at 500 n.mi. or less.

An unmanned transporter is used to accomplish the maneuvers sketched in Figure 3-21. The transporter is initially docked at the space station and remains there when not in use. Following delivery of the experiment module to the 100 × 270 n.mi. orbit the unmanned transporter is undocked from the space station and inserted into the experiment module orbit where the transporter docks to the module. The transporter is either controlled from the space station or its maneuvers are pre-programmed except during docking operations which are accomplished with a closed loop automatic control system. The transporter provides the impulse to circularize the experiment module orbit at 270 n.mi. and also provides the impulse for rendezvous and docking with the space station. Experiment modules are relocated at the space station by the transporter and the velocity necessary to deploy and station keep experiment modules are also provided by the unmanned transporter. Experiment module propulsion is only used for attitude control. The transporter is stationed approximately 500 n.mi. ahead of the space station and provides stationkeeping velocity increments to the modules as they approach this position. It remains at this station unless required to return an experiment module to the space station for periodic servicing.

A manned transporter can be used to accomplish a series of maneuvers identical to those previously described for unmanned transporters. However, maintaining the transporter crew in the stationkeeping orbit for extended periods or returning the crew repeatedly to the space station from the stationkeeping orbit would place unnecessary demands upon this transportation concept. A more efficient use of the manned transporter is sketched in Figure 3-22.

BASELINE ON-ORBIT TRANSPORTATION

(PROPULSION INTEGRAL TO MODULES)

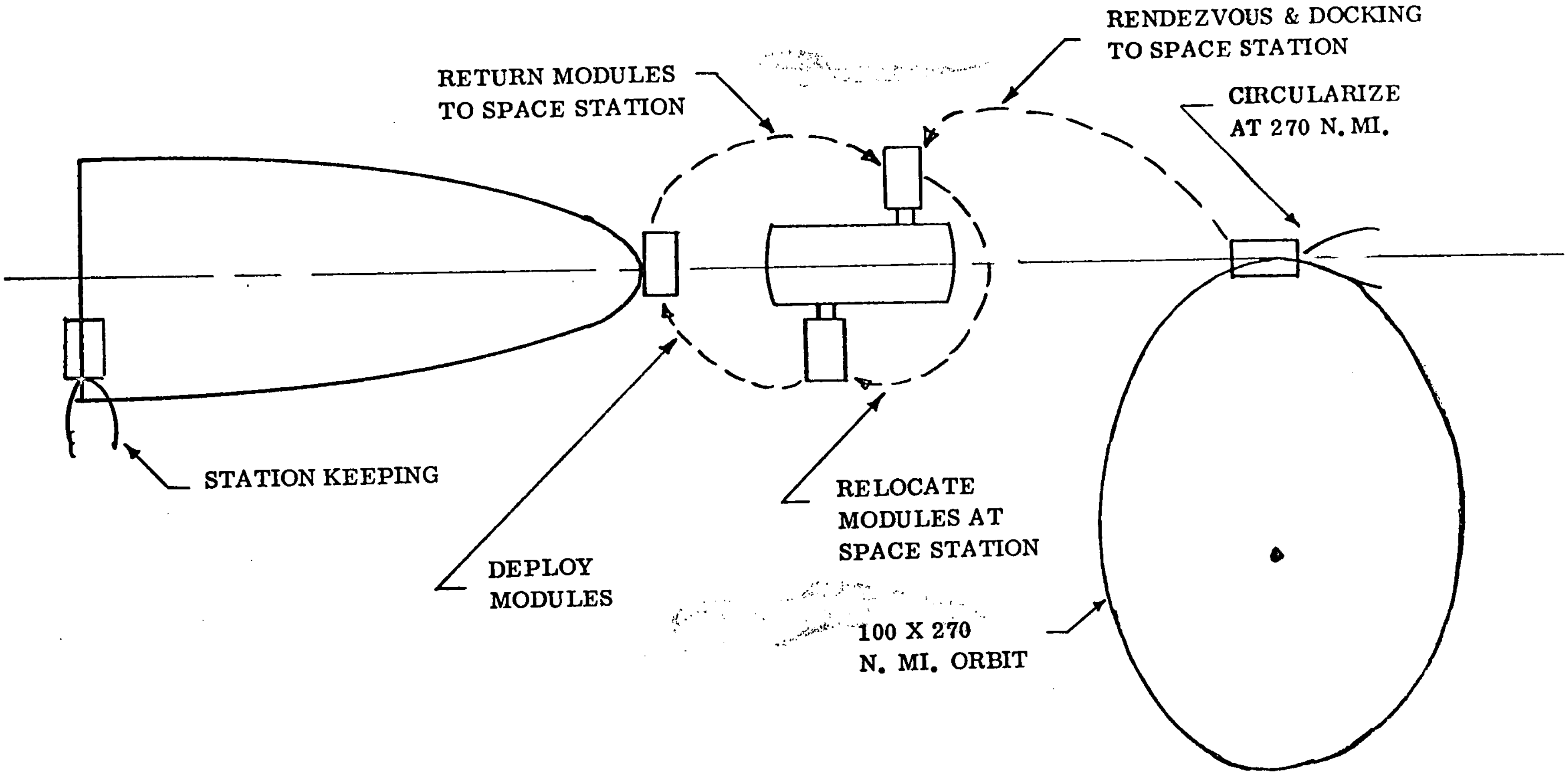


Figure 3-20. Baseline On-Orbit Transportation (Propulsion Integral to Modules)

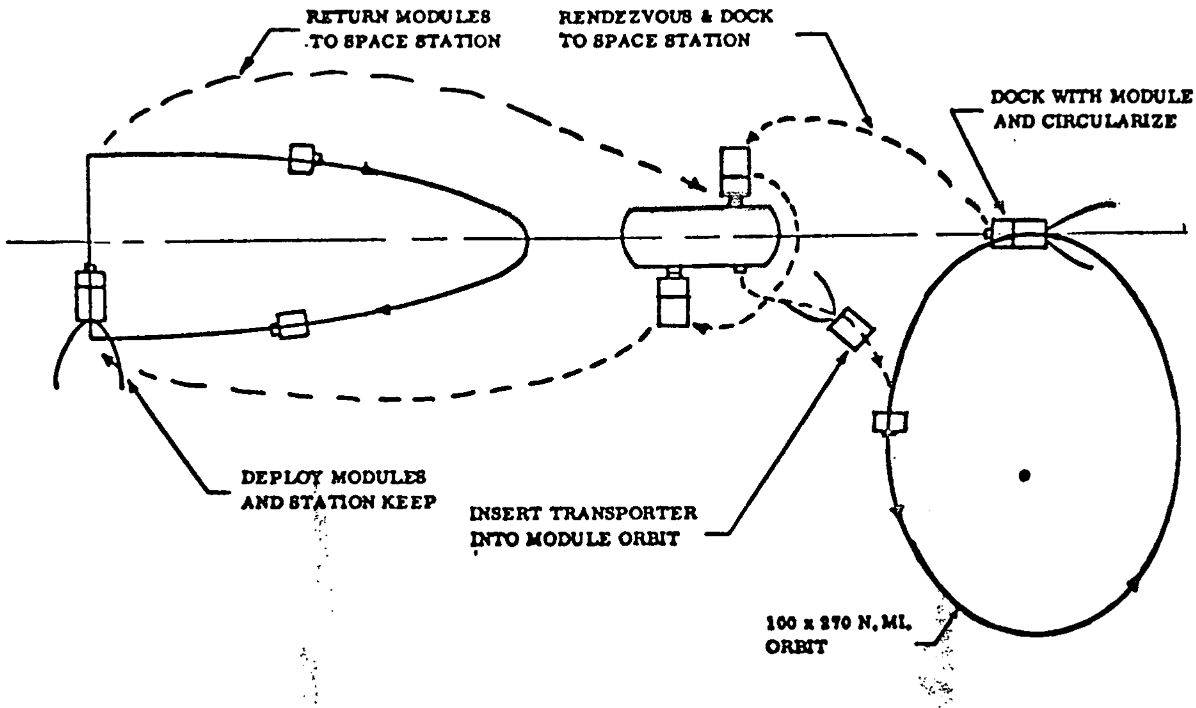


Figure 3-21. Unmanned Transporter On-Orbit Transportation

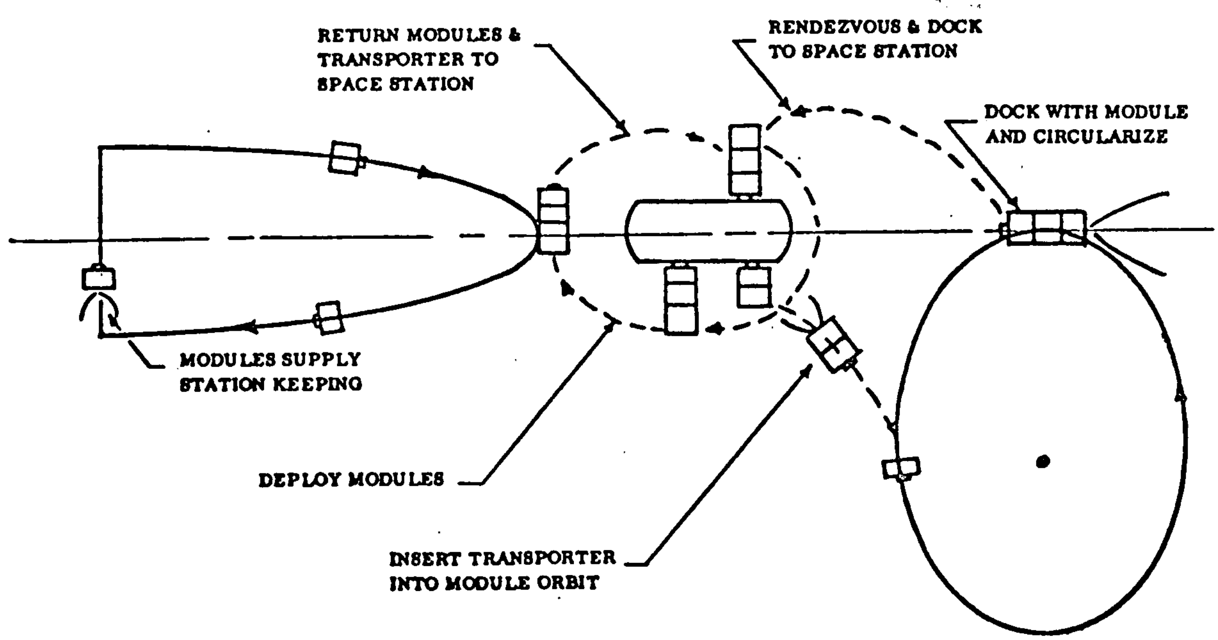


Figure 3-22. Manned Transporter On-Orbit Transportation

The initial delivery and relocation of experiment modules at the space station remain identical to those of the unmanned transporter. However, the concept for delivery and servicing of the free-flying modules differs. Modules are delivered to the apex of the stationkeeping parabola and modules are serviced in-situ in the near vicinity of apex. Experiment module propulsion is used for stationkeeping velocity increments at the 500 n.mi. range point.

3.2.3.3 Free-Flying Astronomy Modules. Characteristics of the 5 astronomy experiments and experiment modules are listed in Table 3-10. Stationkeeping cycles are based in the CIRA 65 Model 5 atmosphere -- an average atmospheric model. Stationkeeping cycles were established using this atmosphere model and the indicated module ballistic coefficient (β) for free-flight parabolic orbits with a maximum range of 500 n.mi. from the space station. The indicated weights are for the baseline experiment modules designs prior to modification for transporter interface.

Velocity increments used for the evaluation of transporter propellant requirements are summarized in Table 3-11. The 12 n.mi. orbit transfer is used for the baseline transportation concept and the manned (in-situ servicing) transporter concept. The 500 n. mi. transfer is used for deploying free-flying modules with an unmanned transporter. Transfers in two orbital periods for the 12 n.mi. case and eight periods for the 500 n.mi. case were selected on the basis of a trade study between the cost of added propellants for more rapid transfers versus the cost of lost experiment time and additional crew time. An out-of-plane velocity increment of 6 fps is applied as free-flying modules are delivered and returned from their stationkeeping orbits to provide additional separation between on-orbit modules.

These velocity increments are combined to obtain velocities for total maneuvers as shown in Table 3-12. Velocity increments for the baseline case, where propulsion is integral to the experiment module, are considerably less than those for the manned and unmanned transporters. This is the result of the additional maneuvers which the transporter must accomplish to move into position to transfer the experiment module and the added maneuvers to return the transporter to its docking port at the space station. As an example, consider the relocation of an experiment module from one space station docking port to another. For the baseline case this requires that the experiment module be undocked (10 fps) and then docked (20 fps) for a total velocity increment of 30 fps. For the manned and unmanned transporter cases the transporter is undocked (10 fps) and docked to the experiment (20 fps). The transporter then undocks the experiment module (10 fps) and docks the experiment module to the new port (20 fps). The transporter must then undock from the experiment module (10 fps) and dock again to the space station (20 fps) for a total velocity increment of 90 fps. The obvious advantage of reducing experiment module weight and costs by removing propulsion and control system components is, at least partially, cancelled by the greater velocity necessary to accomplish the maneuvers.

Table 3-10. Astronomy Experiment Characteristics

FPE	TITLE	LAUNCH YEAR	WEIGHT (lb)	β (lb/ft^2)	STATION KEEPING CYCLE* (days)	EXPERIMENT SERVICE CYCLE (days)
5.1	X-RAY	N	21,600	20	35.2	60
5.2A	STELLAR	N+4	26,800	18	33.4	60
5.3A-1	SOLAR I	N+3	21,880	23	37.8	60
5.3A-2/3	SOLAR II	N+3	13,365	23	37.8	30
5.5	HI-ENERGY	N+2	23,470	8	22.4	30

*CIRA 65 MODEL 5 ATMOSPHERE

Table 3-11. Propulsive Maneuver Velocity Increments

TYPE OF MANEUVER	ΔV (FPS)
POST - BOOST	
UNDOCK AND CIRCULARIZE AT 270 N. MI.	300
RENDEZVOUS AND DOCK FOLLOWING BOOST	85
ON-ORBIT	
DOCK	20
UNDOCK	10
OUT-OF-PLANE COMPONENT	6
ORBIT TRANSFER	
12 N. MI. IN TWO ORBITS	2
500 N. MI. IN EIGHT ORBITS	22
STATION KEEPING	2

Table 3-12. Transportation Requirements Free-Flying Astronomy Modules

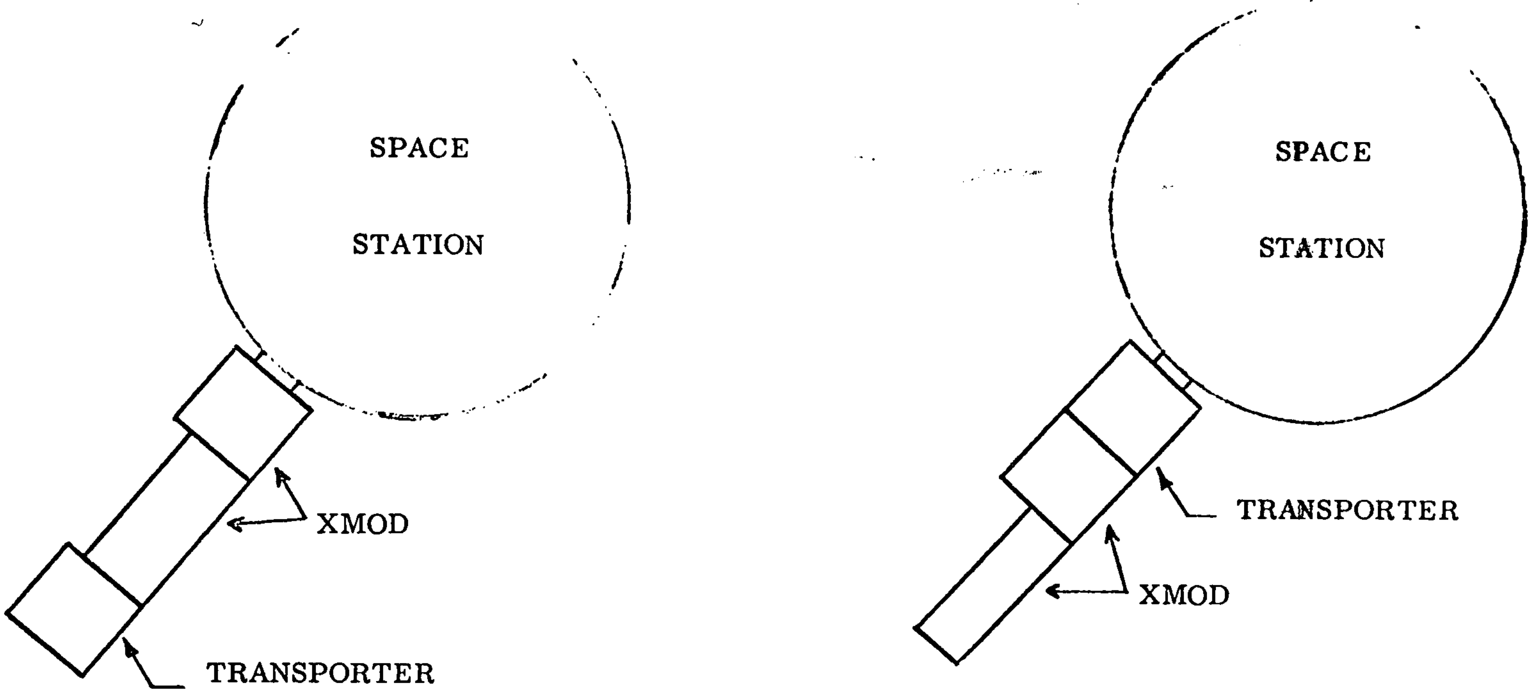
TRANSPORTATION OPERATION	ΔV (FPS)		
	BASE LINE (INTEGRAL PROPULSION)	UNMANNED TRANSPORTER	MANNED TRANSPORTER (IN-SITU SERVICING)
DELIVER MODULE FROM BOOSTER TO SPACE STATION	385	800	800
RELOCATE MODULE AT SPACE STATION	30	90	90
TRANSFER MODULE TO STATION KEEPING ORBIT	18	126	86
IN-SITU SERVICING	--	--	76
RETURN MODULE FROM STATION KEEPING ORBIT FOR SERVICING	28	136	--

Both releasable and captive transporters as sketched in Figure 3-23 were considered. The releasable transporter docks to one end of the experiment module. A second docking port is required on the opposite end of the experiment module for docking with the space station. This requires the addition of a second docking port to all modules with the obvious increases in weight and cost. The captive transporters concept requires that the transporter simultaneously interface with the experiment module and the space station whenever the module is stationed at the space station. The captive transporter concept must have an internal passageway for manned access (IVA) to the interior of the experiment module. This is not possible with the type of cryogenic transporter hypothesized for this analysis. Since the captive transporter is not available to service other modules while it acts as an interface between one module and the space station, additional captive transporters are required.

Modifications of the free-flying astronomy modules for use with the releasable transporters include the addition of a second docking port and a shell structure to support the second docking port. This type of installation is shown in Figure 3-24. The second docking port is added at the telescope aperture end of the module and is hinged so the mechanism can be rotated away from the aperture during experimental periods. Module weight is increased by approximately 2600 pounds when the second port is added. Access for placement of sun shades, thermal tubes and figure sensors is also constrained by the shell structure.

A portion of the reaction control system can be deleted from the experiment modules when a transporter is used. The transporter then serves as the backup RCS. The primary RCS is still required to back up the control moment gyros. Propellant can also be off loaded in the amount of about 590 pounds. The weight of the removed backup RCS is 390 pounds for a total reduction of 980 pounds.

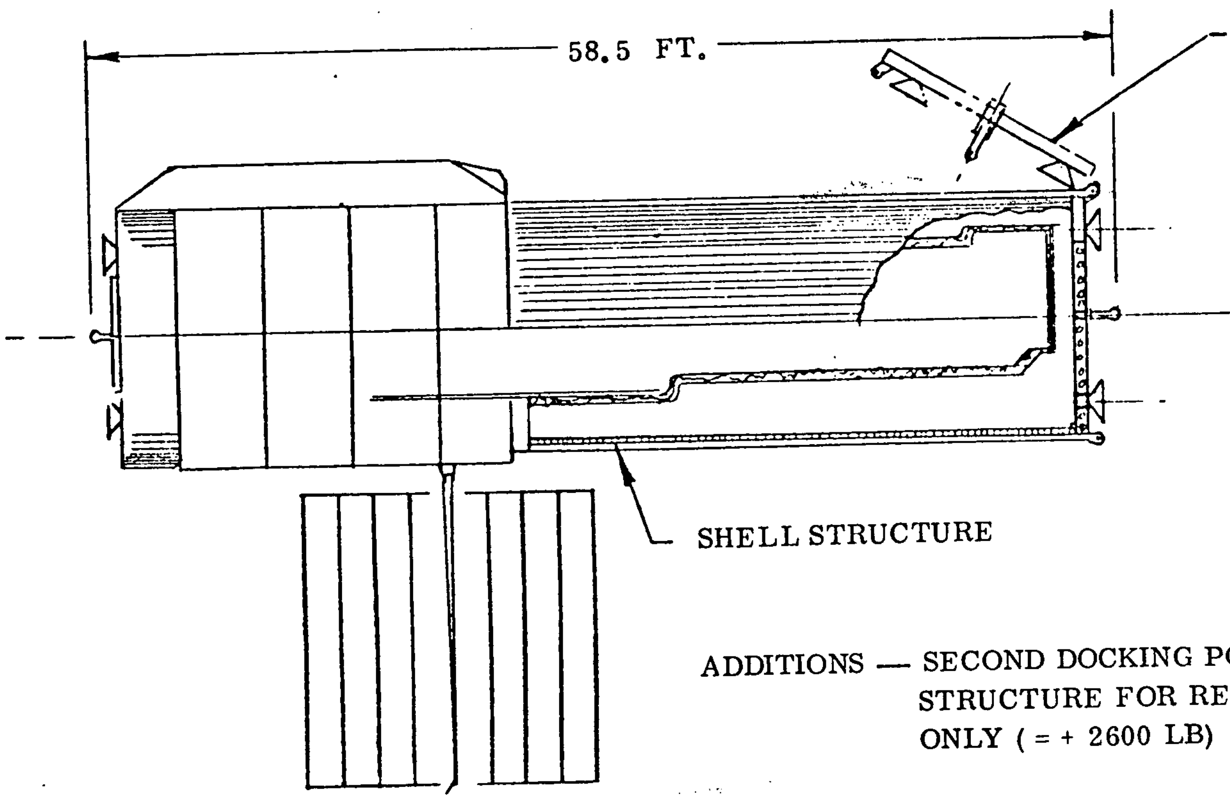
Program cost increments for a 10-year operations period of the five CM-1 free-flight modules transported by an unmanned transporter are shown in Table 3-13. Cost increments are referenced to the baseline transportation concept with propulsion integral to the experiment modules. Transporters supply all velocity increments including stationkeeping. Experiment module DDT&E and production costs are reduced (by \$10.2M and \$1.0M, respectively) due to the elimination of the backup RCS. However, in the case of the releasable transporter, interfaced hardware costs (those additional



RELEASABLE TRANSPORTER

CAPTIVE TRANSPORTER

Figure 3-23. Transporter Concepts with Free-Flying Modules



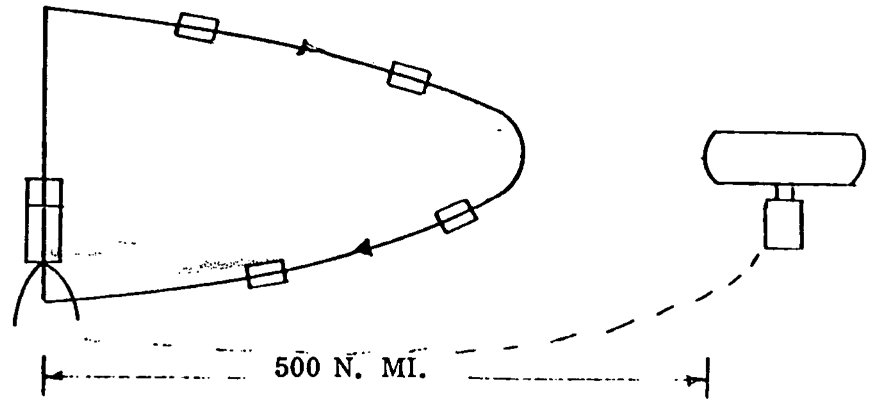
ADDITIONS — SECOND DOCKING PORT AND SUPPORTING STRUCTURE FOR RELEASABLE TRANSPORTER ONLY (= + 2600 LB)

DELETIONS —	BACKUP RCS	-390
	PROPELLANT	-590
	TOTAL	-980 LB

Figure 3-24. Free-Flying Astronomy Module Modifications

Table 3-13. Program Cost Increments Unmanned Transporters Servicing the Astronomy Modules

- COSTS REFERENCE TO PROPULSION INTEGRAL TO MODULES (BASELINE)
- TRANSPORTERS PROVIDE ALL VELOCITY INCREMENTS



ITEM	INCREMENTAL COSTS ($1,000,000)					
					TOTAL-WITH (W/O) TRANSP.	
	DDT&E	PRODUCTION	INTERFACE HARDWARE	10-YEAR OPERATIONS	(W/O) DDT&E OR PROD.	DDT&E & PROD.
CM-1 XMODS (5)	- 10.2	- 1.0	+16.4	0	+ 5.2	+ 5.2
+						
CM-1 TRANSP. (1)	+ 31.1	+13.6	0	+61.3	+61.3	+106.0
PROGRAM						
RELEASABLE TRAN.	+ 20.9	+12.6	+16.4	+61.3	+66.5	+111.2
CAPTIVE TRANSP.	+ 20.9	+12.6	0	+61.3	+50.1	+ 94.8
CM-1 XMODS (5)	- 10.2	- 1.0	+16.4	0	+ 5.2	+ 5.2
+						
CRYO TRANSP.	+365.0	+13.0	0	+ 8.6	+ 8.6	+386.6
PROGRAM	+354.8	+12.0	+16.4	+ 8.6	+13.8	+391.8

costs associated with the second docking port) are increased by $16.4M. Total cost increments are shown with and without transporter development and production costs. The total without DDT&E and production costs corresponds to the case where a transporter is both developed and produced at no cost to the experiment module program - costs are attributable to other sources of funding. Ten-year operation costs included module delivery cost, cost of fuel for on-orbit servicing and station-keeping, and the cost of boosting the transporter to orbit twice during the 10-year operating period. Booster costs are computed at $4.M per launch and transporter propellant costs at $250 per pound. The top portion of the chart contains cost increments for the storable CM-1 transporter. Costs with the cryogenic transporter are shown in the lower portion. Costs between the releasable and captive CM-1 transporter program differ by the interface hardware value of $16.4M. Only releasable transporter costs are shown with the cryogenic transporter since a captive transporter is not possible with the hypothesized configuration. This chart shows that program costs are increased in all cases when an unmanned transporter is used to provide velocity increments for the free-flying modules. The cost increases vary from a minimum of $13.8M for the case where a cryogenic transporter is developed and produced at no expense to the experiment module program to $111.2M when a CM-1 releasable transporter is developed, produced and charged to the experiment module program. The maximum cost increases $391.8M when the cryogenic transporter is developed, produced and charged to the program. Captive transporter total costs do not include the cost of producing at least one additional transporter.

Manned transporters are used in an in-situ servicing mode. There are two considerations which, although difficult to quantify may, at some later date, prove to be of major importance. First, in-situ servicing offers the possibility of reduced experiment sensor exposure to contamination and radiation. Second, in-situ servicing will probably be limited in flexibility, capability and/or quality of servicing.

Crew hours and experiment down time are important considerations which can be quantified. Table 3-14 summarizes the servicing timeline, crew hours required for servicing and experiment down time for a typical service cycle of the baseline concept (servicing at the space station), and for the in-situ servicing case. Total servicing time is 0.8 hour longer for the in-situ case, but experiment down time is reduced by 4.2 hours per service cycle. Crew hours are increased from 38.7 hours for the baseline to 68.4 hours for the in-situ case. This is the result of manning the transporter with two men and requiring that a third crew man monitor the status of the transporter and its crew from the space station.

Experiment down time and crew hours are converted into costs in Table 3-15. Down time costs are computed at the rate of $1500/hour and manhour costs at the rate of $1000/hour.

Table 3-14. In-Situ Servicing Considerations

- REDUCES EXPOSURE OF EXPERIMENTS TO CONTAMINATION AND RADIATION
- LIMITED SERVICING CAPABILITY AND FLEXIBILITY

OPERATION	BASELINE				IN-SITU			
	TIME (HRS)	CREW SIZE (MEN)	CREW HOURS (MAN-HRS)	DOWN TIME (HRS)	TIME (HRS)	CREW SIZE (MEN)	CREW HOURS (MAN-HRS)	DOWN TIME (HRS)
TRIP TO SERVICE LOCATION	2.5	1	2.5	2.5	2.9	3	8.7	.4
PRE-SERVICE	2.5	2	5.0	2.5	2.5	↓	7.5	2.5
SERVICE	8.0	2	16.0	8.0	8.0	↓	24.0	8.0
POST-SERVICE	6.2	2	12.4	6.2	6.9	↓	20.7	6.9
RETURN TO STATION	2.8	1	2.8	2.8	2.5	3	7.5	0
TOTAL	22.0		38.7	22.0	22.8		68.4	17.8

Table 3-15. In-Situ Servicing Cost Increments

SERVICING CONCEPT	EXPERIMENT DOWNTIME		CREW HOURS		DOWNTIME + MANPOWER COSTS ($ × 10^6)
	HOURS	COST ($ × 10^6)*	MAN-HRS	COST ($ × 10^6)*	
IN-SITU	17.8	.0267	68.4	.0684	.0951
BASELINE	22.0	.0330	38.7	.0387	.0717
INCREMENT PER					
SERVICE CYCLE	-4.2	-.0063	+29.7	+.0297	+.0234
YEAR **	-176.	-.265	+1,247.	+1.247	+.982
10-YR PROGRAM	-1,760.	-2.65	+12,470.	+12.47	+9.82

* DOWNTIME COST AT $1,500/HR: MAN-HOURS AT $1,000/MAN-HOUR

** TOTAL OF 42 CYCLES FOR FIVE MODULES

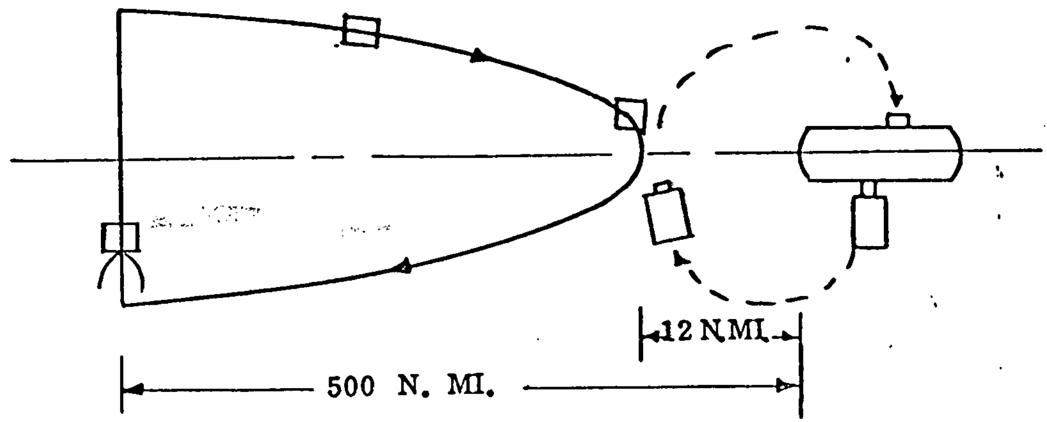
Cost increments are referred to the baseline space station servicing case and are shown per service cycle, per year with a total of 42 service cycles, and for the 10-year program. The effect is to increase costs by $9.82M when experiment modules are serviced in-situ rather than at the space station.

Cost increments over the 10-year operating period are summarized in Table 3-16 for the manned transporter servicing the astronomy modules in situ. The format of this table is identical to that of Table 3-13. The manned transporter delivers experiment modules to the apex of the stationkeeping parabola; in-situ servicing is accomplished in the near vicinity of the stationkeeping parabola apex. Experiment module RCS is used for stationkeeping velocity increments. The additional cost associated with in-situ servicing of $9.8M is tabulated under the 10-year operations column for the experiment modules. Transporter operation cost increments are reduced from those ($61.3M to $20.7M) of the unmanned transporter. This is a result of the transporter being used only for transportation to and from the apex of the stationkeeping parabola rather than to the 500 n.mi. range. However, transporter DDT&E and production costs increase significantly due to the addition of the manned capability. Manned capability is provided for the cryogenic transporter by adding a CM-1 module. Total costs increase when a manned transporter services the astronomy modules from a minimum of $15M when the cryogenic transporter is developed and produced at no expense to the experiment module program to a maximum of $475.6M when the cryogenic transporter is developed, produced, and charged to the program.

Table 3-17 contains a summary of the evaluation of manned and unmanned transporters for use with free-flying astronomy modules. Only releasable transporters are considered in this summary so that both storable (CM-1) and cryogenic (growth version of Centaur) transporters can be compared. Where significant variations would occur with a CM-1 type captive transporter the differences are pointed out in the text. Preferred characteristics are enclosed by heavy dark lines. Note that the baseline characteristics are preferred in all cases with one exception – the propellant required per year. Ten-year program costs are lowest for the baseline (by $111.2M if DDT&E and production costs are included and by as little as $13.8M if these costs are borne by another program). Use of a captive transporter increases CM-1 transporter costs by the value of at least one transporter. Experiment growth capability is evaluated for the weight critical experiment (FPE 5.2 - Stellar Astronomy) and in terms of the volume available for experiment expansion. In both cases the baseline propulsion concept is preferred. If a captive transporter were used, experiment growth would be the same for the baseline and the transporter cases. The number of space station ports necessary is least for the baseline and for the manned transporter cases. Propellant supplied by the space station to the transporter is minimum for the manned cryogenic transporter. However, this is at least partially balanced by the need to store cryogenic propellants rather than storable propellants. Funding flexibility measures the additional funds required above those attributable to the astronomy experiment modules when transporters are used. The baseline case requires the minimum funds and hence is the most flexible and most desirable concept. Technical

Table 3-16. Ten Year Cost Increments of Manned Transporters For In-Situ Servicing of the Astronomy Modules

- COSTS REFERENCED TO PROPULSION INTEGRAL TO MODULES (BASELINE)
- MODULE RCS PROVIDES STATION KEEPING



ITEM	DDT&E	PRODUCTION	INTERFACE HARDWARE	10-YEAR OPERATIONS	TOTAL-WITH (W/O) TRANSP. (W/O) DDT&E OR PROD.	TOTAL-WITH (W/O) TRANSP. DDT&E & PROD.
	INCREMENTAL COSTS ($1,000,000)					
CM-1 XMODS (5)	- 10.2	- 1.0	+16.4	+9.8	+15.0	+ 15.0
+						
CM-1 TRANSP. (1)	+ 85.1	+16.9	0	+20.7	+20.7	+122.7
PROGRAM						
RELEASABLE TRANS.	+ 74.9	+15.9	+16.4	+30.5	+35.7	+137.7
CAPTIVE TRANSP.	+ 74.9	+15.9	0	+27.8	+19.3	+121.3
CM-1 XMODS (5)	- 10.2	- 1.0	+16.4	+9.8	+15.0	+ 15.0
+						
CRYO TRANSP. (1)	+432.7	+27.9	0	0	0	+460.6
PROGRAM	+422.5	+26.9	+16.4	+9.8	+15.0	+475.6

Table 3-17. Evaluation Summary of Astronomy Modules With Releasable Transporters

ITEM	BASELINE-MODULE PROPULSION	UNMANNED TRANSPORTER		MANNED TRANSPORTER (IN-SITU SERVICING)	
		CM-1	CRYOGENIC	CM-1	CRYOGENIC
ΔCOST ($1,000,000)					
WITH DDT&E & PROD.	--	+111.2	+391.8	+137.7	+475.6
W/O DDT&E OR PROD.	--	+ 66.5	+ 13.8	+ 35.7	+ 15.0
EXPERIMENT GROWTH					
WEIGHT - FPE 5.2 (LB)	26,800	28,470	28,470	28,470	28,470
VOLUME	GOOD	LIMITED*	LIMITED*	LIMITED*	LIMITED*
SPACE STATION IMPACT					
DOCKING PORTS	N	N + 1	N + 1	N	N
PROPELLANT (LB/YR)	6,250	28,120	7,040	11,920	3,640
FUNDING FLEXIBILITY					
PROGRAM Δ ($ × 10^6)	--	+111.2	+391.8	+137.7	+475.6
TECHNICAL RISK + Δ's					
MODULE COMPLEXITY	NO	YES	YES	YES	YES
TRANSPORTER	NO	YES	YES	YES	YES
MAN-IN-TRANSPORTER	NO	NO	NO	YES	YES
CRYOGENICS	NO	NO	YES	NO	YES
REMOTE DOCKING	NO	YES	YES	NO	NO

*LIMITATION ON SUN SHADE, THERMAL TUBES & FIGURE SENSOR risks are also minimum for the baseline case, although several transporter concepts are also equally preferred. Module complexity is lowest for the baseline case since the second module docking port is not necessary. This technical risk would be equal for all concepts if captive transporters are considered. If the experiment module program is dependent upon a transporter, all the technical risks to which the transporter is subjected must be shared by the experiment module program. A similar situation exists if man is essential to the experiment module transporter. If cryogenic propellants are used, the experiment module must share the technical risks of storing, transferring, and venting cryogenics during long periods in space. Remote docking, where both vehicles are unmanned, introduces a technical risk with the unmanned transporter. The baseline and manned transporters do not suffer in this category.

This analysis leads to the following conclusions for the use of transporters with the free-flying modules.

a. The use of a transporter is not justified on the basis of cost.

b. Technical risk is lowest and program flexibility greatest with propulsion integral to each experiment module.

c. In-situ servicing is not justified on the basis of cost but may be desirable to reduce experiment exposure to contamination.

It is recommended that the CM-1 design be retained as it is (the baseline configuration) with:

a. Free flying capability

b. Single docking port

c. Compatible with transporters but not dependent upon transporters for accomplishing the baseline experiment module program.

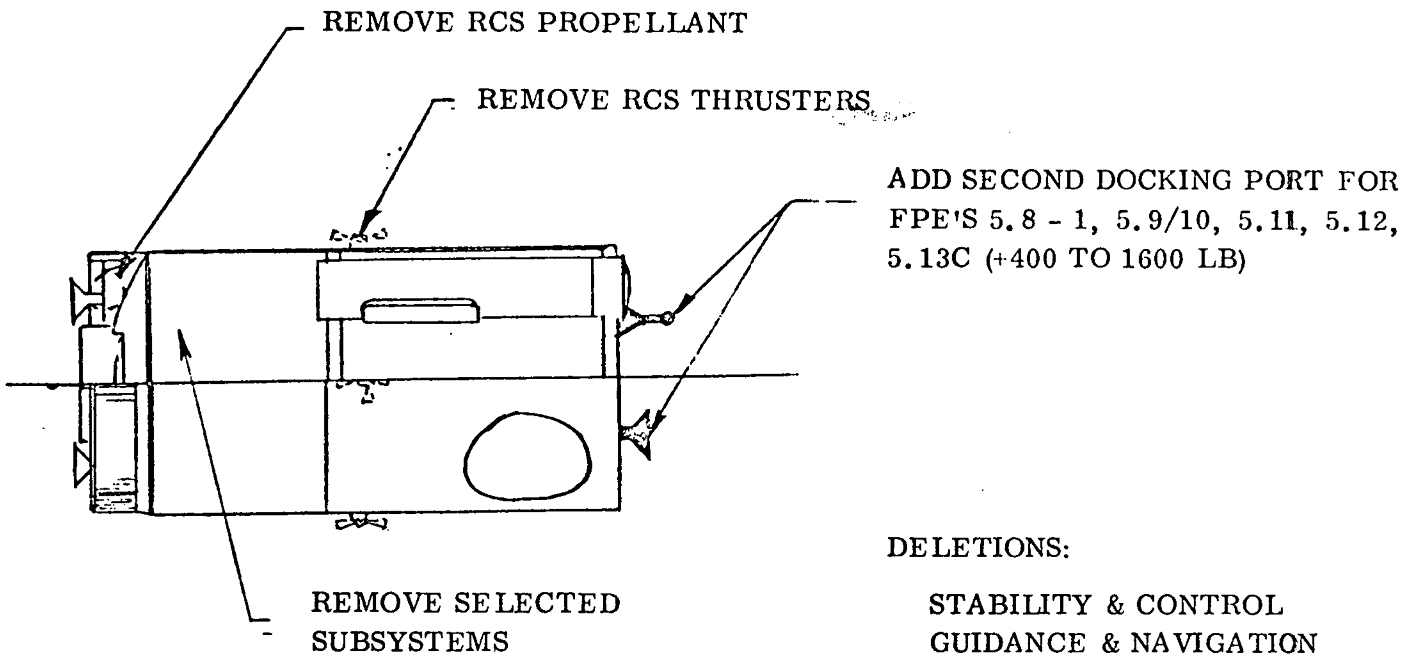
3.2.3.4 Attached Modules. Experiment characteristics and transportation requirements for the attached modules are summarized in Table 3-18. This summary shows the common module type assigned to each FPE, launch year, and the weight of the module including the experiment equipment for the baseline case where propulsion is integral to the experiment module. Only two transportation operations are necessary: delivery from the booster to the space station and relocation of the modules at the space station.

Since no experiment module propulsion or stability and control systems are necessary when a transporter is used, some sizable reductions in experiment module subsystem weight and, hence, cost are possible. All of the stability and control and RCS components can be deleted as can all of the guidance and navigation equipment except for the reflector cube. Figure 3-25 shows the breakdown of these hardware elements.

Table 3-18. Experiment Characteristics and Transportation Requirements, Attached Modules

FPE	TITLE	MODULE	LAUNCH YEAR	WEIGHT (LB)	TRANSPORTATION OPERATION	ΔV (F P S)
5.8-1	COSMIC RAY I	CM-3	N + 4	16,870		
5.8-2	COSMIC RAY II	CM-3	N + 4	30,580		
5.9/10	BIOLOGY I & II	CM-3	N	18,275	DELIVER MODULE FROM BOOSTER TO SPACE STATION	385*
5.16	MATL. SCI.	CM-3	N + 1	20,495		(800)**
5.20-1	FLD. PHY. I	CM-3	N	13,456		
5.11	EARTH SCI. I	CM-4	N	25,640	RELOCATE MODULE AT SPACE STATION ONCE EACH TWO YEARS	30*
5.12	RMS	CM-4	N + 2	22,025		(90)**
5.22	COMP. TEST	CM-4	N + 1	23,615		
5.13C	CENTRIFUGE	CM-4	N	23,510		

* BASELINE
** WITH TRANSPORTER



DELETIONS:

STABILITY & CONTROL	- 70 LB
GUIDANCE & NAVIGATION	- 56
REACTION CONTROL	-868
COMMUNICATIONS (PARTIAL)	- 40
TOTAL HARDWARE	-1034
RCS PROPELLANT	-1920
TOTAL	-2954 LB

Figure 3-25. Attached Module Modifications

Hardware weight can be reduced by 1034 pounds. An additional 1920 pounds of propellant can be removed for a total weight reduction of 2954 pounds. A second docking port must be added when attached modules are used with releasable transporters. Captive transporters are not considered since an additional transporter would be required for each experiment module. A second docking port increases module weight by 400 pounds (where experiment module designs already have a flat bulkhead to which the second port can be attached) to 1600 pounds (where a support structure is necessary to accommodate a second docking port attached to the centrifuge enclosure).

Ten-year program cost increments are summarized in Table 3-19 for the attached module program with unmanned storable (CM-1) and cryogenic transporters. Costs are referenced to the baseline transportation concept with propulsion integral to the experiment module. Deletion of subsystem components reduces DDT&E and production costs significantly for the five CM-3 and four CM-4 modules. After including CM-1 transporter DDT&E costs, program DDT&E costs are still reduced by $46.1M. Interface hardware costs are increased by $7.0M as a result of the second docking port and operations costs increase by $15.5M. The net result is a reduction in program cost of $22.6M after including the cost of developing and producing the CM-1 transporter. If transporter development and production costs are not assignable to the experiment module program, a reduction in program cost of $61.6M results for the cryogenic transporter. With development and production costs assignable to the experiment module program, program costs with the cryogenic transporter are increased by $316.4M.

When a manned transporter is used to deliver and relocate attached modules, the added costs of developing and producing the manned transporter exceed the reductions in common module development and production costs as shown in Table 3-20. If development and production costs are assignable to the experiment module program, program costs are increased by $35.7M with CM-1 transporter and by $402.3M with a cryogenic transporter. Without development and production costs, total program costs are reduced by $52.7M when the CM-1 transporter is used and $58.3M when the cryogenic transporter is used. The crew is carried within the CM-1 module when the cryogenic transporter is manned.

The evaluation of transporter use with attached modules is summarized in Table 3-21. Cost, funding and technical increments are referenced to the baseline transportation concept. Preferred characteristics are again enclosed in heavy dark lines. Minimum 10-year program costs are obtained with the use of an unmanned transporter. Costs are reduced by $22.6M when DDT&E and production costs of a CM-1 transporter are assignable to the experiment module program. Costs are reduced by $61.6M when cryogenic transporter DDT&E and production costs are not included. Experiment growth capability is measured in terms of weight critical experiment (FPE 5.8 - Cosmic Ray) and available volume internal to the common module. Both of these items are improved when transporters are used as a result of subsystem deletions.

Table 3-19. Ten-Year Cost Increments Attached Modules with Unmanned Transporters

ITEM	INCREMENTAL COSTS ($1,000,000)					
					TOTAL-WITH (W/O) TRANSP.	
	DDT&E	PRODUCTION	INTERFACE HARDWARE	10-YEAR OPERATIONS	(W/O) DDT&E OR PROD.	DDT&E & PROD.
CM-3 XMODS (5)	- 35.2	- 7.7	+2.6	0	-40.3	- 40.3
CM-4 XMODS (4)	- 28.4	- 4.9	+4.4	0	-28.9	- 28.9
CM-1 TRANSP. (1)	+ 17.5	+13.6	0	+15.5	+15.5	+ 46.6
PROGRAM	- 46.1	+ 1.0	+7.0	+15.5	-53.7	- 22.6
CM-3 XMODS (5)	- 35.2	- 7.7	+2.6	0	-40.3	- 40.3
CM-4 XMODS (4)	- 28.4	- 4.9	+4.4	0	-28.9	- 28.9
CRYO.TRANSP. (1)	+365.0	+13.0	0	+ 7.6	+ 7.6	+385.6
PROGRAM	+301.4	+ 0.4	+7.0	+ 7.6	-61.6	+316.4

Table 3-20. Ten-Year Cost Increments Attached Modules with Manned Transporters

ITEM	INCREMENTAL COSTS ($1,000,000)					
					TOTAL-WITH (W/O) TRANSP.	
	DDT&E	PRODUCTION	INTERFACE HARDWARE	10-YEAR OPERATIONS	(W/O) DDT&E OR PROD.	DDT&E & PROD.
CM-3 XMODS (5)	- 35.2	- 7.7	+2.6	0	-40.3	- 40.3
CM-4 XMODS (4)	- 28.4	- 4.9	+4.4	0	-28.9	- 28.9
CM-1 TRANSP. (1)	+ 71.5	+16.9	0	+16.5	+16.5	+104.9
PROGRAM	+ 7.9	+ 4.3	+7.0	+16.5	-52.7	+ 35.7
CM-3 XMODS (5)	- 35.2	- 7.7	+2.6	0	-40.3	- 40.3
CM-4 XMODS (4)	- 28.4	- 4.9	+4.4	0	-28.9	- 28.9
CRYO TRANSP. (1)	+432.7	+27.9	0	+10.9	+10.9	+471.5
PROGRAM	+369.1	+15.3	+7.0	+10.9	-58.3	+402.3

Table 3-21. Evaluation Summary for Attached Modules

ITEM	BASELINE-MODULE PROPULSION	UNMANNED TRANSPORTER		MANNED TRANSPORTER	
		CM-1	CRYOGENIC	CM-1	CRYOGENIC
ΔCOST ($1,000,000)					
WITH DDT&E & PROD.	0	-22.6	+316.4	+35.7	+402.3
W/O DDT&E OR PROD.	0	-53.7	- 61.6	-52.7	- 58.3
EXPERIMENT GROWTH					
FPE 5.8-2 WEIGHT (LB)	30,580	28,030	28,030	28,030	28,030
VOLUME	ADEQUATE	IMPROVED	IMPROVED	IMPROVED	IMPROVED
SPACE STATION IMPACT					
DOCKING PORTS	N	N + 1	N + 1	N + 1	N + 1
PROPELLANT (LB/YR)	1,240	4,230	1,090	4,650	2,430
FUNDING FLEXIBILITY *					
PROGRAM Δ ($ × 10[6])	0	+487.4	+316.4	+559.3	+912.3
TECHNICAL RISK + Δ's					
MODULE COMPLEXITY	UNCHANGED	REDUCED	REDUCED	REDUCED	REDUCED
REMOTE DOCKING	NO	YES	YES	NO	NO
TRANSPORTER	NO	YES	YES	YES	YES
MAN-IN-TRANSPORTER	NO	NO	NO	YES	YES
CRYOGENICS	NO	NO	YES	NO	YES

*ABOVE ATTACHED MODULE ONLY PROGRAM

The number of required space station docking ports is minimum with the baseline concept. Propellant resupply requirements per year are minimum for the unmanned cryogenic transporter but only slightly less than that of the baseline case. Funding flexibility is greatest (minimum dependency on funding of programs above that for the attached module program) for the baseline. Module complexity technical risk is minimum when module subsystems are deleted for use with the transporters. The other technical risks are minimum for the baseline transportation concept where propulsion is integral to the experiment modules.

The following conclusions are derived from the analysis of transporters with attached modules.

a. Attached module program costs are reduced with a CM-1 transporter.

b. Additional weight and volume capability is provided with the use of the transporter.

c. Funding flexibility is reduced if module design is dependent on transporter use.

d. Technical risk and required number of docking ports are minimum for the baseline propulsion concept.

3.2.3.5 Program Conclusions and Recommendations. Total experiment module program cost increments referenced to the baseline integral experiment module propulsion concept are shown in Table 3-22. Costs are shown for a transporter used with both attached and free-flying modules and for a transporter used only with attached modules. When transporter DDT&E and production costs are assignable to the experiment module program, use of the transporter increases program costs by a minimum of $43.9M with an unmanned CM-1 transporter. If the transporter is used only with the attached module program, costs with the unmanned CM-1 transporter are reduced by $22.6M when transporter development and production costs are included. Program costs are reduced by $61.6M when development and production costs of an unmanned cryogenic transporter are not assignable to the experiment module program.

Conclusions for the use of a transporter with the total experiment module program are:

a. Costs are reduced by $22.6M (including transporter, DDT&E and production costs) in the case where attached experiment modules are only used with a unmanned CM-1 transporter.

b. When experiment modules are dependent upon a transporter,

   1. Operational flexibility is reduced since the capability for module self-propulsion is deleted or reduced.

   2. Funding flexibility is reduced since additional funds above those required for the basic experiment module program must be allocated.

Table 3-22. Program Cost Evaluation

COST INCREMENT	TRANSPORTER FOR ATTACHED & FREE-FLYING MODULES		TRANSPORTER FOR ATTACHED MODULES ONLY	
	UNMANNED ($\$ \times 10^6$)	MANNED* ($\$ \times 10^6$)	UNMANNED ($\$ \times 10^6$)	MANNED* ($\$ \times 10^6$)
CM-1 TRANSPORTER				
WITH DDT&E & PRODUCTION	+ 43.9	+ 71.4	- 22.6	+ 35.7
W/O DDT&E OR PRODUCTION	+ 12.8	- 17.0	- 53.7	- 52.7
CRYOGENIC TRANSPORTER				
WITH DDT&E & PRODUCTION	+ 330.2	+ 486.5	+ 316.4	+ 471.5
W/O DDT&E OR PRODUCTION	- 47.8	- 43.3	- 61.6	- 58.3

* IN-SITU SERVICING

3. Technical risk is increased since the transporter hardware concepts have not been thoroughly flight proven.

It is recommended that the experiment modules be designed to:

a. Retain experiment module docking compatibility with transporters which is available in the baseline module designs through a single docking port.

b. Operate independently of transporters for the baseline missions by using propulsion integral to the modules as provided in the baseline designs for on-orbit transportation.

c. Maintain maximum funding flexibility by minimizing experiment module dependency on transporter programs and thereby minimize the impact of redirection of funds for other programs on the experiment module program.

3.2.4 SPECIAL EXPERIMENT FLIGHT MISSIONS. One of the experiment FPEs other than the astronomy experiments contain experiments that are operated in the detached free-flying mode:

FPE 5.20 (Fluid Physics) is operated detached to achieve the sustained g level (10^{-6} to 10^{-3} g) conditions required to meet experiment objectives.

The relative flight paths and performance requirements of these detached operations are presented in the following paragraphs.

3.2.4.1 Elevated g Level Experiments. Fluid physics experiments require sustained levels of 10^{-3} to 10^{-6} g for periods from two to 1000 hours, while maintaining proximity to the station for communication and data transmittal. Achieving these by thrusting or other means must be accomplished in a manner that does not result in transferring the module to a significantly different orbit. Another requirement is that dynamic perturbations, gravity gradients, and other accelerations be kept to a very low level — not to exceed 10% of the experiment g-level. Several methods have been considered as shown in Figure 3-26.

a. Orientation of both the module and thrust held constant in inertial space. This produces an outward spiral flight path that is acceptable for low g-levels but creates excessive distances for higher g-levels.

b. Constant centripetal thrust, or tethered module. Module is placed in an outer orbit and thrust force (or tether tension) is applied. When altitude and thrust are properly selected, the module and station will rotate at the same angular rate. This results in an earth-oriented experiment that produces one module revolution per orbit. The resulting gravity gradient within the module appears within acceptable bounds for higher g-level experiments, but outside the limits for lower-g experiments. The tether mode is attractive from a propellant savings standpoint, but needs in-depth analysis of the effects of perturbations.

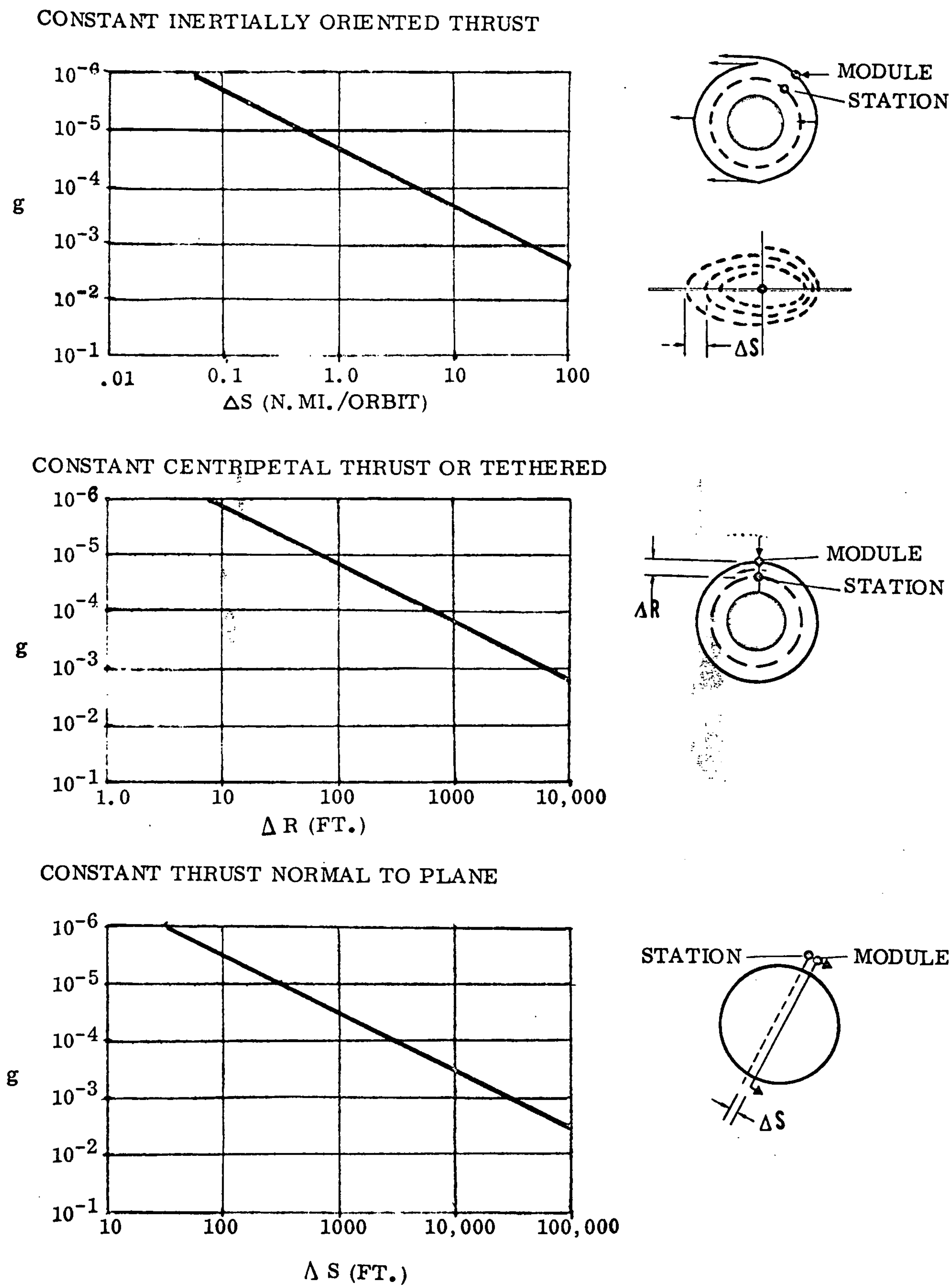


Figure 3-26. Alternate Flight Modes for Sustained g Level Experiments

c. Apply constant thrust normal to the orbital plane. This method appears to produce no significant body-originated perturbations and is a candidate for all g-levels.

These various methods provide a choice of conditions to the experimenter regarding orientation and level of perturbation.

Tables 3-23 and 3-24 list the sustained-g flight and ΔV requirements for experiment implementation using propulsive methods to achieve the required g levels. The FPE 5.20 Fluid Physics experiments are organized in this table in three groupings: 5.20-2, -3 and -4 representing short term non-cryogenic, and medium and long term cryogenic experiments, respectively.

Table 3-23 identifies g levels, flight times and ΔV values per flight for each of the FPE 5.20-2, -3, and -4 sub-experiments. The number of separate flights required at each of the g levels is identified in Table 3-24 along with the total ΔV required for that sub-experiment (i.e., 5.20.4-1) and for that FPE (i.e., 5-20-2). After each of the flights the experiment module is returned to the space station for experiment modification, recovery of data, or to replenish test fluids, propellants, or other expendables. Forty flights are required for FPE 5.20-2 and a total ΔV of 4216 fps is expended. FPE 5.20-3 requires 25 flights and a Δ V = 5897 fps is developed. Ten flights are necessary to accomplish FPE 5.20-4 and a Δ V = 11,053 fps is expended.

3.2.5 ALTERNATE ORBITS FOR ASTRONOMY MODULES. Astronomy modules baseline designs are based on the assumption that experiments will be accomplished in or nearly in the space station orbit. However, some experiment conditions might require that astronomy modules operate in an orbit which is different from that of the space station. The module is returned to the space station for periodic servicing in these cases.

The question that arises then is should the capability for positioning the modules in a different orbit, and returning them to the space station for servicing be incorporated into module designs, or should this capability be provided by a space tug.

3.2.5.1 Candidate Orbits. The baseline orbit for module design is identical to that of the space station – 270 n.mi. circular × 55° inclination. Experiment programs which may benefit by operations in other orbits are:

Experiment	Potential Alternate Orbit
Solar Astronomy	Sun synchronous for continuous viewing.
All Astronomy	High altitude (300 n.mi.) to avoid viewing interruptions for orbit maintenance.
Stellar Astronomy	Very high altitude to reduce earth occultation, for continuous (1 orbit) viewing.
X-Ray Astronomy	Equatorial or low inclination to avoid high radiation areas (South Atlantic Anomaly).
Earth Observations	Polar orbit for global coverage.

Table 3-23. Fluid Physics Experiments ΔV Requirements Per Flight Per g Level

FPE GROUPING	EXPERIMENT NO.	THRUSTING TIME & ΔV REQUIREMENTS PER FLIGHT: 10^{-3} g TIME (HRS)	10^{-3} g ΔV (FPS)	10^{-4} g TIME (HRS)	10^{-4} g ΔV (FPS)	10^{-5} g TIME (HRS)	10^{-5} g ΔV (FPS)	10^{-6} g TIME (HRS)	10^{-6} g ΔV (FPS)	TOTAL ΔV (FPS) PER FLIGHT
5.20-2	5.20.4.1	0.27	31.4	0.27	3.14	0.27	0.314			35
	5.20.4.4	1.14	132							132
		1.44	167							167
	5.20.4.3	1.47	171	1.47	17.1			1.47	0.17	188
	5.20.4.7	2.0	232			2.0	2.32			234
		1.0	116			1.0	1.16			117
	5.20.4.8			1.04	12					12
				2.76	32					32
	5.20.4.6	0.5	58					0.5	.058	58
5.20-3	5.20.4.2	17.8 (In 5 Flights)	2064	33.5 (In 2 Flights)	389	144 (In 4 Flights)	167	51.8 (In 2 Flights)	6	2626 in 13 flights
	5.20.4.9	1.65	192							192
				1.65	19.2					20
						1.65	1.92			2
	5.20.4.12	7.0	812							812
				80.0	928					928
						120	139			139
5.20.4	5.20.4.10			50.0	580					580
		10	1160							1160
		12.2	1417							1417
		1.15	134	100	1161					1295
		5.4	626			476	552	2000	232	1410
		0.5	58	5.0	58					116

Table 3-24. Fluid Physics Experiments. Δ V Requirements - Total

FPE Grouping	Expt. No.	Number of Sustained G Flights × ΔV Requirements per Flight (fps)	Undocking & Docking ΔV per Flt(fps)	Total Expt. ΔV (fps)
5.20-2	5.20.4.1	13 × 35*	30	845
	5.20.4.4	4 × 132; 1 × 167	30	845
	5.20.4.3	4 × 188*	30	872
	5.20.4.7	2 × 234; 2 × 117	30	822
	5.20.4.8	7 × 12; 3 × 32	30	480
	5.20.4.6	4 × 58*	30	352
		(5.20-2 Total)		(3,896)
5.20-3	5.20.4.2	1 × 348; 1 × 1090; 1 × 25; 1 × 278; 1 × 86; 1 × 14; 1 × 232; 1 × 303; 1 × 12; 1 × 4; 1 × 2; 2 × 116	30	3,016
	5.20.4.9	3 × 192; 3 × 20; 3 × 2	30	912
	5.20.4.12	1 × 812; 1 × 928; 1 × 139	30	1,969
		(5.20-3 Total)		(5,897)
5.20-4	5.20.4.10	1 × 580; 4 × 1160; 1 × 1417; 2 × 1295; 1 × 1410; 1 × 116	30	11,053
		(5.20-4 Total)		(11,053)

* Baseline experiment program change deletes 10^{-2} g test level.

Study ground rules place a space station in the required polar or near polar orbit to support polar type missions. Support to modules in an equatorial orbit is assumed to be provided by a space station in an equatorial orbit. However, any space station support for inclined orbits is assumed to come from the station at 270 n.mi. × 55°. Candidate alternate experiment module orbits are discussed in the following paragraphs.

3.2.5.2 Analysis of Operation at Higher Altitudes. The support of modules operating in orbits other than the space station orbit must consider the differences in orbit precession rates which exist between the module and the space station orbits. Since orbital precession rate decreases with altitude, the two orbits will rapidly become noncoplanar if they are at the same inclination. Orbit resynchronizing occurs periodically, but at long intervals.

Precession rate differences with altitude can be equalized by placing the experiment module at a lower inclination angle since precession rate increases with lower inclination.

Parametric performance data was developed for two methods of operating modules in higher orbits:

a. Module in a 55° inclined orbit at altitudes from 300 to 4000 n.mi., supported by a station in a 270 n.mi. × 55° inclination orbit.

b. Module in an orbit with the altitude and inclination selected to produce a precession rate equal to station orbit precession, thereby maintaining coplanar orbits continuously.

In addition to propulsive considerations, module operation (in orbits other than the space station) imposes functions normally supplied by the space station on the module or on ground systems. These functions include navigation and guidance, experiment programming, data handling, and experiment monitoring. This investigation is limited to performance requirements only.

Method No. 1. This method places the module in an orbit higher than that of the space station, but at the same inclination angle as the station. Since the orbital plane precession caused by earth oblateness decreases with altitude, the two orbits will have different precession rates. This difference in precession rates will soon result in orbits that are not coplanar. Return of the module to the station must await resynchronization of the orbital planes or ΔV must be expended by the module to effect a plane change. Module return from coplanar orbits is considered in this method — plane change maneuvers are discussed in the Second Method. Velocity increments required to deliver the module to a higher orbit or return the module to the space station are shown in Figure 3-27. Synchronization periods are plotted in Figure 3-28. The values shown are calculated as follows:

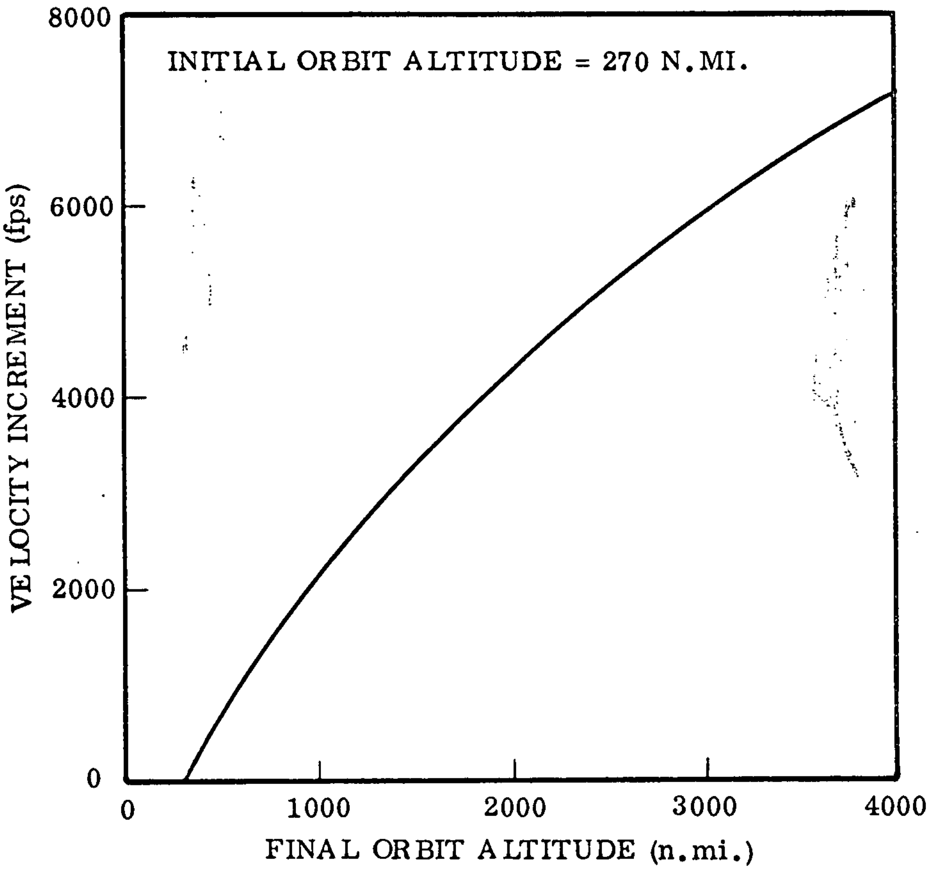


Figure 3-27. Velocity Requirements for Transfer Between Coplanar Circular Orbits

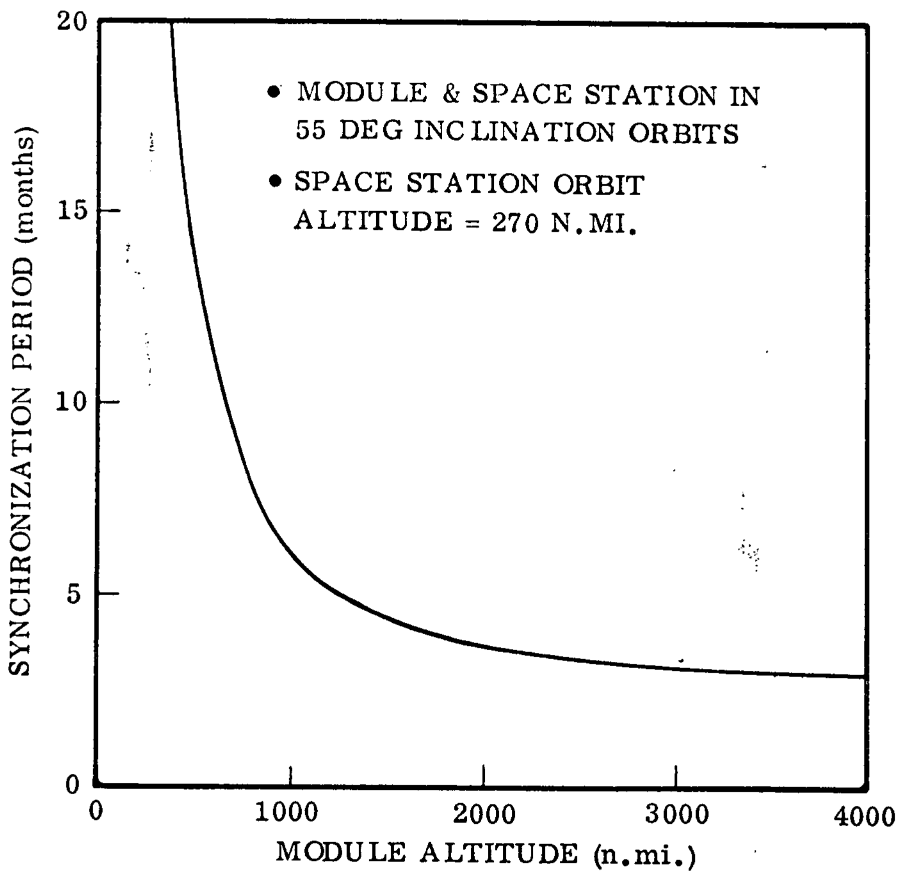


Figure 3-28. Module/Space Station Synchronization Periods

1. Differential orbital precession between station and module orbits is computed from the orbital precession ($\dot{\Omega}$) equation:

$$\dot{\Omega} = -9.97\left(\frac{R}{a}\right)^{3.5} (1 - e^{2})^{-2} \quad \cos i \text{ (where } \dot{\Omega} \text{ is in degrees/day)}$$

where $e = o$, circular orbit

$\cos i = \cos 55° = 0.573$

$R = 3440$ n. mi. earth radius

$a = (3440 + h)$ n. mi. module altitude

$$\dot{\Omega} = -9.97\left(\frac{3440}{3440 + h}\right)^{3.5} (0.573) = -5.71\left(\frac{3440}{3440 + h}\right)^{3.5} \quad \text{deg/day}$$

2. Synchronization frequency:

$$\text{Months to resynchronize} = \frac{360°}{(\dot{\Omega}_s - \dot{\Omega}_m)\ 30 \text{ days/mo.}}$$

where $\dot{\Omega}_s$ = station precession rate = -4.40 deg/day

$\dot{\Omega}_m$ = module precession rate, deg/day

3. ΔV Requirements to deliver module to a higher orbit or to return module to station.

$$\Delta V_{tr} = \sqrt{\frac{K}{r_p}}\left[\sqrt{\frac{2(r_a/r_p)}{1+(r_a/r_p)}}\left(1 - \frac{r_p}{r_a}\right) + \sqrt{\frac{r_p}{r_a}} - 1\right]$$

where r_a = radius of apogee

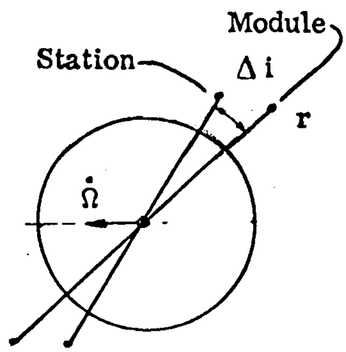
r_p = radius of perigee

$K = 1.407 \times 10^{16}\ ft^3/sec^2$

Method No. 2. For this method the module is placed at a higher altitude than the station, and at an inclination where module and station orbital plane precession rates are equal. The module can then be returned at any time for servicing. The only requirement is that the position of the two bodies be 180° apart in their orbits as required to complete a Hohmann transfer.

a. Inclined Orbit – The required module inclination angle for equal precession rates as the station, and the ΔV requirements for return of the module are shown in Figures 3-29 and 3-30. These parameters are calculated as follows:

1. Required module inclination:



$$\dot{\Omega} = -9.97\left(\frac{R}{a}\right)^{3.5}(1-e^2)^{-2}\cos i, \text{ where } a = R + h,$$

$\dot{\Omega} = -4.40°/\text{day}$ for station @ 270 × 55°

$$\cos i = \frac{\dot{\Omega}\ \text{Station}}{-9.97\,(R/a)^{3/5}} = \frac{-4.40}{-9.97(R/a)^{3.5}} = \frac{0.442}{(R/a)^{3.5}}$$

$$i_m = \cos^{-1}\frac{0.442}{(R/a)^{3.5}}$$ degrees, module orbit inclination.

2. ΔV requirements are minimized by combining the velocity increment required for the Hohmann transfer with the plane change ΔV. Combined plane change and Hohmann transfer velocity increments can be approximated by accomplishing one-half of the plane change with each of the Hohmann transfer velocity impulses.

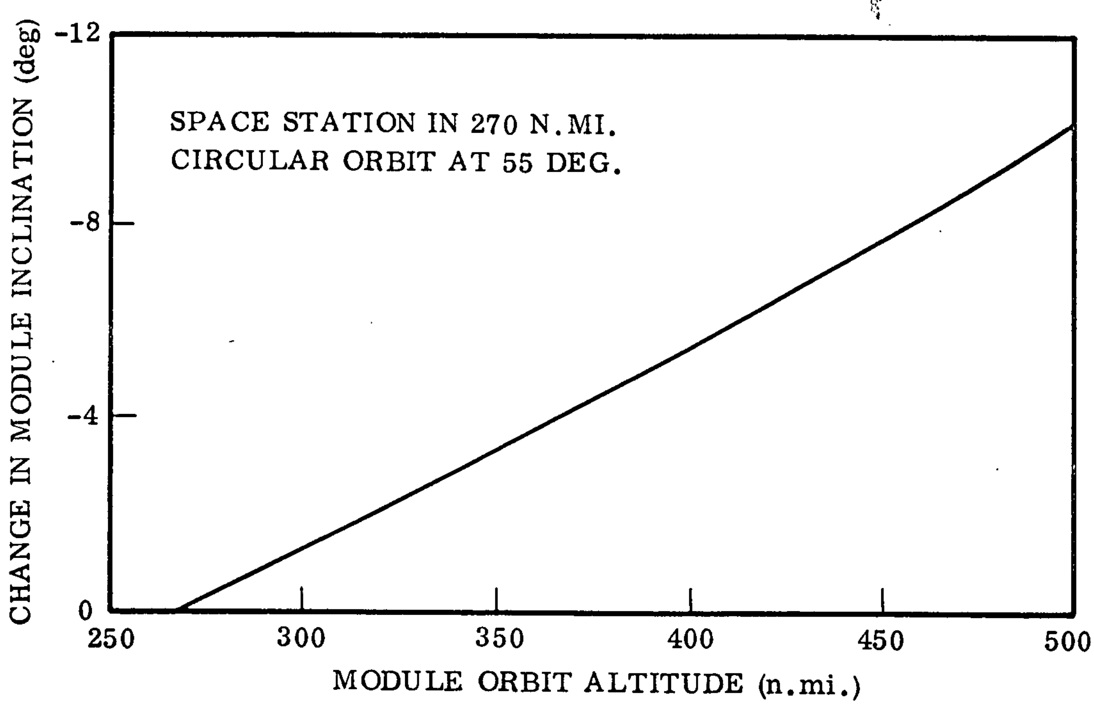


Figure 3-29. Change in Module Inclination for Equal Module and Space Station Precession Rates

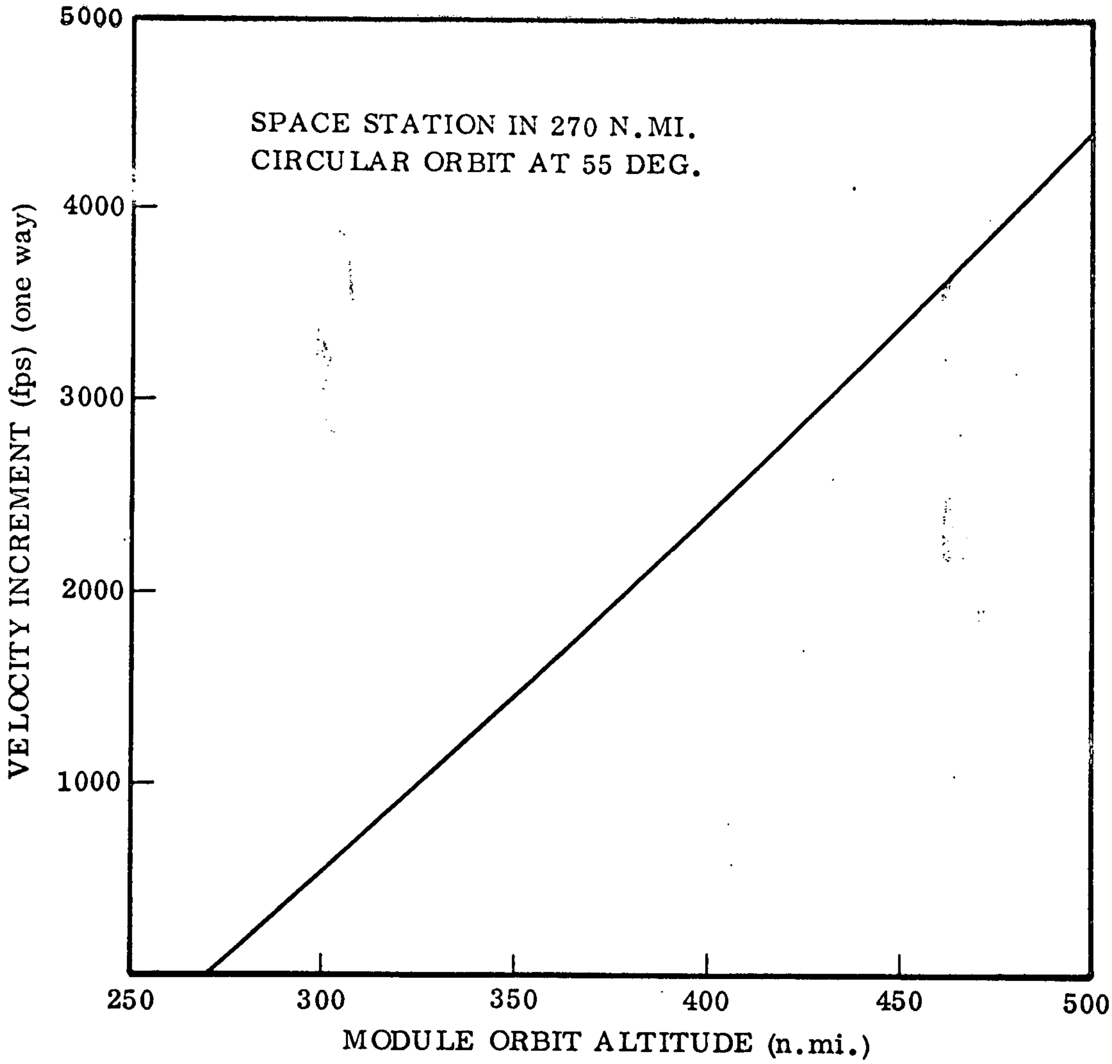


Figure 3-30. Velocity Required to Deliver or Return a Module to an Equal Precession Rate Orbit

This approximation is adequate when apogee and perigee altitudes do not differ greatly. However, as apogee altitude approaches synchronous altitude while the perigee remains close to the earth, the value of this approximation decreases; and the optimal division of the plane change angle between perigee and apogee should be determined.

Hohmann transfer velocity impulses at apogee and perigee are:

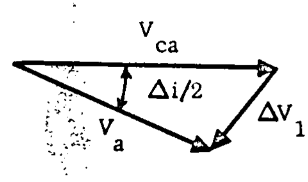
$$\Delta V_a = \sqrt{\frac{K}{r_a}} \left(1 - \sqrt{\frac{2}{1 + (r_a/r_p)}} \right)$$

$$\Delta V_p = \sqrt{\frac{K}{r_p}} \left[\sqrt{\frac{2\,(r_a/r_p)}{1 + (r_a/r_p)}} - 1 \right]$$

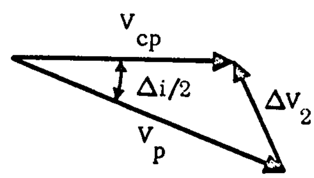
where ΔV_a = apogee velocity impulse

ΔV_p = perigee velocity impulse

and the combined Hohmann transfer and plane change velocity impulses applied at apogee (ΔV_1) and perigee (ΔV_2) are:



$$\Delta V_1^2 = \Delta V_{ca}^2 + V_a^2 - 2\, V_{ca} V_a \cos \frac{\Delta i}{2}$$



$$\Delta V_2^2 = V_{cp}^2 + V_p^2 - 2\, V_{cp} V_p \cos \frac{\Delta i}{2}$$

where V_{ca} = circular velocity at apogee

V_{cp} = circular velocity at perigee

$V_a = V_{ca} - \Delta V_a$

$V_p = V_{cp} + \Delta V_p$

3. Total ΔV for module delivery or recovery is then

$$\Delta V_t = \Delta V_1 + \Delta V_2$$

3.2.5.3 Conclusions. The preliminary conclusions drawn from a comparison of the two methods for operating experiment modules at orbits higher than that of the space station are:

a. At lower module altitudes (≲500 n.mi.) Method No. 2 (synchronized precession) is preferred. This method results in continuous coplanar space station and experiment module orbits. The synchronization period for Method No. 1 exceeds one year for altitudes of 500 n.mi. or less.

b. For the higher altitude (≈2000 n.mi.) Method No. 1 non-synchronized precession becomes a candidate for the preferred method due to the much lower ΔV requirements as compared to Method No. 2 at the high altitudes. The synchronization period at 2000 n.mi. is about once per four months which may be operationally acceptable.

c. In the region between ~500 to 2000 n.mi. altitude there is a tradeoff between the ΔV penalty for Method No. 2 vs. the infrequent service opportunities provided by Method No. 1.

3.2.5.4 Effect on Module Design Criteria. The conclusions drawn from the performance requirements for servicing modules in higher orbits are:

a. The ΔV capability required to return modules from orbits higher than 325 to 350 n.mi. appears to be better provided by a separate space tug vehicle rather than by inclusion in module designs.

b. The ΔV for return of modules from below 325 to 350 n.mi. is small enough to potentially be part of module design. However, experimentation advantages for orbits below 325 n.mi. are not sufficiently clear to warrant penalizing the baseline module design. If the experiment benefits are determined to be worth the additional ΔV, at a later date, this capability can be added without significantly affecting module baseline design.

c. In-situ servicing of higher orbit modules with a space tug carrying crew and service capabilities to the module, rather than returning the module to the station for servicing, should be considered.

3.2.6 FACTORS AFFECTING MODULE FREE-FLYING CAPABILITIES. For free-flying experiment modules, normal orbital operations will require an RCS capability for flight safety purposes. Augmenting this for delivery and orbital maneuvers appears quite economical (see Section 3.2.3).

However, for attached modules, free-flying capability is linked only to the programmatic and cost considerations listed below, and since no RCS is needed once attached modules are docked to the station, deleting this capability would result in a reduction in module production costs of about 30 million dollars for the eight attached modules. These considerations include:

a. Type of launch vehicles available at the onset of the experiment program.

b. Docking techniques selected for the shuttle orbiter - stand-off or hard dock.

c. Availability of space tug or other transport vehicle as part of the space station system.

d. Delivery technique used for modules that exceed the shuttle or launch vehicle capability to circular orbit at station altitudes (Ref. Section 3.1).

Table 3-25 summarizes the programmatic conditions where this reduction in module production cost is possible for the attached module case. Table 3-26 summarizes the equipment that can be deleted by removing free-flying capability from attached modules.

Review of Table 3-25 shows that (1) where a tug is not available, free-flying capability is required in all cases except for the case where the shuttle hard docks a module of less than 25,000 pounds, and (2) where a tug is available, free-flying requirements of attached modules is a consideration only in cases where module weight requires the use of an elliptical delivery orbit.

Current weight estimates of the attached modules (10% contingencies, no growth allowance) indicate that three out of eight attached modules exceed shuttle delivery capability to circular orbit, and seven out of eight exceed Titan IIIF capabilities to circular orbit. Considering an allowance for module growth, and a potential reduction in net shuttle payload by considering module deployment mechanisms weight as payload deductible, it is reasonable to assume that the elliptical delivery method by the shuttle may be needed for a significant number of the attached modules.

Section 3.2.3 of this volume presents the results of a study of the potential use of a tug or transporter vs. integral module propulsion.

Table 3-25. Program Conditions vs. Attached Module Free Flying Capabilities
R = Free Flying Capability Required
NR = Free Flying Capability Not Required

Case	Module Weight	Launch & Delivery Condition					
		Shuttle Launch Hard Dock Delivery		Shuttle Launch Stand-Off Delivery		Expendable Launch Vehicle	
		Tug	No Tug	Tug	No Tug	Tug	No Tug
A	<25000 lb	NR	NR	NR	R	--	--
B	>25000 lb		R		R	--	--
	Tug circ.	NR		NR			
	Tug not circ.	R		R			
C	<18000 lb	--	--	--	--	NR	R
D	>18000 lb	--	--	--	--		R
	Tug circ.					NR	
	Tug not circ.					R	
Cases Where Free-Flying Capability Reqd		Module wt >25k lb and tug does not circularize	Module wt >25k lb	Module wt >25k lb and tug does not circularize	All cases	Module wt >25k lb and tug does not circularize	All cases

Table 3-26. Equipment Requirements for Attached Modules (Reference Section 3.2.3)

A. Deletions possible by eliminating free-flying capabilities:

	Weight (lb)
Stability and Control System	70 pounds
Guidance and Navigation	56 pounds
Reaction Control System	868 pounds
Communication System	40 pounds
Totals	1,034 pounds
Total Cost (8 modules)	$30M *

* Costs include production only since DDT&E costs for these subsystems would be totally borne by free-flying modules. These subsystems are common between free-flying and attached modules and subsystem DDT&E costs are currently prorated between the two types of modules.

B. Additions required for use with a space tug:

Second docking port for four modules plus FPE 5.13C centrifuge (weight varies + 400 pounds to + 1,600 pounds)

Cost: $7M

SECTION 4

EXPERIMENT MODULE OPERATIONAL INTERFACES

Module operating requirements are based on the experiment modules being a part of the total space station system and, as such, deriving significant support from the other elements and being constrained to be compatible with these support elements. Modules are delivered to orbit by the earth-to-orbit shuttle (or expendable launch vehicles). Attached modules dock to the space station and remain docked for their normal mission life.

Free-flying modules dock to the station for initial activation/calibration, free-fly for experiment operations, and periodically return to the station for servicing. During the free-flying mode, experiment and module operations are controlled by the space station, and experiment data and module subsystem status are transmitted back to the station for processing, action, and retransmittal to ground.

Modules are also to be capable of being serviced while in the free-flying mode by the shuttle or other manned service vehicles.

The operational interfaces between module and other system elements are presented in the following paragraphs and graphically related in Figure 4-1.

System Element	Type of Interface
Section 4.1 Space Station	Power, data, thermal, pointing, stability, physical characteristics, and crew
	Torque
	RF
	Docking
	Suitcase experiment installations.
	Ground Communications
Section 4.2 Logistic System	Launch Vehicle
	Resupply of experiment update equipment, spares, propellant, test fluid, and film.

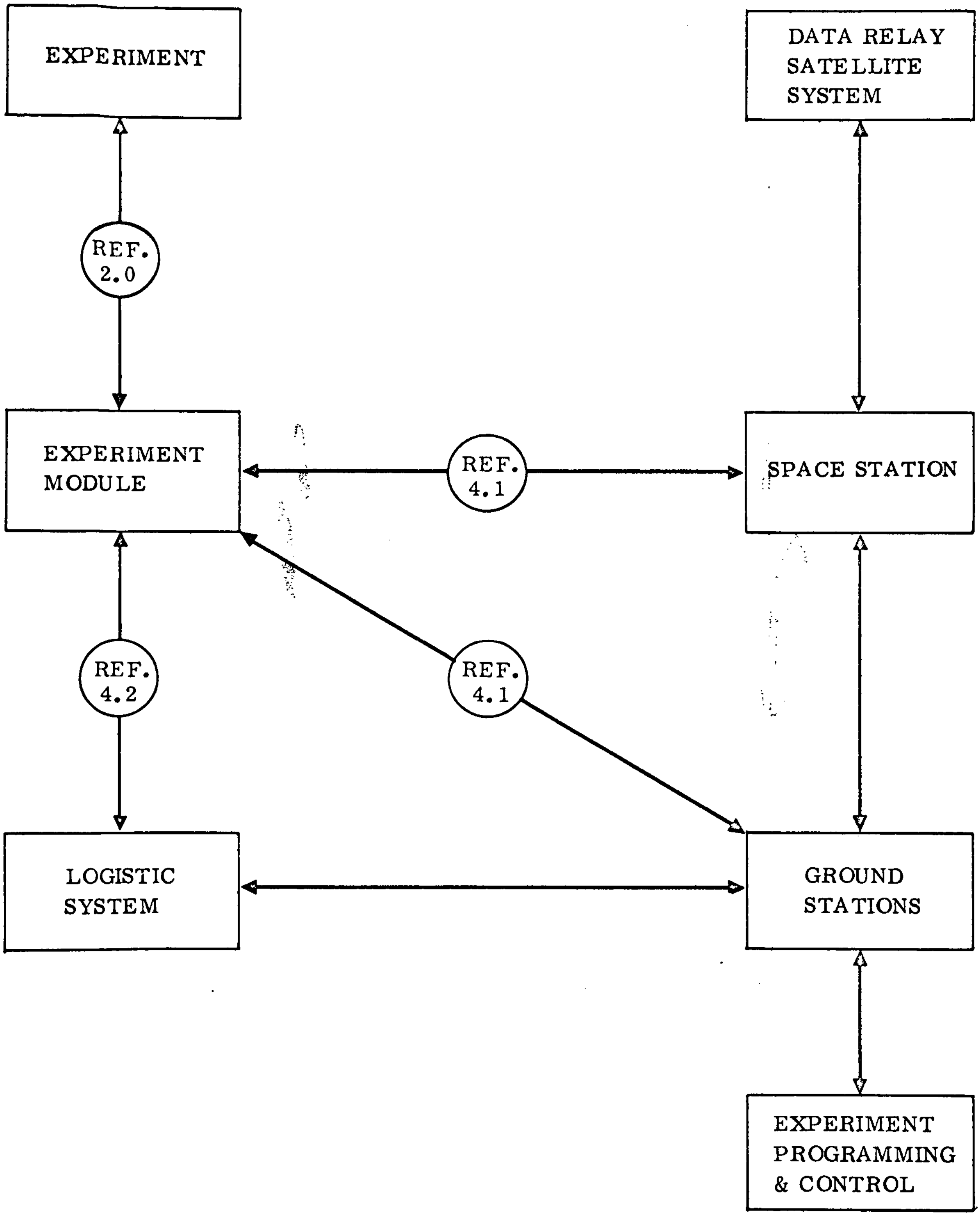


Figure 4-1. Module Operational Interfaces

Table 4-1. Space Station Interface Summary

Item	Maximum Values of Attached Modules	Maximum Values of Detached Module
Thermal	None	
Electrical - Peak Average	7.0 kW 5.2 kW	
Data:		
Hardline Digital Data (Rate)	26.4×10^6 bPS	
Hardline TV/Analog (Bandwidth)	4×10^6 Hz	
RF Digital Data (Rate)		1×10^6 bPS
RF TV/Analog (Bandwidth)		0.20×10^6 Hz
Telemetry, Tracking and Command	S-Band	S-Band
Magnetic Torque	None	
Pointing	Nadir ± 0.25 deg	

Propellant loading is required to support experiment operations for five detached modules. Attached modules could require topping off of propellant storage tanks after initial delivery to provide for module disposal or frequent shifting of docking port location if necessary to optimize thermal conditions. Propellant transfer resupply from the space station is performed by umbilical lines to the module RCS tanks. Annual resupply requirements for 6000 lbs. of hydrazine propellant are detailed in Section 4.2.

Table 4-2. Space Station Interface Requirements

EXPER. NAME	COMMON MODULE CM-1	CM-3	CM-4	FPE	OPERATIONAL MODE	POWER A AVG. P PEAK (KW)	MAX EXP DIGITAL DATA RATES (BITS/SEC)	ANALOG DATA/TV BAND-WIDTH (HZ)	PREFERRED MOUNTING LOCATION	LENGTH (FT)	DIAMETER FT)	LAUNCH WEIGHT SHUTTLE (LB ÷ 1000) (3)	TYPICAL MISSION LENGTH (MONTHS) (13)	DOCKING FREQUENCY (DOCKS/DAYS) (5)	DOCKING PORT USAGE (DAYS/DOCK)	CREW (10)	POINTING/ ORIENTATION	STABILITY	OTHER
X-RAY	X			5.1	DETACHED	(2) 0.69 P 0.53 A	8 x10^3	0.2x10^6 Hz	—	45.8	13.67	21.0	60	1/60 DAYS	(12) 2-3	2 MEN SERVICE (11)	N/A	N/A	NOTE (17)
STELLAR	X			5.2A	DETACHED	(2) 1.77 P 1.38 A	1x10^6	0.2x10^6 Hz	—	60.0	13.67	30.6	60	1/60 DAYS	(12) 2-3	2 MEN SERVICE (11)	N/A	N/A	NOTE (17)
SOLAR	X			5.3A	DETACHED	(2) 1.28 P 0.94 A	1x10^6	0.2 x 10^6 Hz	—	53.9	13.67	26.8	60	1/30 DAYS	(12) 2-3	2 MEN SERVICE (11)	N/A	N/A	NOTE (17)
HIGH ENERGY	X			5.5	DETACHED	(2) 0.99 P 0.84 A	10x10^3	0.2x10^6 Hz	—	27.0	13.67	26.1	60	1/30 DAYS	(12) 2-3	2 MEN SERVICE (11)	N/A	N/A	
PLASMA PHYSICS				5.7/5.12	ATTACHED	2.0 P 1.8 A	80 x10^3	10x10^3 Hz TV 3x10^6 Hz	—	38.9	13.67	20.8	24	N/A	N/A	2 MEN 5 TIMES/YR. 5-10 DAYS/ EXPER.	N/A	N/A	LARGE ANTENNA ERECTED ON MODULE
COSMIC RAY		X		5.8	ATTACHED	4.5 P 3.7 A	10 x10^3	—	TOP OR SIDE MOUNTED (14)	51.9	13.67	29.8	60	ATTACHED	CONTIN.	1 MAN 8 HRS/DAY 2 MEN FOR SET-UP	ZENITH ± 45°	NONE	ATTITUDE KNOWN WITHIN ± 2 DEG NOTE (17)
SPACE BIOLOGY			X	5.9/10/23	ATTACHED	5.5 P 5.2 A	220 x10^3	TV 2 CHAN. 3x10^6 Hz	—	59.1	13.67	32.4	24	ATTACHED	CONTIN.	2 MEN 8 HR/DAY EACH	NONE	5 × 10^{-4} g MAX	ISOLATED EC/LS NOTE (17)
SPACE BIOLOGY	EXPERIMENT UNIQUE			5.9/5.10	ATTACHED	INCL. IN 5.9/5.10/ 5.23	INCL. IN 5.9/10/23		ROTATION AXIS NORM TO ORBIT PLANE	20.0	9.5	INCL. IN 5.9/10/23	24	ATTACHED	USES 5.9/5.10-1 CONTIN.	INCL. IN 5.9/5.10-1	NONE	NONE	NOTE (17) TORQUE INTERFACE FRESH WATER WASTE WATER
EARTH SURVEYS			X	5.11A (1)	ATTACHED (1)	7.0 P 1.65 A	26.4 × 10^6	3.6 ×10^6 Hz TV 3x10^6 Hz	BOTTOM MOUNTED (1)	15.1	13.67	21.1	24	ATTACHED (6)	CONTIN.	2 MEN 8 HR/DAY EACH	± 0.25 DEG EARTH ± 60 CONICAL	0.02 DEG/SEC	NOTE (17)
CENTRI-FUGE	EXPERIMENT UNIQUE			5.13C	ATTACHED	0.51 A	25 x10^3	TV 3x10^6 Hz	ROTATION AXIS NORM TO ORBIT PLANE	20.0	9.5	6.8	24	ATTACHED	CONTIN.	1 MAN-CONDUCT 1 MAN-SUBJECT 8 HR/DAY EACH	NONE	2x10^3 g MAX 0.03 DEG/SEC^2 MAX	TORQUE INTERFACE FRESH WATER WASTE WATER
MATERIALS SCIENCE		X		5.16	ATTACHED	(3) 5.3 P 3.1 A	1x10^3	1 Hz TV 3x10^6 Hz	—	31.4	13.67	20.6	24	ATTACHED	CONTIN.	2 MEN 8 HR/DAY EA	NONE	5 × 10^{-4} g MAX	X-RAY EQUIP./ PERSONNEL INTERFACE NOTES (18), (17)
FLUID PHYSICS		X		5.20-1	ATTACHED	(4) 1.2 P 1.0 A	1x10^3	TV 3x10^6 Hz	—	31.4	13.67	15.9	24	ATTACHED	CONTIN.	2 MEN 8 HR/DAY EA.	NONE	5 × 10^{-4} g MAX	NOTES (18), (17)
FLUID PHYSICS	X			5.20-2	DETACHED	(4) 1.73 P 1.33 A	5.78x10^3	TV 6 CHAN. 3x10^6 Hz	—	37.9 (7)	13.67	31.9 (9)	3	40/90 DAYS	USES 5.20-1 AN AVERAGE OF 2 DAY/DOCK	INCL. IN 5.20-1	N/A	N/A	NOTES (18), (17)
FLUID PHYSICS	EXPERIMENT UNIQUE			5.20-3	DETACHED	(4) 4.33 P 1.73 A	6 x10^3	TV 3x10^6 Hz	—	(7) 27.8	13.67	7.8 (8) 36.1 (9)	6	25/180 DAYS	USES 5.20-1 AN AVERAGE OF 7 DAY/DOCK	INCL. IN 5.20-1	N/A	N/A	NOTES (18), (17)
FLUID PHYSICS	EXPERIMENT UNIQUE			5.20-4	DETACHED	(4) 1.53 P 0.50 A	6 x10^3	TV 3x10^6 Hz	—	(7) 27.8	13.67	9.6 (8) 37.7 (9)	12	10/365 DAYS	USES 5.20-1 AN AVERAGE OF 7 DAY/DOCK	INCL. IN 5.20-1	N/A	N/A	NOTES (18), (17)
COMPONENT TEST			X	5.22	ATTACHED	2.0 P 1.75 A	20x10^3	TV 3x10^6 Hz	SIDE OR BOTTOM	38.3	13.67	23.0	24	ATTACHED	CONTIN.	1 MAN 8 HR/DAY 2 MEN FOR SET-UP	± 2.0 DEG EARTH	0.02 DEG/SEC	WASTE WATER NOTE (18)
PHYSICS & CHEMISTRY		X		5.27	ATTACHED	2.6 P 2.4 A	1 × 10^3	TV 3×10^6 Hz		31.4	13.67	21.3	24	ATTACHED	CONTIN.	2 MEN 8 HR/DAY EACH	(16)	N/A	X-RAY EQUIP./ PERSONNEL INTERFACE NOTES (18), (17)

GENERAL NOTES

(a) Experiment modules require navigation, guidance data for initial or subsequent docking.

(b) Data functions and maximum values for attached and detached modules are shown in Table 2-1.

(c) Interface guidelines for EC/LS are shown in Table 4-3.

(d) Hydrazine propellant, cryogenic test fluid (LO_2, LN_2, LH_2) or other fluid resupply provided by space station through umbilicals. Ref. Section 4.2 for logistics.

(e) Personnel eye protection is required from reflected laser beams. Filters, eliminating radiation above 7,000 angstroms are required on space station windows from which exposure to reflected signal may occur. EVA suit viewing plates will require similar protection.

(f) EVA operation should not provide contamination sources (e.g., moisture) for astronomy modules.

(g) Voice communication required to any module while attached and manned.

SPECIFIC NOTES

(1) Baseline earth survey module is attached to the bottom of the space station. Another operational mode (dual mode) uses an attached section and a free-flying section.

(2) Power for detached modules when docked reflects sequential and parallel checkout of subsystems and experiments.

(3) Includes circularization and docking propellant. Does not include interstage adapter or nose cone weight.

(4) Combined power for 5.20-1 and -2 or in -3 and -4 shown in Figure 4-2.

(5) Docking frequency based on experiment requirements. Module servicing may require additional docking.

(6) In detached mode, typical mission duration 7 days. Could use attached section dock up to 28 days.

(7) Includes propulsion slice and CM-1.

(8) Includes test fluids.

(9) Fully loaded operating weight including propulsion slice.

(10) Experiment crew only. Flight operations crew required for detached module rendezvous docking, maneuver and station-keeping.

(11) Astronomy modules require operating crew in back-up mode.

(12) Time required for equipment to outgas in vacuum after exposure to atmosphere before high voltage elect. components are energized.

(13) Mission length and unspecified in most cases.

(14) Detectors must not view horizon. Change in detector orientation may require change in module or space station orientation 1/month.

(15) Does not include 24,000 lb. total absorption and assembled on-orbit from segments weighing a minimum of 350 lbs.

(16) Sustained g experiments conducted in a detached module.

(17) Film storage vault and processing required.

(18) Experiments produce contaminants such as N_2, H_2, He, metal particles, film processing chemicals, etc., which must be vented overboard or controlled by space station.

FPE	Title	Total Power (kw)
5.8	Cosmic Ray - Peak	4.5
	- Avg	3.7
5.9/10/23	Bio Lab - Peak	5.5
	- Avg	5.2
5.11A	Earth Survey - Peak	7.0
	- Avg	1.65
5.27	Physics & Chem - Peak	2.55
	- Avg	2.35
5.16	Materials Lab - Peak	5.3
	- Avg	3.05
5.20	Fluid Physics - Peak	1.2
	- Avg	1.0
5.22	Comp Test - Peak	2.0
	- Avg	1.75

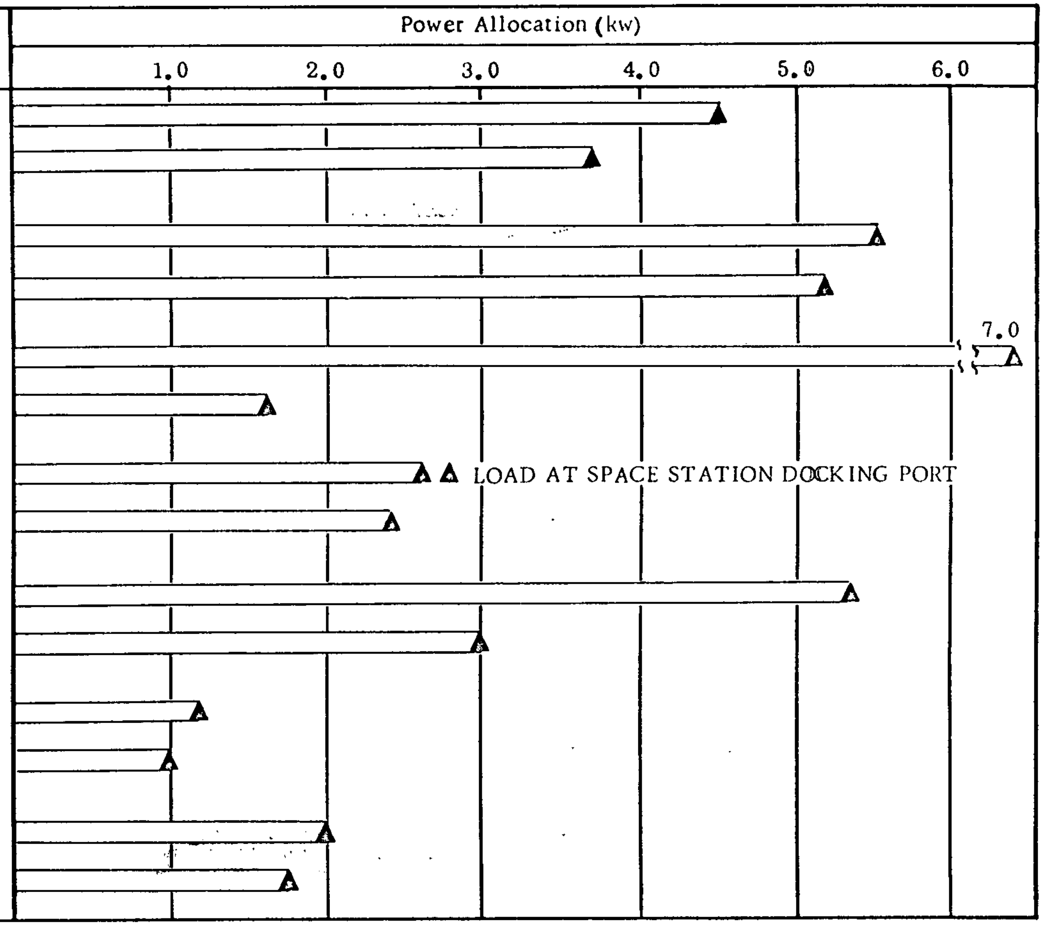


Figure 4-2. Space Station Interface Loads, Power to Attached Modules

FPE	Title	Total Power (kw)
5.1	X-Ray - Peak	0.693
	- Avg	0.526
5.2A	Stellar - Peak	1.383
	- Avg	1.176
5.3A	Solar - Peak	1.283
	- Avg	0.936
5.5	High Energy - Peak	0.993
	- Avg	0.843
5.20-1/ 5.20-2	Fluid Physics - Peak	2.53
	- Avg	1.93
5.20-1/ 5.20-3	Fluid Physics - Peak	5.13
	- Avg	2.33
5.20-1/ 5.20-4	Fluid Physics - Peak	2.33
	- Avg	1.10

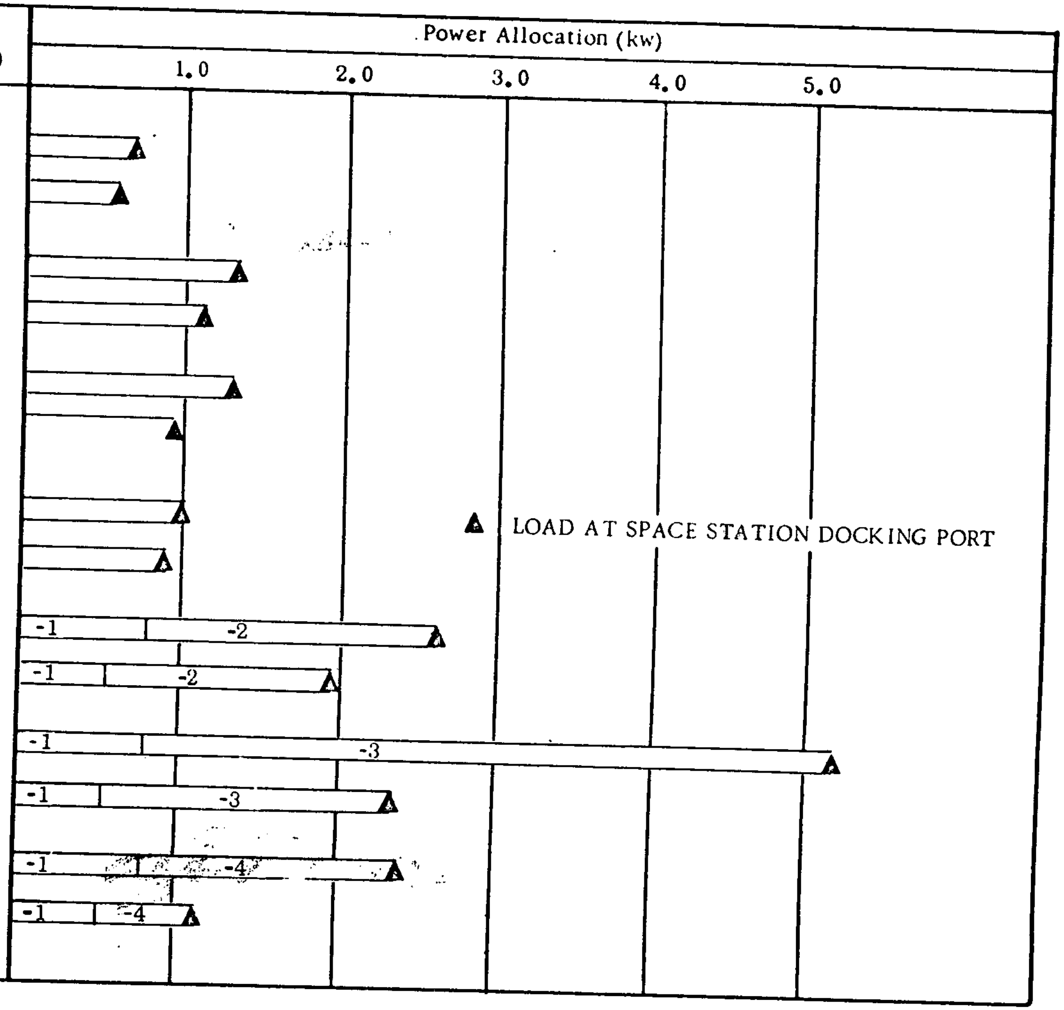


Figure 4-3. Space Station Interface Loads, Power to CM-1 Modules while Docked, Excluding Stability and Reaction Control

Table 4-3. Source of EC/LS Functional Support

EC/LS FUNCTIONS	CM-1 WHILE ATTACHED*	CM-3	CM-4 NOMINAL	CM-4 BIO-LABORATORY
Air Flow Control	EM/SS	EM/SS	EM/SS	EM
Air Cooling/Heating	EM	EM	EM	EM
Air Purification and Monitoring	SS	SS	SS	EM
Atmospheric Pressure Control	SS	SS	SS	EM
Atmospheric Gas Supply	SS	SS	SS	SS
Pressure Suit Circuit	EM/SS	EM/SS	EM/SS	EM/SS
Water Processing and Supply	SS	SS	SS	SS
Water Storage and Dispensing	SS	SS	SS	EM
Metabolic Waste Collection	SS	SS	SS	EM
Nutrition, Hygiene, and Waste Management	SS	SS	SS	SS

Notes: SS = Space Station
EM = Experiment Module
* CM-1 does not require EC/LS support while detached (depressurized and unmanned)

4.1.3 TORQUE INTERFACE. Two of the experiment unique payloads contain centrifuges. FPE 5.9/5.10/5.23 Space Biology contains the bio-centrifuge. FPE 5.13C Centrifuge contains the manned centrifuge for biomedical experiments. In the centrifuge design recommended as a result of this study, both centrifuges have a single rotating head attached to and rotating external to the supporting module or space station. Counter momentum systems are not considered part of the centrifuge designs and therefore during starting and shutdown operations torque will be transmitted to the supporting element. In addition, the mounting location of these two centrifuges should be made in consideration of precession torques generated by space station angular maneuvers. Figure 4-4 shows the centrifuge operating characteristics.

The growth version of FPE 5.8 Cosmic Ray lab module contains two superconducting magnet coils. With this experiment design concept, torque interaction with the space station is eliminated.

4.1.4 DOCKING INTERFACE. Figure 4-5 depicts the current module/space station docking interface concept. The probe and drogue mechanism is based on a NASA concept. The experiment module design uses similar docking elements, but reverses two of the components to provide a "neuter"mechanism. This concept permits operational flexibility in that any module can dock to any other module, or to the space station, space shuttle or other orbital vehicle. A nominal 5-inch snubbing stroke is provided for the probes, plus an additional 5-inch stroke to accomplish seal mating and lock-down under positive control. Umbilicals around the docking ring circumference are mated manually after docking is completed and may subsequently be covered with access panels.

Each experiment module and the propulsion slice incorporates at least one docking mechanism. The following modules include a second docking mechanism since they function as basic labs servicing other existing or projected lab elements.

FPE 5.9/5.10/5.23	Space Biology Lab
FPE 5.16	Materials Science and Processing Lab
FPE 5.20	Fluid Physics Lab
FPE 5.22	Component Test and Sensor Calibration Lab
FPE 5.27	Physics and Chemistry Lab

Three experiment unique payloads utilize docking mechanisms. The fluid physics intermediate term cryogenics (FPE 5.20-3) and long term cryogenics (FPE 5.20-4) experiments each include two docking mechanisms which permit exchanging the test tanks on orbit. The manned centrifuge (5.13C) incorporates a single docking mechanism.

4.1.5 RF INTERFACE. Tables 4-4 and 4-5 summarize the expected experiment module and related elements rf links and rf emanations.

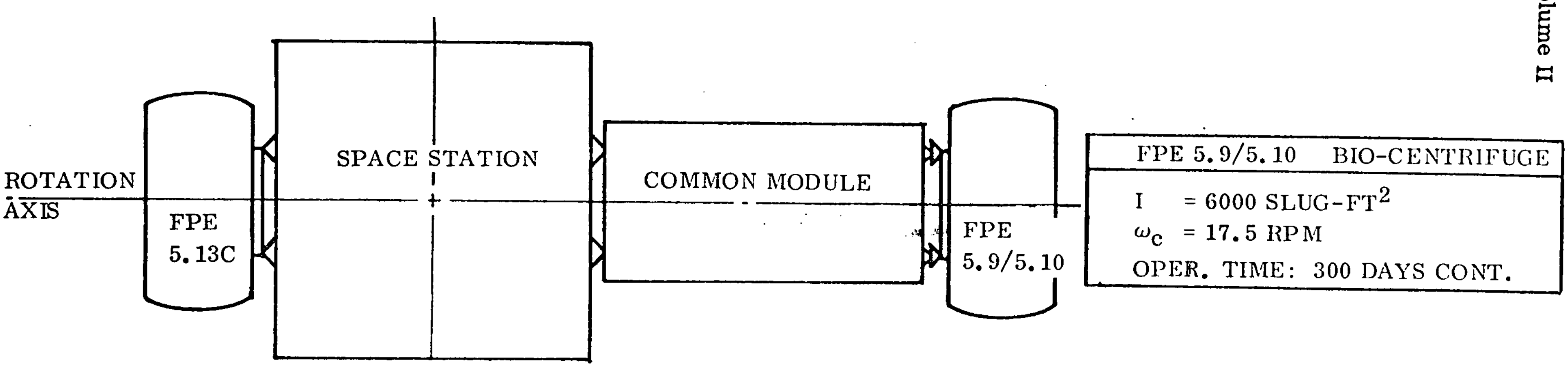
Table 4-4. Module/Station RF Links

Link No.	Freq (MHz)	Nominal Range (N.Mi.)	Location	Function
1	2200-2300	500	All detached mod. + sub-satellites	Wideband digital
2	2200-2300	500	All detached modules	TV*
3	1800	500	Space station or ground	Command

*Up to 6 TV links required for FPE 5.20 Fluid Physics

Table 4-5. Module RF Emanations

Operational Frequency or Band	Power	Location	Function
250 MHz	1 Milliwatt	FPE 5.9/5.10 Inside Experiment	Experiment Telemetry
250 MHz	1 Milliwatt	FPE 5.13C Inside Experiment	Experiment Telemetry
5-10 GHz	2500 Watt Total Input Power	FPE 5.11 External	Experiment Sensors
1.2 GHz	50 Watt Input	FPE 5.11 External	Experiment Sensor
8 GHz	130 Watt Input	FPE 5.11 External	Experiment Sensor



FPE 5.13C MANNED CENTRIFUGE						
Experiment	I Slug-Ft^2	ω $\frac{RAD}{SEC}$	α $\frac{RAD}{SEC^2}$	T Ft-Lb	M_o Ft-Lb-Sec	Oper. Time $\frac{Hrs}{90 Days}$
Mobility	4500	1.44	.0360	162	6480	41
Work Bench	↑	1.18	.0245	110	5300	48
Hygiene		1.47	.0368	166	6510	113
Reentry		4.90	.1230	554	22000	4
Cardio Vas.		4.58	.0763	343	21000	16
& Vesti.		2.40	.1200	540	10800 }	142
Effects	↓	2.40	.2400	1080	10800 }	
Therapeutic	4500	2.70	.1590	715	12150	7

Figure 4-4. Torque Interface

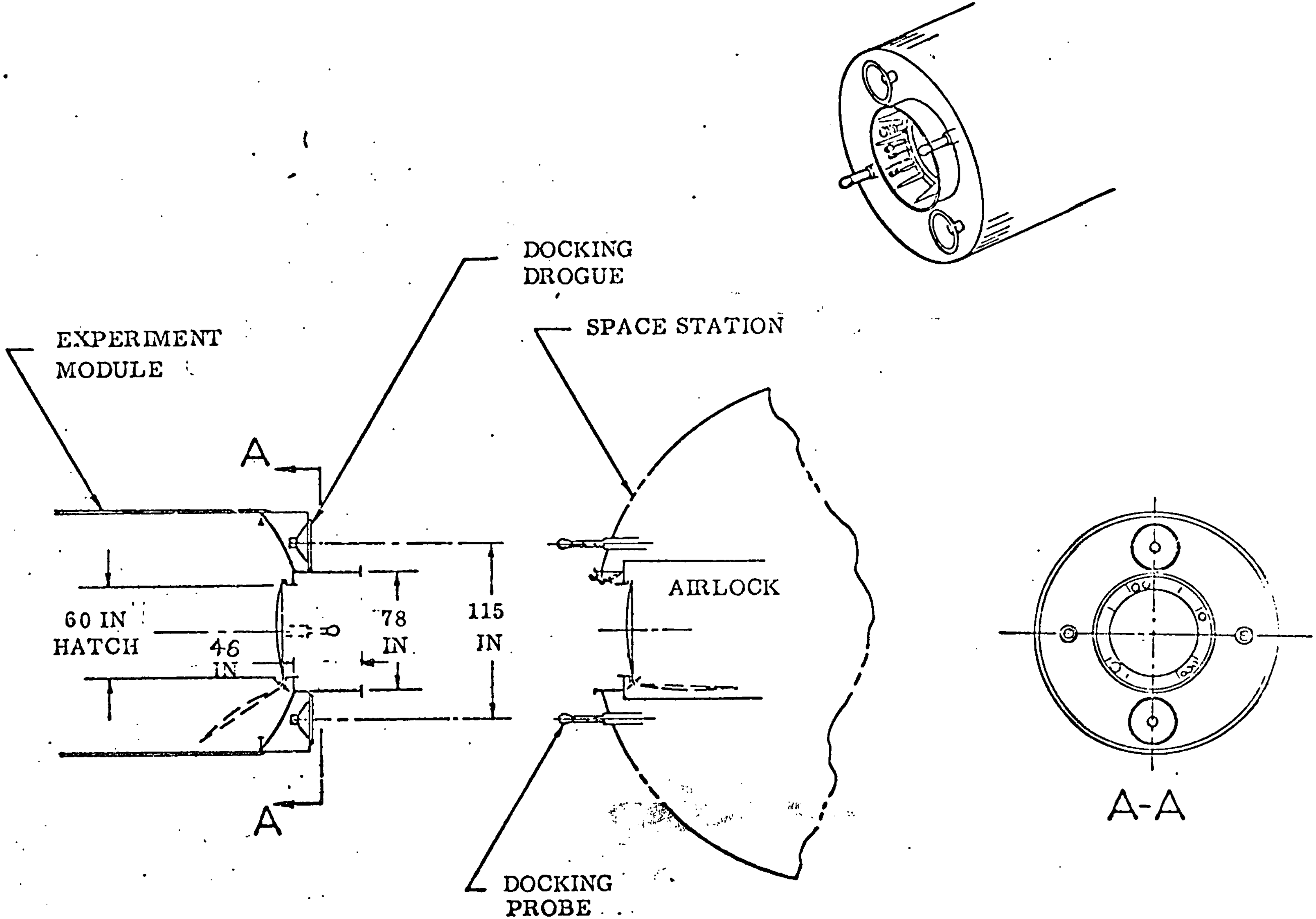


Figure 4-5. Experiment Module/Space Station Docking Interface

4.1.6 "SUITCASE" EXPERIMENT INSTALLATION. Suitcase experiments are those carry-on type experiments that do not require separate modules. These are: FPE 5.17 Contamination Measurements, and FPE 5.18 Exposure Experiments. Experiments in this category are accommodated by either attached or detached modules or the space station, depending on the experiment requirements. Tables 4-6 and 4-7 show those suitcase experiments which have been allocated to the space station.

Station mounted experiments consist of active measurement instrumentation and passive samples for contamination and exposure assessments related to FPE 5.17 Contamination Measurements and FPE 5.18 Exposure Experiments.

4.1.7 GROUND INTERFACES. Module interfaces directly with the ground during the on-orbit operational phase are limited to a back-up communications link. Compatibility with MSFN stations is provided in module subsystems for tracking, telemetry, and control functions.

4.2 LOGISTIC SYSTEM INTERFACES

Experiment modules have been designed based on certain characteristics of both expendable launch vehicles and space shuttle. These characteristics then constitute an assumed interface with these vehicles and are presented in the following paragraphs.

4.2.1 EXPENDABLE LAUNCH VEHICLE INTERFACE. The following are interface criteria used to establish module design criteria for use with Int 20, S-1B or T-III launch vehicles:

a. Payload cylindrical length: 60 ft.

b. Payload diameter: 15 ft.

c. Peak acceleration: 6 g axial, 3 g lateral.

d. Payload fairing: provided by the payload when required.

e. Launch vehicle provides navigation, guidance data to module prior to separation.

f. Separation retro provided by the launch vehicle, separation systems provided by module.

g. Nosecone and payload interstage -- compatible with the payload diameter.

h. Typical payload delivery to transfer ellipse or circular orbit at the station altitude (space station is assumed at 270 n.mi. altitude, 55° inclination).

i. Module provides circularization at apogee of transfer ellipse.

Table 4-6. FPE 5.17 Contamination Measurements – Space Station Requirements Location Selection Based on Measurements Best Suited to Experiment Objectives

Expt. No.	Experiment Title	Operating Mode Active/Passive	Experiment Equipment	Location Criteria Orientation, Distance & Contaminants to be Measured	Measurement and Evaluation Method	Support Requirements Crew	Power Data	Space Station Mounting Location and Requirements
1.	Sky Background Brightness Measurements	Active	(1) Photometer 25#, 1.8 ft^3 mounted on 2 axis table. (1) Operating panel operating temp photom. - space amb. panel 70F ±20F.	Maximize coverage of celestial sphere. Pointing 0.5. Deploy to 8 ft from station. Radial direction.	Direct real time reading from photometer.	IVA — Operate scan	15 W to 60 W — 350 Sps	Mount on boom on exterior of station coincident with orbital plane, to achieve max. spherical coverage. Mount panel inside station.
2.	Particle Sizes & Distribution Measurements	Active	(1) Coronagraph 10 #, 1.6 ft^3 mounted pointing table. (1) operating panel operating temp corona. - space amb. panel 70F ±20F.	Maximize solar view. Pointing 0.1 deg.	Direct real time reading from coronagraph, TV recording	IVA — Oper.	50 W to 75 W — TV	Mount on boom for solar viewing.
3.	Real Time Contamination Monitor	Active	(50) Microbalance instr. 5"×8" ×1" - 10# ea. (1) panel for each set of instr. - 15#. Oper. temp. Instr. - space amb. Panel 70F ± 20F.	Various locations on station & module, exterior surfaces.	Direct reading from microbalance instr. Optical surfaces, solar panels, thermal control surfaces.	EVA — Place & retrieve instr.	35 W to 60 W per set	Mount microbalance units adjacent to critical surfaces, near RCS, dump ports, optical surfaces, etc. Mount panel in station.
4.	Optical Surface Degradation	Passive	(1) Carousel type sample array with 12 samples of optical matls., and measuring instr. Total 200 samples/2 yrs. Oper. temp. — space amb.	Orient carousel axis to >45° with line to sun, locate on station in area free of RCS plume, dumps, etc.	Direct readout from instr. in carousel. Samples returned to earth for further analysis.	EVA — Place & retrieve samples	10 W to 100 W — 10 Hz 100 Hz	Mount carousel on exterior of station. 45° from sun view, relatively clean area; free of RCS, dumps. Mount panel in station.
5.	Thermal Control Surfaces Degradation	Passive	(4) Exposure strip racks each with 1 strip of 10, 1" dia. sample thermal coatings. 20# each, 3"×12" racks. (1) hand-held (EVA) reflectometer.	Mount on exterior of space station in areas free of direct RCS plume station dump ports, etc. Maximize solar exposure.	In situ measurement of reflectivity using hand-held reflectometer.	EVA — Place, retrieve, meas.	None	Mount racks on exterior of station in max. solar exposure, free of RCS and dumps
6.	Surface Adsorbed Contaminant Measurement	Passive	(1) set of 12 collectors 4"×8" ×.85"@8# ea. (4) microbalance units. 5"×8"×4" @ 10# ea. Total (4) sets collect/2 yrs.	Mount in grid pattern of RCS engine plume. Maximize solar exposure	Real time reading from microbalance instr. Collectors returned to earth for analysis.	EVA — Place/ retrieve collect	35 W —	Mount collectors and microbalance instr. in grid pattern on station exterior in direct RCS plume area. Maximize solar view.
7.	Contaminant Cloud Composition Measurement	Active	(6) Mass spectrometers 8"×8"×9" (@ 8# each) (1) Operating Panel	Maximize spherical coverage of station. From 1 ft. outwards to map contaminant cloud.	Direct reading from spectrometers	IVA — Oper.	24 W 1 Mhz Thermal control instr.	Mount on booms to cover outwards to 50 ft. from station
8.	Contaminant Dispersal Measurements	Active	(2) Cameras combined TV and photographic. 10"×12"×18" @ 20# each. (1) Operating Panel	Locate to view all eject ports & sources of leakage - RCS dumps, etc.	Direct TV POW film	IVA — Oper.	25 W to 150 W TV	Mount on booms to cover all normal eject points.
9.	Charged Contaminant Cloud Experiments	Active	(2) Electric field meters. (1) Magnetometer, 10"×12"× 15" @ 25#. (1) Operating Panel.	Maximize spherical coverage around station out to 60 ft.	Direct reading from instrument.	IVA — Oper.	8 W	Mount on booms to cover exterior of station outwards to 60 ft.

Table 4-7. FPE 5.18 Exposure Experiments — Space Station Requirements Location Selection Based on Exposure to Environment Best Suited to Experiment Objectives

Expt. No.	Experiment Title	Operating Mode Active/Passive	Experiment Equipment	Location Criteria Orientation Sensitivity to Contamination	Measurement & Evaluation Method	Support Requirements Crew	Support Requirements Power Data	Space Station Selected Mounting Location and Requirements
1.	Meteoroid Composition	Active	3'× 3' target plate. Impact flash spectrom. Impact mass spectrom. Wt = 25#. Vol = 10 ft^3 per instrument.	Pointed away from earth - min. 50% time. Not sensitive to contamination.	Direct reading from mass spectro. Film from flash spectro. plate returned to earth.	EVA Film & Plate Retr.	50 W. 30 Hz Thermal control of film	For earth oriented SS, mount target plate and spectrometers on top exterior of SS. Provide power and thermal control of film.
2.	Meteoroid Flash Analyzer	Active	4 channel optics sensor assy — radiometer, photo-emissive diode. Electronic assy — Wt. 14# for 2 pkgs. -20F to 120F oper. temperature	Pointed towards center of earth - 10°. Field of view - 730°. Very sensitive to any contaminants on optical surfaces.	Direct readings from sensor electronics	IVA on/off	7.5 W. 100 Hz Thermal control of sensor & elect. reqd.	Not acceptable for SS mounting due to contamination expected.
3.	Meteoroid Impact & Erosion	Passive	Vicor glass panel 60"×16"×3" Wt. 13#	Pointed away from earth zenith - 90°. No shadowing. Sensitive to RCS plume impingement or other sources of erosion.	To be returned to earth for analysis - weight & light transmission. No evaluation in space	EVA	None	Probably not acceptable for SS mounting due to RCS on docking modules, logistics craft. Potential impingement.
4.	Meteoroid Velocity	Active	3'×4' detector consisting of sets of (2) 12"×12" capacitors fronting soft aluminum plates (6"×12") with connected logic network. Wt 100#, 12 sq. ft. × 6" thick.	Pointed away from earth zenith 90°. No shadowing. Not sensitive to contamination.	Direct reading from logic network. (3) 12"×12" det. plates to be selected & returned to earth for analysis.	EVA Detector Retrieve	10 W. 100 Bits Thermal control det. & logic.	For earth oriented SS, mount detector assy on top exterior of SS. Install detector logic on interior of module. Provide power & thermal control. Thermal control of detector assy to -110F to +260F.
5.	Meteoroid Flux & Velocity	Active	(3) independent optical systems mounted in 1.3 cu. ft. box, nonparallel aimed. Wt. =5#. Oper. temperature -20 to +110F.	Pointed away from earth zenith 45°. FOV - 10° (for all 3 instru. Very sensitive to light scattering & to deposition on optical surfaces.	Direct reading from electronic system in optical instruments.	IVA on/off	2 W. 400 Bits Thermal control.	Not acceptable for SS mounting due to contamination expected.
6.	Orbital Fatigue	Passive	(3) test specimen strips. 0.1"× 0.5"×6.0" long. (1) fatigue test machine. 15"×4"×2" - 35#	No specific orientation. May or may not be sensitive to contamination effects. Best test may be to expose to variety of environments.	Specimens fatigue tested to failure prior to exposure to station atmosphere, using in-space fatigue tester. Failed specimens returned to earth.	EVA Retrieve	100 W. 1 per min.	Mount test specimens (2) on station exterior in variety of environments. Mount fatigue test machine at convenient location free of environmental extremes.
7.	Spacecraft Surfaces	Passive	(4) 1'×1' thermal control coated specimens. (1) hand held (EVA) reflectometer. (1) color camera (hand held).	Maximize exposure to sun. No shadowing. Sensitivity to contaminants which affect reflectivity or endurance of thermal coatings.	In situ measurement of reflectivity of thermal coating at 1, 3, 6, 12 & 24 mo. exposure periods. Specimens returned to earth after mission for further analysis.	EVA Reflect. meas. & conduct fatigue test	Self contained in reflect.	Not acceptable for SS mounting due to contaminants & RCS firings.
8.	Material Bulk Properties	Passive	(50) samples of typical spacecraft materials. 1"×6"×6" approx. 2# each.	Maximize exposure to sun. No shadowing. Sensitive to any source or type of contaminant.	Pre & post exposure measurements of bulk properties using space or earth labs. at 1, 3, 6, 12, & 24 mos.	EVA Retrieve spec. IVA - test	None	Not acceptable for SS mounting due to contamination.

4.2.2 SPACE SHUTTLE INTERFACE. The following are interface criteria used to establish module design criteria for use with the space shuttle:

a. Maximum time to on-orbit is 48 hours (24 hours pad + 24 hours phasing) assuming that loading, topping, and chilldown on pad using umbilicals will be a requirement.

b. Experiment modules will be self-sustaining while contained in the shuttle/ payload compartment.

c. Experiment module is the active vehicle for docking to the shuttle. However, the shuttle will have the capability of active docking to the module. Shuttle will provide the active electronics for dockings.

d. Shuttle will provide payload deployment mechanism and standardized payload mounting.

e. Maximum payload envelope is 15 ft - 0 in. dia. x 60 ft - 0 in. long.

f. Limit load is 3 g in any direction.

g. Modules are loaded and checked out prior to shuttle movement to pad.

   1. Loaded horizontal or vertical.

   2. Five days maximum time to pad.

   3. Umbilicals are provided into cargo bay from ground/booster liftoffs.

   4. Doors closed at T-2 hours or as required by launch operation.

   5. Perishables supplied through T-0 from ground support.

   6. Emergency access to the experiment module will be provided on the launch pad.

h. No cargo bay environmental control is available during flight. Prior to liftoff cargo bay is cooled as required from ground sources. No cargo bay acoustical level control is provided. Assume 24 hours between liftoff and dock on-station. All module thermal control is self-contained during this period.

i. Payload weight is 25,000 lb to 270 n. mi. x 55° inclination orbit.

j. Experiment modules containing hazardous material will have self-contained protective devices or provisions against all hazards.

The primary structural tiedown interface between the experiment module payload and the shuttle orbital payload compartment is through a system of six tiedown pins, four of which are located on two sides of the module and two at the bottom.

Longitudinal loads are taken by the two horizontal pins located nearest the module center of gravity; vertical loads are reacted by all four of the horizontal fittings.

Lateral or torsional loads are reacted by all six of the fittings.

Auxiliary sway fittings will be required for some of the longer experiment configurations such as the three-meter stellar telescope and the 1-1/2 meter XUV solar telescope.

The end view of the CM-1 baseline module (Figure 4-6) illustrates the accommodation within a shuttle payload bay having a circular envelope of 15 feet. The 13 feet 2 inches dimension is the pressure shell inside diameter. Exterior to this shell is the insulation, meteoroid bumper/radiator panels with an outside diameter of 13 feet 8 inches.

The solar cells arrays, RCS engines, and magnetic torquing bars have been configured for launch stowage within the eight-inch annulus. The solar cell arrays consist of flat panels tangent to the module diameter. These wrap around the module exterior and are secured against the meteoroid bumper. The five-element bar magnet is arranged in a flat configuration of two rows to lower the stowed profile. The elevation and azimuth drive mechanisms are also configured to maintain a low profile.

The module-to-shuttle support fittings project to the extremes of the 15-foot-diameter payload bay.

4.2.3 LOGISTICS RESUPPLY REQUIREMENTS. Estimates of logistics items to be delivered to orbiting experiment modules include updated experiment apparatus, spares needed to replace failed module equipment, propellant consumed in stationkeeping, maneuvering, and docking, and other expendables such as film, test fluids, batteries, and pressurizing gases, and are shown in Figure 4-7.

Propellant consumption for stationkeeping astronomy modules is variable and is based on an average year (CIRA model 5 atmosphere) for average module ballistic coefficients. Docking propellant is also variable and can be reduced by extending the docking frequency. A typical frequency of 60 days was used for astronomy modules.

Module spares quantities are based on estimates of sparing level and MTBF.

Large propellant usage occurs for fluid physics (FPE 5.20) due to frequent docking and for sustained g requirements. Components testing (FPE 5.22) incorporates long term fuel cell tests and other experiments requiring considerable test fluids.

Experiments -- assuming all in operation at one time (worst case) -- require approximately 100,000 pounds of supplies each year, consisting chiefly of propellants for sustained-g fluid physics experiments, cryogenics for fuel cell component tests, and biology laboratory makeup atmosphere gases. Requirements for film, specimens, and experiment update equipment appear relatively modest.

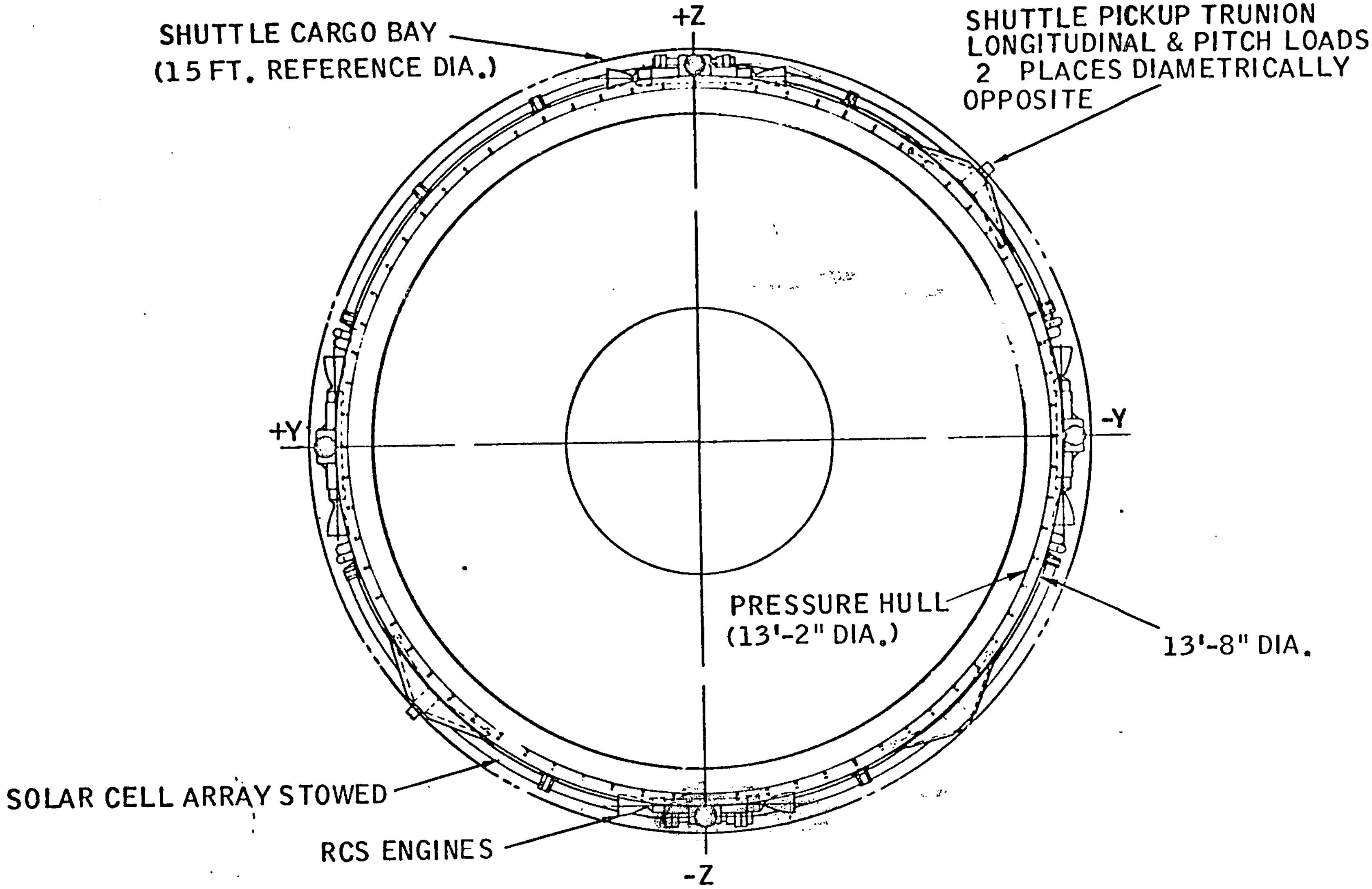


Figure 4-6. Baseline Module Clearance, Shuttle Cargo Bay

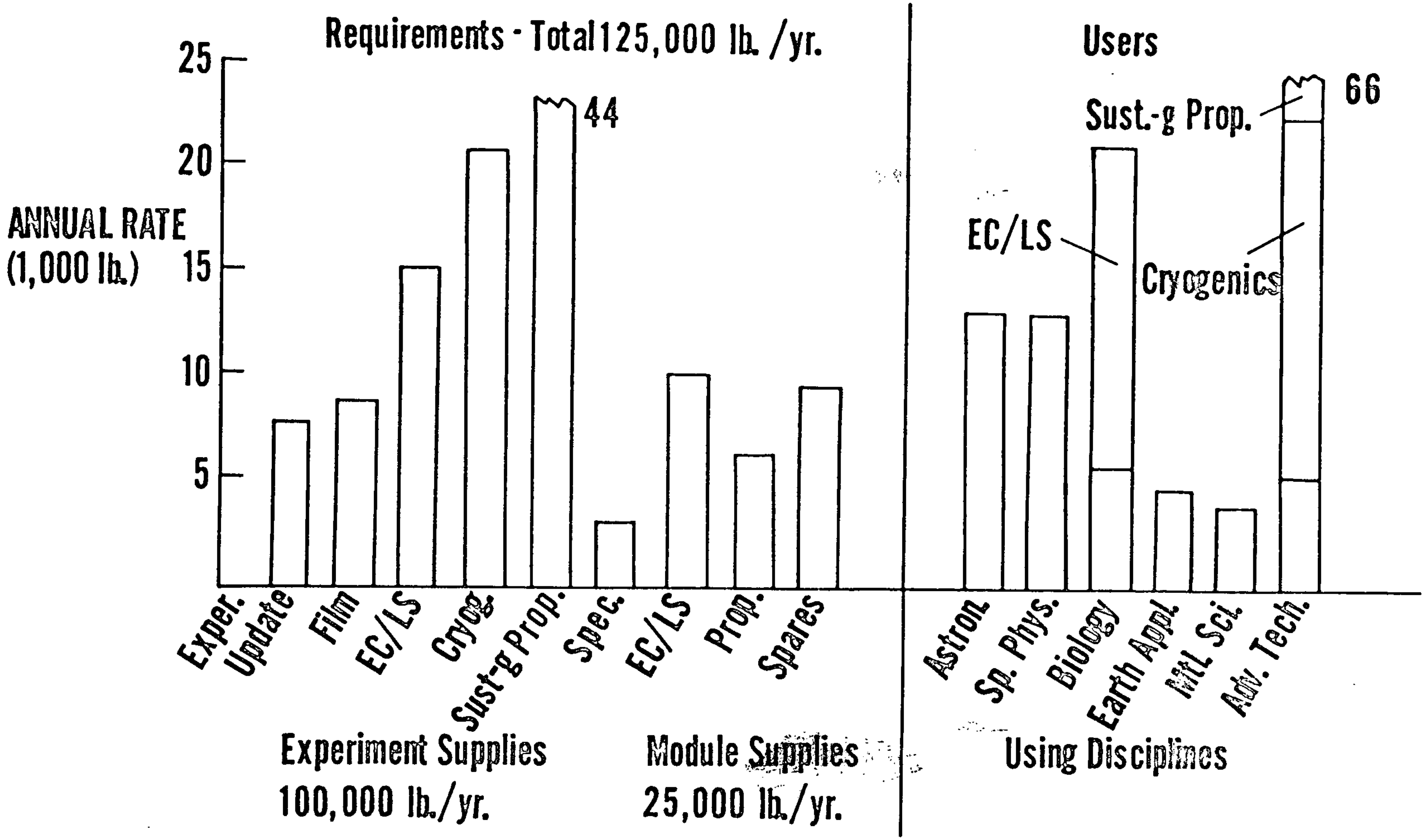


Figure 4-7. Experiment & Module Logistics

Experiment module supply requirements (again, worst case, all in operation) are about equally divided between atmosphere makeup (leakage in station-to-module dock, and module structure and hatches), propellants for free-flying modules, and subsystem spares including replacement batteries and solar panels -- resulting in a total of approximately 25,000 pounds per year.

Detailed logistics weight estimates for delivery to orbit are shown in Tables 4-8 through 4-11. The following categories of logistics were established for purposes of the analyses and each is shown in the form of annual rates:

a. Experiment update requirements.

b. Propellant (stationkeeping, docking, sustained g thrusting).

c. Spare including components, batteries and solar panels.

d. Other, such as film, pressurizing gas, and experiment test fluids.

The following paragraphs discuss basic assumptions related to each category.

Experiment apparatus updating is considered fundamental to the experiment module program throughout the mission lifetime. Typical mission lifetimes and update frequency were estimated for each FPE. An experiment weight breakdown was prepared and average annual equipment updating weights were generated.

Table 4-8 shows a sample of the method used to derive experiment update equipment logistics requirements. Table 4-9 summarizes experiment updating logistics for each FPE.

Propellant consumption for stationkeeping astronomy modules is based on average year atmospheric data (CIRA Model 5). An average module ballistic coefficient of 20 lb/ft^2 and I_{sp} of 220 sec was used for purposes of analysis. The docking interval for astronomy modules was set at 60 days. Table 4-10 summarizes propellant logistics. Fluid physics docking totaled 75 for FPE 5.20-2, -3 and -4 over about a year period; however, propellant consumption for fluid physics experiments is mostly determined by sustained g thrusting requirements. Reduction in docking frequency would contribute to reduction of operational propellant for all detached modules. Substantially all of the resupplied propellant is hydrazine.

Both experiment and module spares will be required during the mission lifetime. Currently, only module spares weight has been estimated.

Pressurizing gas is assumed to be required for three conditions: (1) initial pressurization of modules when delivered to orbit, (2) daily losses when docked estimated at about 2 lb/day, and (3) pump down losses after each docking arbitrarily set at 5% of the pressurized volume.

Table 4-8. FPE 5.2A Stellar Astronomy Experiment Update Logistics

Item	Weight (lb)		Updating Required
Primary Mirror	4000		No
Primary Mirror Supports	500		No
Insulation	310		No
Telescope Truss Work	3000		No
Secondary Mirror	150		No
Secondary Mirror Supports	240		No
Flip Mirror	100		No
Photometer	30	—385	Yes
Polarimeter	30		Yes
Spectrographs	65		Yes
Cameras (2)	160		Yes
Video	100		Yes

Batteries and solar panels are assumed to last for two years. Other logistics requirements including film and large quantities of cryogenic test fluids for Components Test FPE 5.22 and Fluid Physics FPE 5.20. Table 4-11 summarizes the other logistics requirements.

Return logistics requirements are generally the same as "up" logistics for non-comsumable hardware items such as batteries, solar panels, film, emulsions, spares and updated experiment equipment.

Table 4-9. Experiment Equipment Update Summary

FPE	NAME	COMMON MODULE -1	COMMON MODULE -3	COMMON MODULE -4	OPNL MODE Attached	OPNL MODE Detached	OPNL MODE Suitcase	Typical Update Frequency	Typical Mission Life (years)	Experiment Weight (lb x 100)	Wt. of Experiment Equipment Updated Mission (lb x 100)	Average Wt. Experiment Equipment Updated (lb/yr)
5.1	X-RAY	X				X		1/yr	5	33	9.8	196
5.2A	STELLAR	X				X		1/yr	5	87	3.9	78
5.3A	SOLAR	X				X		1/yr	5	69	3.8	76
5.5	HI-ENERGY	X				X		1/yr	5	78	2.0	40
7/5.12	PLASMA PHYS/HANGAR		X		X			1/2yr	2	50	18	900
5.8	COSMIC RAY		X		X			1/yr	5	340	68.	1360
9/10/23	BIOLOGY			X	X			1/2yr	2	90	13.	650
5.9/10	BIO CENTRIFUGE	EXPERIMENT			X			1/2yr	2	38	17.5	875
5.11	EARTH SURVEYS			X	X			1/2yr	2	46	30.7	1535
5.13C	CENTRIFUGE	EXPERIMENT			X			1/2yr	2	10	Negl	Negl
5.16	MAT'L SCIENCE		X		X			1/2yr	2	56	Negl	Negl
5.20-1	FLUID PHYSICS		X		X			1/2yr	2	7.85	Negl	Negl
5.20-2	FLUID PHYSICS (Incl. Prop. Slice)	X				X		1/2yr	1/4	51	Negl	Negl
5.20-3	FLUID PHYSICS	EXPERIMENT				X		1/2yr	1/2	35	Negl	Negl
5.20-4	FLUID PHYSICS	EXPERIMENT				X		1/2yr	1	52.5	Negl	Negl
5.22	COMPONENT TEST			X	X			1/yr	2	17.5	1080	540
5.27	PHYS/CHEM LAB		X		X			1/2yr	2	62	1920	960
5.17	CONTAMINATION						X	1/2yr	2	8.5	Negl	Negl
5.18	EXPOSURE						X	1/2yr	2	4	Negl	Negl

NOTES: Updated equipment is generally experiment sensors.

Telescopes are assumed to require no updating during a typical mission.

Table 4-10. Propellant Logistics[6]

FPE	TITLE	ΔV for Station-keeping/mission cycle (FPS)	Yearly ΔV for Stationkeeping (FPS)	ΔV for one Deploy/Return/dock Cycle (FPS)(1)	Yearly ΔV for Deploy/Dock (FPS)	Module Operational Wt. (lb×1000)	Stationkeeping Propellant +5% Contingency (lb/yr)	Deploy/Dock Propellant +5% Contingency (lb/yr)	ΔV for Exp. Period (FPS)	Propellant Consumed in Exp. Period (lb)
5.1	X-Ray	5.6	33.6	59.2	355	21.0	105	1100		
5.2A	Stellar	5.6	33.6	59.2	355	30.5	215	1490		
5.3A	Solar	5.6	33.6	59.2	355	27.0	134	1415		
5.5	High Energy	5.6	33.6	59.2	355	26.0	130	1375		
5.20-2	Fluid Physics					27.0(2)			4216	17000(3)
5.20-3	Fluid Physics					26.5(2)			5897	23200(4)
5.20-4	Fluid Physics					29.0(2)			11053	48000(5)

Notes: Based on average ballistic coefficient $\beta = 20$, for average year (Model 5 Atmosphere), $I_{sp} = 220$ sec, and a typical mission cycle of 60 days assumed.
Actual mission cycle for return/dock/deploy could vary from 30 days to 90 days of longer.

(1) Includes 12 FPS for out of plane thrusting and deployment 12 n. mi. average.
(2) Average Weight.
(3) Consumed in 3 months.
(4) Consumed in 6 months.
(5) Consumed in 12 months
(6) Does not include approximately 5000 lbs propellant consumed in initial-delivery circularization of the Free Flying Modules.

Table 4-11. Spares, ECLS and Other Logistics Summary

FPE	NAME	OPNL MODE: Common Module -1	-3	-4	Attached	Detached	Suitcase	Film Spares: Year or Exp. per Film Process/Storage (lb)	Yearly Module Spares Wt. (lb)	Solar Panels (3) (lb/yr)	Battery Replacement (3) (lb/yr)	Press. Gas: Loss while Docked (lb/yr)	Loss in Docking (lb/yr)	Initial Dock (lb)		OTHER	NOTES
5.1	X-Ray	x				x		288	128	270	280	24	47.5	158		1500 lb/yr-LN_2LH_2	
5.2A	Stellar	x				x		500 (5)	128	170	280	24	47.5	158			
5.3A	Solar	x				x		1200 (5)	128	300	280	24	47.5	158			
5.5	H-Energy	x				x		80 (1)	128	270	280	24	47.5	158		(6)	
5.7/5.12	Plasma Phys/Hangar		x		x			720 (4)	600	-	210	730	-	245		Barium canisters - 40 lb/yr Propellant - 240 lb/yr	
5.8	Cosmic Ray		x		x			450 (2)	600	-	210	730	-	158		3000 lb/yr-Dewar with liquid helium magnets	
5.9/10/23	Biology			x	x			1080	600	-	210	730	-	158		16,000 lb/yr - food, O_2, & H_2O, LiOH	(1) Emulsion packs (4) during first 28 days. Resupply required for retest.
5.9/10	Bio. Centrifuge Exp.				x			-	-	-	-	730	-	90			
5.11	Earth Surveys			x	x			2000	600	-	210	730	-	245		240 lb/yr - LN_2	
5.13C	Centrifuge Exp.				x			80	-	-	-	730	-	90			(2) Emulsions.
5.16	Mat'l. Science		x		x			144	600	-	210	730	-	158		80 lb/yr gas, 120 lb/yr LN_2 2000 lb/yr avg. specimen	(3) Batteries and solar panels are assumed to have a two yr life.
5.20-1	Fluid Physics		x		x			1420	600	-	210	730	-	158			
5.20-2	Fluid Physics (Incl. Prop. Slice)	x				x		-	128	90	280	160	316	158			(4) Total film requirements for FPE experiment sequence.
5.20-3	Fluid Physics Exp.					x		-	-	-	-	348	198	158			
5.20-4	Fluid Physics Exp.					x		-	-	-	-	159	79	158		3000 lb/yr - LH_2	(5) Film requirement to be deleted if electronic imaging is used.
5.22	Component Test			x	x			60	600	-	210	730	-	245		11,750 lb/yr - LH_2, LO_2, LN_2	
5.27	Phys/Chem Lab		x		x			260 (4)	600	-	210	730	-	158		1600 lb/yr - LH_2, LN_2, & LHe	
5.17	Contamination						x	100	-	-	-	-	-	-			(6) Closed cycle refrigeration assumed - negl logistics reqmts.
5.18	Exposure						x	24	-	-	-	-	-	-			

SECTION 5

ENVIRONMENT

Experiment modules must survive launch by either reusable or expendable boosters and operate on-orbit for periods up to ten years. Preliminary launch and on-orbit environmental criteria and requirements are presented and discussed in this section.

5.1 LAUNCH ENVIRONMENT

Both reusable (space shuttle) and expendable (Titan IIIC, Titan IIIF or Saturn 1B) launch vehicles are to be considered as potential boost vehicles for the experiment modules. Load, factors, acoustic levels, and thermal criteria for worst case environments are discussed in the following paragraphs. The general requirement is that the experiment modules survive the launch environment with no damage.

5.1.1 LOAD FACTOR ENVIRONMENT. Maximum boost or reentry load factors for the space shuttle vehicle are 4 g in any direction (Reference 5-1). Design load factors with expendable launch vehicles typical of the Titan III class are 6 g longitudinal and 3 g lateral.

5.1.2 ACOUSTIC ENVIRONMENT. A reasonable acoustic design environment during boost to orbit of experiment modules is the environment existing internal to the shroud of an expendable booster. The acoustic spectrum tabulated in Table 5-1 is representative of this type of acoustical environment. This data is the average of the acoustical noise measured forward of the transtage during several Titan IIIC flights. Test and design criteria acoustic levels are commonly 6 db above measured values to provide adequate safety margins. Space shuttle cargo bay acoustic levels have yet to be determined.

5.1.3 THERMAL ENVIRONMENT. Thermal criteria for expendable launch vehicles are not demanding; the payload area can be conditioned while on the ground to maintain temperatures within the desired limits during boost. Space shuttle cargo bay temperatures, however, may be extreme. The exact temperatures to be expected are yet to be determined since designs have not been finalized. However, present designs show uninsulated LOX tanks adjacent to the cargo bay, which indicates that very low temperatures are to be expected during boost. Cargo bay temperatures may also be quite high during reentry and landing, particularly if an emergency condition arises which requires dumping the orbiter LOX supply as a safety measure.

Table 5-1. Acoustic Environment

Center Frequency of 1/3 Octave Band (Hz)	Acoustic Level * (db)
20	112
25	110
32	113
40	112
50	113
63	116
80	118
100	117
125	121
160	121
200	125
250	126
315	127
400	128
500	127
630	125
800	122
1,000	120
1,250	117
1,600	115
2,000	113
2,500	113
3,150	108
4,000	103
(overall level = 136 db)	

*Average of several measurements in internal compartment forward of Titan III-C transtage. Add 6 db for test and design criteria.

5.2 ON-ORBIT ENVIRONMENT

Radiation (natural and induced), meteoroid, and contamination environments to which the experiment modules will be subjected are discussed in the following paragraphs. These environments are described for the baseline experiment module circular orbit of 270 n.mi. x 55 deg.

5.2.1 RADIATION ENVIRONMENT. The radiation environment in space consists of cosmic rays. trapped (Van Allen) radiation, solar flare particle events, and whatever radiation is generated by man while on-orbit. The space station nuclear power source is the major contributor of man-made radiation. The radiation requirement is shown in Table 5-2 in allowable radiation limits for crewmen (Reference 5-2). Permissible dosage limits for film and photosensitive emulsions are approximately two orders of

Table 5-2. Crew Radiation Limits

Radiation Depth	Dose (rem)		
	Career	Year	30 Days
Skin (0.1 mm)	2400	240	150
Eye (3 mm)	1200	120	75
Marrow (5 cm)	400	40*	25

*May be doubled to 80 rem if crewman is not exposed to radiation during the next 12-month period.

magnitude more sensitive to radiation than man. Special shielding and frequent resupply will be necessary to reduce film fogging to acceptable limits. All other experiment module materials are less radiation sensitive than man by at least two orders of magnitude. Transistors and diodes are the most sensitive items. It is anticipated that shielding which is adequate to protect man for 30 days on-orbit will also reduce radiation to levels which are satisfactory for the other experiment module materials.

Natural radiation, particularly solar flare radiation, is a strong function of time. A reasonable estimate of the extreme radiation environment expected in the 1975 period from all natural sources is presented in Table 5-3 (Reference 5-3) and reproduced below. This data holds only for a 270 n.mi. by 55 deg orbit since radiation is also a strong function of orbital altitude and inclination angle.

Table 5-3. Estimated Natural Radiation Dose (1975 Period)

Shield Thickness (gm/CM^2 of Al)	Dose (REM/6 month)	
	Skin Dose	Depth Dose
2.0	50.2	11.6
5.0	23.6	9.8
8.0	17.1	8.6
15.0	10.7	5.6

Radiation from the space station nuclear reactor power supply varies widely with distance and geometric relationship to the reactor core. Expected dosage levels from space station nuclear power supplies to which an experiment module will be subjected is assumed to be less than 0.01 rem/hr, based on a 250 ft separation distance.

Radiation sensitivity by FPE is summarized in Table 5-4. Film is the most sensitive item found in most FPEs. Several of the FPEs have instruments or emulsions which are particularly sensitive to radiation, as noted in the table. Man is present for all FPEs either for periodic servicing or to conduct sustained operations. Biology specimens (small vertebrates, plants, and primates) are also sensitive to radiation levels.

5.2.2 METEOROID ENVIRONMENT. The meteoroid protection design requirement is a 0.9 probability of no experiment module pressure skin punctures over a 10-year period. Sporadic and stream meteoroid flux models for the 1975 to 1985 period are defined mathematically in Reference 5-3.

Reference 5-4 presents a graphical solution of a total meteoroid flux-mass model. It is an average cumulative total meteoroid (average sporadic plus average stream) flux-mass model and is shown in Figure 5-1. In the near vicinity of the earth this flux-mass model is modified by gravitational and earth shielding effects. The model is corrected by multiplying the values from Figure 5-1 by the gravitational defocusing factor (0.965 at a 270 n.mi. orbit altitude) and by the earth shielding factor at a 270 n.mi. orbit altitude (0.69). Defocusing and shielding factors for orbital altitudes other than 270 n.mi. are presented in Reference 5-4.

5.2.3 CONTAMINATION ENVIRONMENT. The problem of potential contamination of optical, and other sensitive surface, by effluents from spacecraft is of concern in two primary areas: the near vicinity to the space station and in the vicinity of detached free-flying modules. In the vicinity of the space station the problems of concern are:

a. The extent and type of contamination that may exist in the vicinity of the space station,

Table 5-4. Radiation Sensitivity by FPE

FPE/TITLE	RADIATION SENSITIVE ITEM			
	MAN			
	PERIODIC SERVICING	SUSTAINED OPERATION	FILM	OTHER
5.1 X-Ray	X	—	—	X-Ray Instruments
5.2 Stellar	X	—	X	Photometer
5.3 Solar	X	—	X	X-Ray Telescope, Misc. Instr.
5.5 High Energy	X	—	—	X and γ-Ray Instruments, Emulsions
5.7/12 Plasma Physics	—	X	—	------
5.8 Cosmic Ray	—	X	X	Emulsions, Cosmic Ray Detectors and Multipliers
5.9 Small Vertebrates	—	X	X	Small Vertebrates
5.10 Plants	—	X	X	Plants
5.11 Earth Surveys	—	X	X	IR Instruments
5.16 Materials Science	—	X	X	------
5.17 Contamination	X	—	X	------
5.18 Exposure	X	—	—	------
5.20 Fluid Physics	X	—	X	High Speed Film
5.22 Component Test	—	X	X	LWIR Sensor
5.23 Primates	—	X	X	Primates
5.27 Physics & Chemistry Lab	—	X	X	------

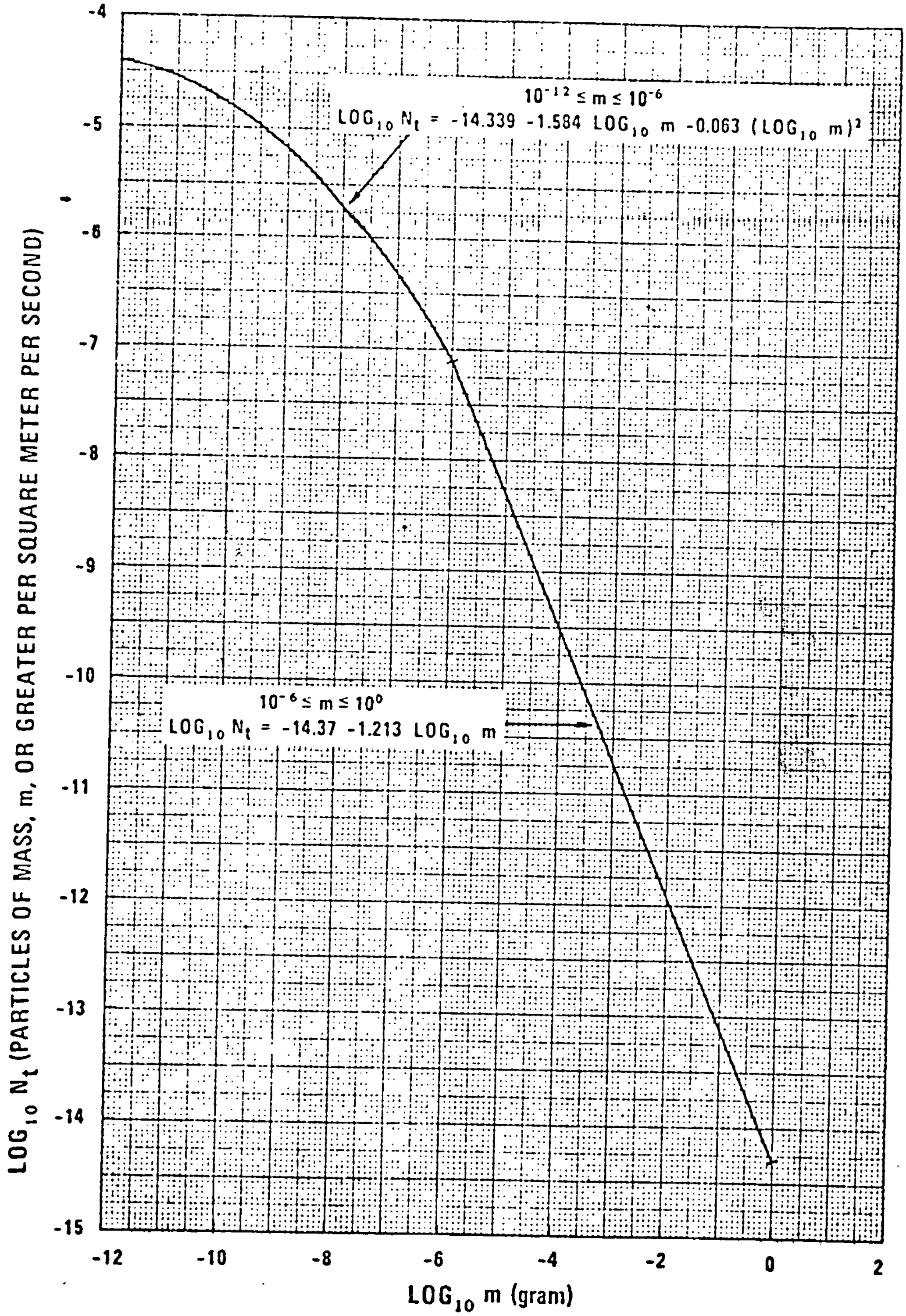


Figure 5-1. Average Cumulative Total Meteoroid Flux-Mass Model for 1 A.U.

b. The effect this may have on instruments exposed to this environment.

c. The degree of success for observations made through a column of the contaminant.

An estimate of the density profile and brightness of the contaminant cloud about the space station can be calculated using the method of Reference 5-5 and described here. These equations are for contaminants emitted in a continuous flow; ejecta expelled in bursts are not included in this preliminary estimate.

The contamination model considers spherical particles and gas leakage leaving the station radially outward. A spherical contaminant cloud with mean radius is assumed

$$R_m = \frac{U_0^2}{\dot{U}} + R_s$$

to be established about the spacecraft where R_s is the approximate station radius, U_0 the initial contaminant particle ejection speed, and $\dot{U}$ the particle acceleration due to atmospheric drag. For the case of spherical debris, acceleration is estimated by

$$\dot{U} = \frac{3}{4} \frac{\zeta_a}{\zeta_r} v^2$$

with v the satellite orbital speed, r the particle radius, ζ the debris particle mass density, and ζ_α the ambient mass density

The quantity of interest is the radiance (B) of the sunlight scattered by the debris cloud. This is conveniently expressed, relative to the mean solar radiance $B_\odot$, by

$$\left(\frac{B}{B_\odot}\right)_\phi = \omega_\odot \bar{\sigma}(\phi) M$$

where: $\omega_\odot$ is the solid angle of the sun from the scatterer, $\bar{\sigma}(\phi)$ the mean scattering function at angle ϕ with respect to sun rays and M the total column mass density.

When the mean cloud radius is much larger than the spacecraft radius (i.e., $R_m/R_s > 10$), the cloud mass density assuming contaminant flow may be estimated by the relation:

$$4\pi R^2 M(R,r)\, U_0 = \left(\frac{dm}{dt}\right)_r$$

Mass density of particles with radius r at distance R from the station is given by $M(R,r)$, and $\left(\frac{dm}{dt}\right)_r$ is the rate of mass loss from the satellite due to particles of radius r. The expression for the column mass density at any point in the cloud is obtained by integrating from the point of interest (R) to the mean cloud radius (R_M):

$$M(R,r) = \frac{\left(\frac{dm}{dt}\right)_r}{4\pi U_0} \int_R^{R_M} \frac{dR}{R^2}$$

$$= \frac{\left(\frac{dm}{dt}\right)_r}{4\pi U_0} \left(\frac{1}{R} - \frac{1}{R_M}\right)$$

Consequently, the relative brightness $\left(\frac{B}{B_\odot}\right)$ decreases as R^{-1} provided $R_m \gg R$. As R approaches R_m the relative brightness drops sharply.

A list of space station contaminant sources is given in Table 5-5 along with mass loss rates and initial velocities. Important contaminants resulting from propellant

Table 5-5. Space Station Contamination Sources

Source	Mass Rate (lb/day)	Initial Velocity (cm/sec)
Atmospheric Leakage & Dumps @ 50% Relative Humidity	18	3×10^4
CO_2 Dumps	15	3×10^4
Fluid Leakage	7	1×10^4
H_2 Cryogenic Boiloff	5	1×10^4
Fecal Water	3	7×10^2

exhausts, propellant loading leakage, EVA missions and module dockings are not included in the table. More detailed information about the nature and magnitude of these latter contaminants is required before they can be included.

Figures 5-2 and 5-3 show the mass density and relative brightness from scattered sunlight at an experimental module which is located within the space station contaminant cloud. Viewing from the module is radially away from the space station at a light scattering angle (ϕ) of 60°. These calculations assume an average spherical

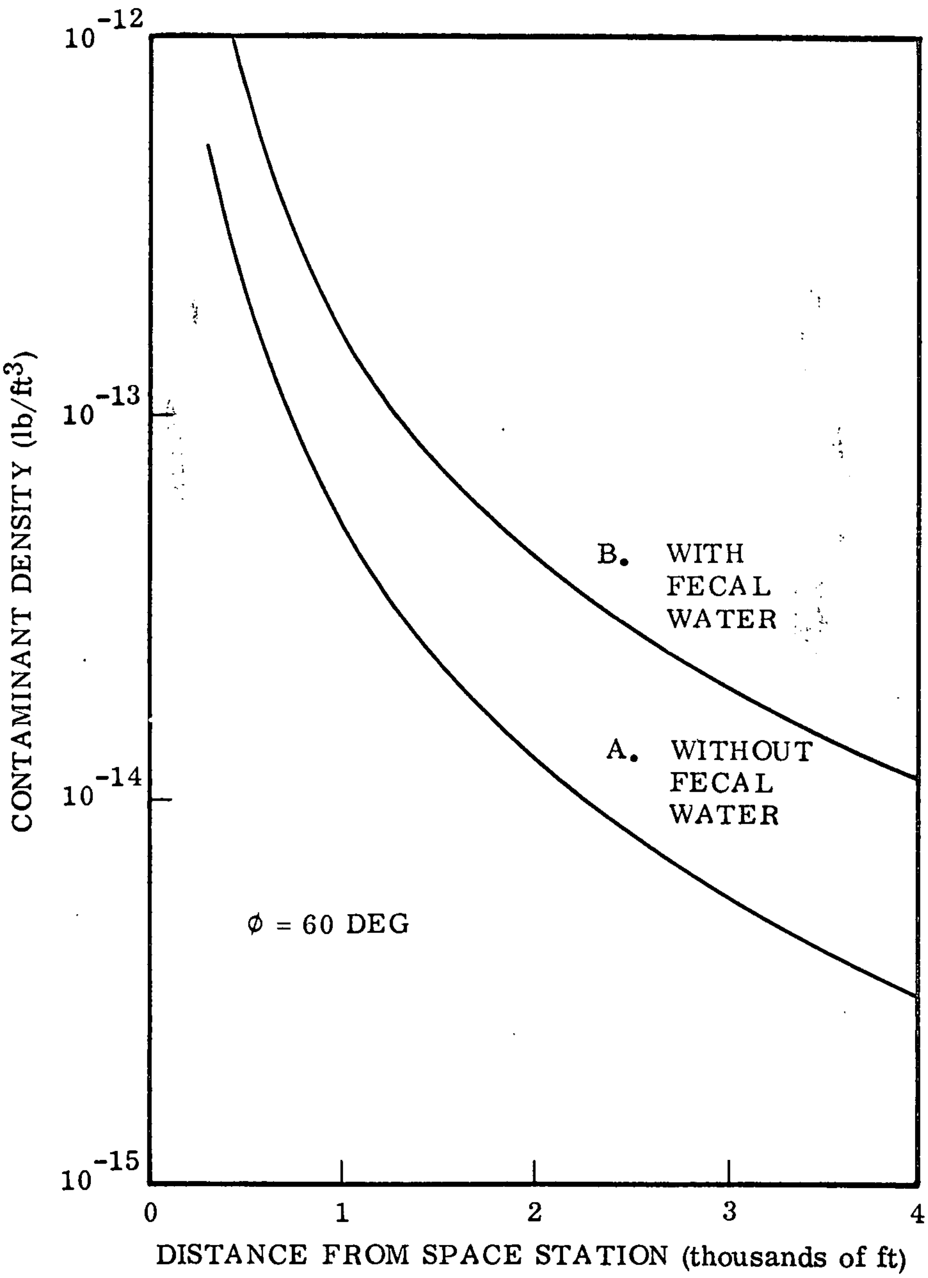


Figure 5-2. Density of Space Station Contaminant Cloud

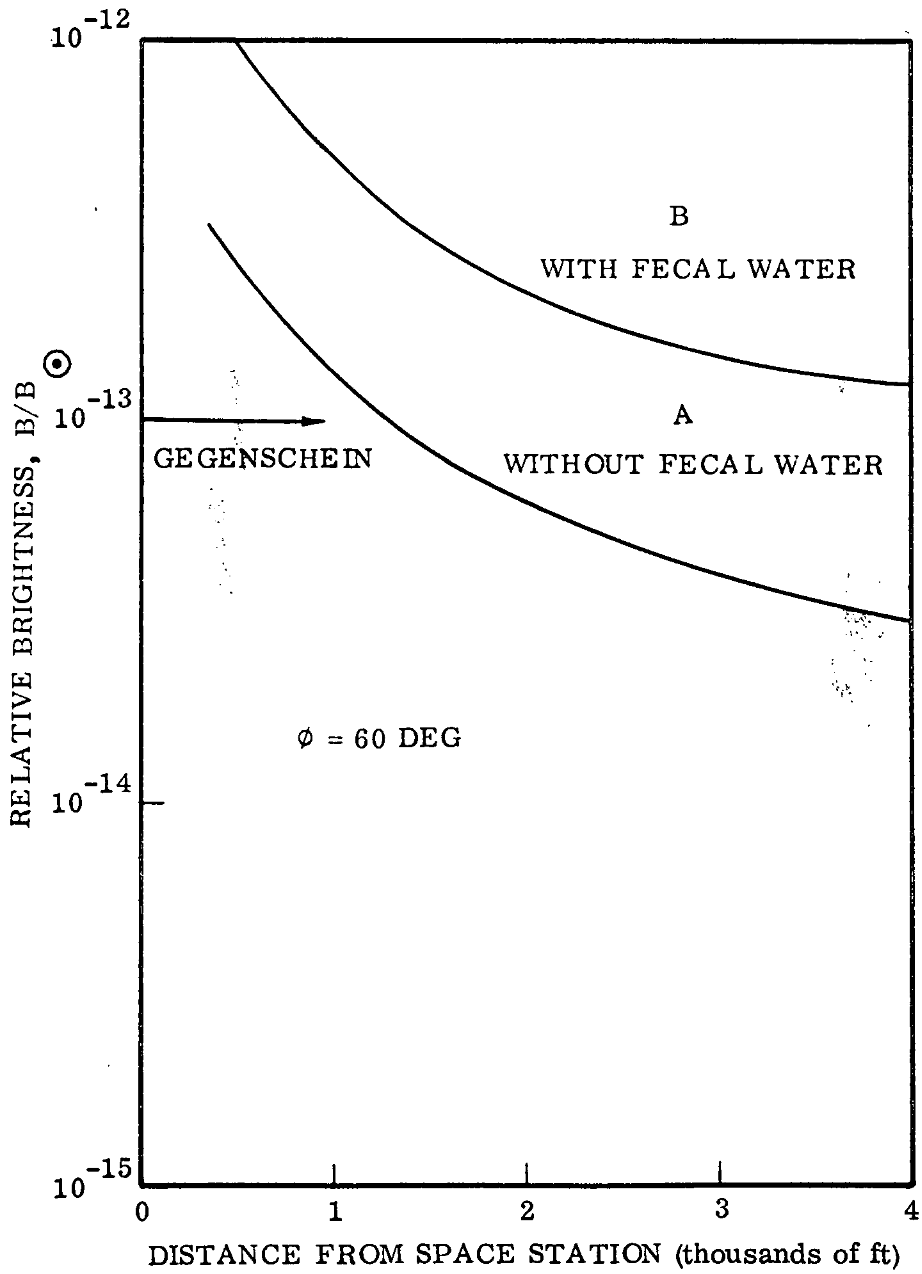


Figure 5-3. Effect of Space Station Contaminant Cloud on Relative Brightness

particle radius of r = 3 micron, $\bar{\sigma}(\phi) = 8 \times 10^2$ cm^2/g, $\omega_\odot = 6.7 \times 10^{-5}$ STER and a 270 n.mi. orbital altitude. Data is presented for two conditions: Condition A is based on the space station contamination sources of Table 5-5 excluding fecal water; Condition B includes fecal water. It is assumed that 100% of the escaping water is converted into ice crystals. These figures show that both contaminant density and relative brightness are increased by approximately an order of magnitude when fecal water contributes to the contaminant cloud.

Figure 5-3 shows the brightness of the Gegenschein (the brightness measured in the ecliptic plane looking directly away from the sun) as a reference point. Minimum brightness of about 0.2 of the Gegenschein level is found near the 75 deg ecliptic latitudes viewed in a direction away from the sun. Ideally, brightness due to contaminants would be a small fraction of the natural background level so the sum of the two would be approximately equal to the natural background brightness. Figure 5-3 shows that the experiment module must be at least 4000 feet away from the space station to reduce the brightness due to contaminants to the Gegenschein level when fecal water is part of the contaminant cloud. If fecal water is not in the contaminant cloud, the module must still be removed from the space station by 1000 feet to reduce brightness due to contaminants to the Gegenschein level.

Caution: some of the major contaminants (propellant exhausts, etc.) have not been considered in these calculations, and the spherical continuous flow model underestimates the debris profile and scattered brightness for periodically dumped contaminants. The treatment of crystalline particles also needs to be improved, both with respect to their scattering properties and to explicit consideration of their lifetimes.

The brief high velocity exhaust from the station RCS and from RCS of logistics vehicles, and modules docking to or leaving the station needs to be added to the steady spherical expanding cloud. These exhaust products may have a contaminating effect on any exposed surfaces in the near vicinity of the station (dependent on propellants, thrust levels, and surface properties), but will probably be of sufficiently short (seconds) duration infrequency in occurrence, and sufficiently high in temperature to have no very significant effect on viewing column reflectances.

Conclusions drawn from these considerations are:

a. Viewing of very faint sources of light for long periods of time (distant stars) from positions immediately adjacent to the station may be impeded by the reflectance from sunlighted particles in the viewing column. Viewing in some other spectral regions may also be effected.

b. Exposure of optical surfaces to the environment existing in the immediate vicinity of the space station may result in temporary or permanent degradation of the optical properties of the surface, either by deposition/condensation or RCS exhaust erosion.

Detached modules were selected to house the contamination-sensitive astronomy experiments since the contamination problem is reduced when moisture from a manned atmosphere exists only while modules are in the vicinity of the space station. Viewing column reflectance is therefore believed to be reduced below the level of concern.

The major remaining problem is the potential contamination created by the module RCS, and by materials outgassing. Contamination potential is minimized by selection of propellants and propulsion systems and through module design and operating techniques.

a. The selection of propellants and propulsion systems must consider the potential contamination of optical surfaces created by the exhaust products.

b. Module design and operating plans must consider methods to prevent exposure of optical surfaces during periods of potential contamination such as module RCS firings, or when module is docked to the space station.

APPENDIX I

EXPERIMENT EQUIPMENT WEIGHTS BY FPE

Experiment Equipment Weight Summary

FPE	Title	Experiment Item	Experiment (lb)	Added Support/Control Item	Added Support/Control (lb)	Total (lb)
5.1	X-Ray	Polarimeter	350	Insulation	100	3300
		Spectrometer	100	Telescope Drive	150	
		High Res. Scope	200	Detector Housing	350	
		X-Ray Detectors	30	Sensor Turret Instl.	600	
		X-Ray Mirrors	300	Misc Struc. Supports	420	
		Telescope Tube	400	Misc Exp. Support	300	
5.2A	Stellar	Primary Mirror	4000	Primary Mirror Supp.	500	8685
		Spectographs	65	Insulation	310	
		Cameras	160	Telescope Trusswork	3000	
		Video	100	Secondary Mirror	150	
				Sec. Mirror Supp.	240	
				Flip Mirror	100	
				Photometer	30	
				Polarimeter	30	
5.3A	Solar	1.5M Photoheliograph	4000			6875
		Heliograph Controls	75			
		Spectroheliograph	660			

Experiment Equipment Weight Summary (Continued)

FPE	Title	Experiment Item	Experiment (lb)	Added Support/Control Item	Added Support/Control (lb)	Total (lb)
		1-6 Radii Coronagraph	660			
		5-30 Radii Coronagraph	220			
		0.5M Solar Telescope	880			
		Magnetograph	200			
		Vidicon	180			
5.5	High Energy	X-Ray Spectroscope	800			7800
		X-Ray Telescope	515			
		X-Ray Spectrometer	5000			
		X-Ray Chamber	1485			
5.7	Plasma Physics	Measurement Eqpt	1800			1800
5.8	Cosmic Ray (Growth Version)	Total Absorp. Det.	24000			34180
		Tad Photomultiplier	910			
		Shower Counter	3000			
		Tasc Photomultiplier	280			
		Magnet-Dewar	3000			
		Liquid Cerenkov	1000			
		Spectrometer Assembly	200			

Experiment Equipment Weight Summary (Continued)

FPE	Title	Experiment Item	Experiment (lb)	Added Support/Control Item	Added Support/Control (lb)	Total (lb)
		Detector Bays	400			
		Spare Detectors	150			
		Emulsion Storage	100			
		Emulsion Processing	100			
		Control Console	200			
		Computer & Recorder	500			
		Microfilm Storage	20			
		Spare Photomulti.	120			
		Spare Electronics	200			
5.9/ 10/23	Biology	Centrifuge	800	Centrifuge Instr.	110	12846
		Laminar Flow Bnchs(2)	2400	Acc. Isolation Equip.	400	
		Verte. Speci. & Cages	1475			
		EC/LS (90 Day Supply)	800			
		Atmosphere Monitor	162			
		Plant Speci. & Racks	1127			
		EC/LS	800			
		Atmosphere Monitor	162			

Experiment Equipment Weight Summary (Continued)

FPE	Title	Experiment		Added Support/Control		Total
		Item	(lb)	Item	(lb)	(lb)
		Research Equip.	110			
		Monkey Housing	1500			
		Chimp. Housing	3000			
5.11	Earth Surveys	Metric Camera	360	Tracking Tele.	250	4600
		Multispectral Camera	185	Indexing Camera	30	
		Multispec. IR Scan.	150	Day/Nite TV	50	
		IR Infer./Spectro.	65	Misc. Res. & Supt.	1525	
		IR Atmos. Sounder	45			
		IR Spectro./Radio.	65			
		MW Scanner	76			
		Multifreq. MN Rad.	50			
		MW Atmos. Sounder	80			
		Radar Imager	620			
		Act. - Pass MW Rad.	100			
		VW Polarimeter	50			
		VHF Sferics	22			
		Absorp. Spectro.	95			

Experiment Equipment Weight Summary (Continued)

FPE	Title	Experiment Item	Experiment (lb)	Added Support/Control Item	Added Support/Control (lb)	Total (lb)
		Laser Altimeter	371			
		UV Imager Spectro.	150			
		Radar Alt./Scatter	75			
		Photo-Imaging Camera	145			
		Data Collection	11			
		Imaging Spectro. Cam.	30			
5.12	RMS	Subsatellites	1300	Control Eqpt	500	3200
				Fuel & Tanks	900	
				Service Eqpt	500	
5.16	Materials Sci.	Thin Film	285	X-Ray Diffraction	1650	5580
		Glass Casting	215	Electron Diffraction	210	
		Spherical Casting	185	Refraction Meter	400	
		Single Crystals	165	2 Color Pryometers	20	
		Composite Casting	215	Matrl. Test Mach.	200	
		Variable Density Casting	215	X-Ray	200	

Experiment Equipment Weight Summary (Continued)

FPE	Title	Experiment Item	Experiment (lb)	Added Support/Control Item	Added Support/Control (lb)	Total (lb)
				Metallograph	100	
				Chem. Lab.	200	
				Mass Spectrograph	300	
				Furnace	1000	
				Spectroscope	20	
5.20-1	Fluid Physics	Crit. Reg. & Comb. Tests	160	Flt. Cont. & Data Display	625	785
5.20-2	Fluid Physics	Interface Stab.	935			5141
		Capillary Studies	2850			
		Cond. Heat Trans.	476			
		Rotat. Liq. Globules	320			
		Two Phase Flow	460			
		Film Stab. & Inert. Sep.	100			
5.20-3	Fluid Physics	Boiling Heat Trans.	600			3460
		Propellant Trans.	1430			
		Slush Hydrogen	1430			

Experiment Equipment Weight Summary (Continued)

FPE	Title	Experiment Item	Experiment (lb)	Added Support/Control Item	Added Support/Control (lb)	Total (lb)
5.20-4	Fluid Physics	Long Term Cryo. Stor.	5252			5252
5.22	Component Test	Work Bench	200	Misc. Research Equip.	570	1650
		Computer/Console	75			
		Optical Bench	100			
		IR Calibration	75			
		MW Radiometer	45			
		Fuel Cell	100			
		Fluid/Gas Comp.	50			
		Heat Exchanger	75			
		Air Bearings	25			
		MW Sensor	5			
		Telescope Optics	15			
		LWIR Sensor	150			
		Film Developing	150			
		Space Welding	10			
		Develop. Flowmeter	5			

REFERENCES

1.1 Candidate Experiment Program for Manned Space Stations, NASA document NHB 7150.XX, May 15, 1969.

3-1.1 ATM Follow-on Study, Report ED-2002-795. Volume II, April 1969.

3-1.2 Saturn IB Vehicle and Performance Study, September 1969.

3-1.3 Logistic Systems Data for Experiment Module Study. MSFC PD-MP-A. July 2. 1969.

3-2.1 Wiedner, D. K., Ed., Natural Space Environment Criteria for 1975-1985 NASA Space Stations, NASA Technical Memorandum, Report No. 53865, George C. Marshall Space Flight Center, August 1. 1969.

3-2.2 Eggleston, D. M., Relative Orbital Motion on Stationkeeping, Convair Divison of General Dynamics Report GDC-ERR-1440, January 1, 1970.

5-1 Statement of Work Space Shuttle System Program Definition (Phase B), NASA RFP No. 10-8423, February 1970.

5-2 Guidelines and Constraint Document — Space Station Program Definition, Phase B. MSC-00141, Revision O, 12 June 1970.

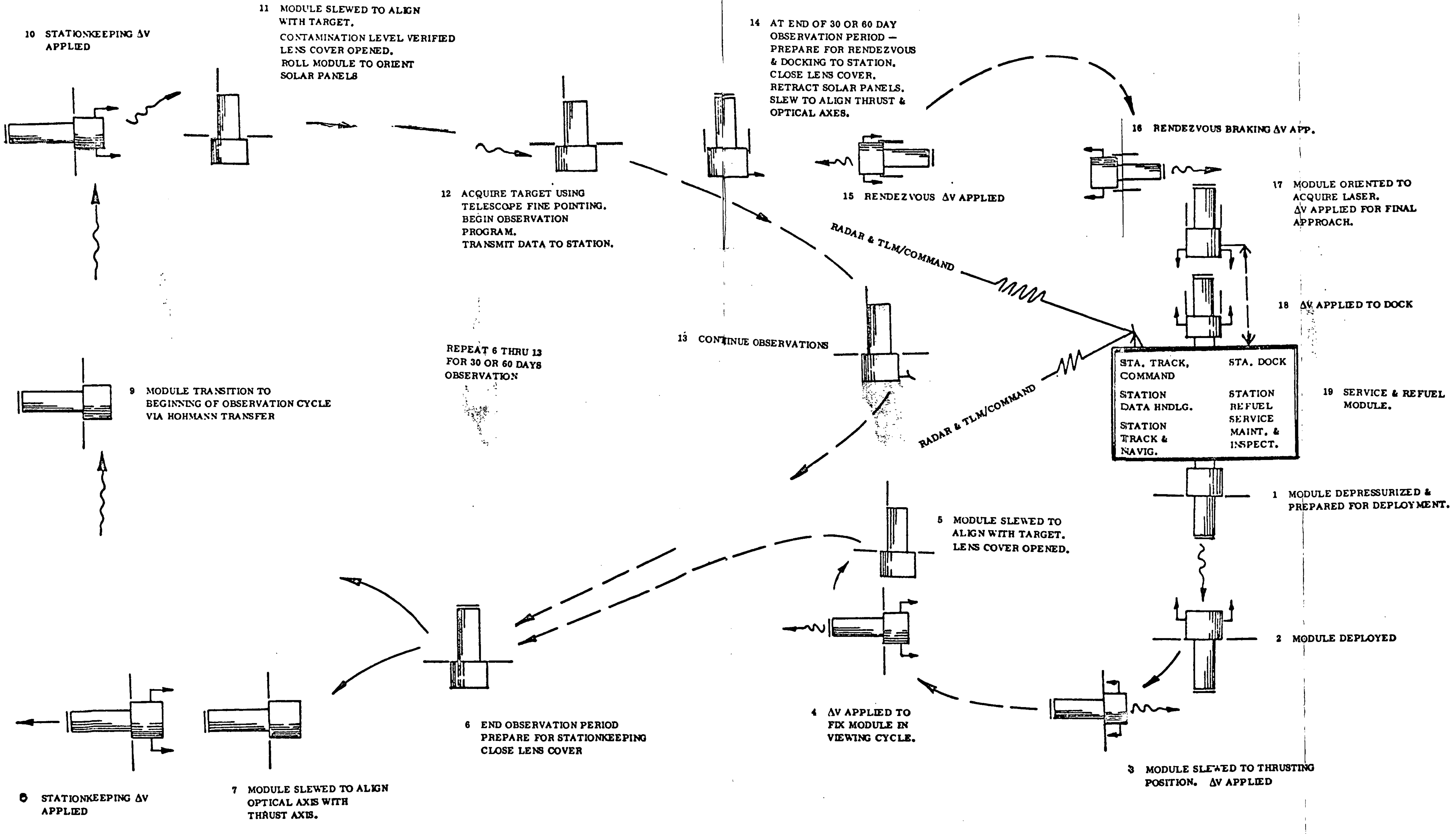
5-3 Weidner D. K. (ed.). Natural Environment Criteria for 1975-1985 NASA Space Stations, NASA TMX 53865, 31 October 1969.

5-4 Meteoroid Environment Model – 1969 (Near Earth to Lunar Surface), NASA SP-8013. March 1969.

5-5 Newkirk, Gordon, The Optical Environment of Manned Spacecraft, High Altitude Observatory, Boulder, Colorado, March 1967.

Experiment Equipment Weight Summary (Continued)

FPE	Title	Experiment		Added Support/Control		Total
		Item	(lb)	Item	(lb)	(lb)
5.27	Physics & Chemistry Lab.	Artif. Meteroids	200	Refraction Meter	400	6220
		Capillary Study	200	Electron Diffraction	210	
		Ultrapure Metals	165	2 Color Pyrometers	20	
		Critical State Stdy	100	Mat. Test. Mach.	200	
		Bubble Formation	935	X-Ray	200	
		Liquid Drops	320	Spectroscope	20	
		Chemical Lab	200	X-Ray Diffraction	1650	
		Mass Spectograph	300	Metallograph	100	
		Furnace	1000			



MISSION PHASE	ΔV (FPS)
RENDEZVOUS & DOCK (INITIAL)	85
UNDOCK	10
DEPLOYMENT	15
STATIONKEEPING	4
RETURN	15
DOCK	20

Figure 3-9. Typical Astronomy Module Mission Profile