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SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS STUDY—FINAL REPORT

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FOREWORD

This final report, submitted to National Aeronautics and Space Administration (NASA) Headquarters, Washington, DC 20546, presents the results of the Space Station Needs, Attributes and Architectural Options Study performed by the Space and Electronics Systems Division of the Martin Marietta Corporation under NASA Contract NASW-3686.

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TABLE OF CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

FIGURES

VOLUME II	MISSION DEFINITION (cont)	Page

TABLES

Page

VOLUME II MISSION DEFINITION (cont)

Page

VOLUME II MISSION DEFINITION (cont)

1.0 INTRODUCTION

1.1 PURPOSE

The overall objectives of the Space Station study are to: identify missions that are enhanced or enabled by a permanent manned space station in low earth orbit; characterize the attributes and capabilities that will be necessary to satisfy mission requirements; recommend space station implementation approaches, architecture options, and evolutionary growth; and define the programmatic/cost implications.

The purpose of this volume is to survey the space applications and science programs appropriate to the era beyond 1990 and select those user missions which can utilize the Space Station to an advantage, and further, to define user mission concepts so that requirements, which will drive the Space Stations (SS) design, can be developed.

1.2 SCOPE

The primary purpose of this study was to identify, collect, and analyze the science, applications, commercial, U.S. national security and space operations missions that would require or be materially benefited by the availability of a permanent manned space station in low earth orbit and to identify and characterize the space station attributes and capabilities which will be necessary to satisfy these mission reqirements. Emphasis is placed on the identification and validation of potential users, their requirements, and the benefits accruing to them from the existence of a space station, and the programmatic and cost implications of a space station program. Less emphasis has been placed on detailed design beyond that necessary for the identification of system attributes, characteristies, implementation approaches, architecture options, and ROM costs.

The study results are presented in six volumes as follows:

Volume I presents an executive summary highlighting the specific results obtained during each phase of the study as described in Volumes II through VI (classified information excepted).

Volume II presents the results of our mission definition activities including the identification, modeling and validation of potential user missions, their requirements and the benefits that could accrue to the users from the existence of a space station.

Volume III presents the space station user requirements, their integration and time phasing, and the derivation of system and user accommodation requirements. The derivations of user requirements and space station accommodations encompassed a traceability analysis, parametric studies, and an analysis of economic, performance, and social benefits afforded by the existence of a space station.

Volume IV presents the results of our study efforts describing our analyses and defining our recommended space station implementation approaches, architecture options, and evolutionary growth.

Volume V presents the affordability analysis conducted to determine the affordable mission model, quantification of economic benefits, estimate of the ROM costs for each of the architectural options and their associated program and element schedules.

Volume VI presents the results (classified) of our analysis for the DOD National Security mission. This volume was published under a separate cover and is available through the DOD Task Manager at Space Division (SDXR), Los Angeles, California.

Appendix A, Acronyms and Abbreviations, presents a reference list common to all volumes of this report.

Appendix B, Reference Bibliography, presents a listing of all primary references used to develop the date presented throughout the report.

Appendix C, Mission Concept Reference Data, presents the detailed mission definitions and user mission requirements for each mission defined in the Space Station Mission Model presented in Volume II.

The scope of this volume is to present an affordable mission set for each science and applications discipline and a general set of requirements. This will assure that the SS concepts are developed to effectively and efficiently accomplish the objectives of the user.

The final element of the user missions task is to assist in the benefits analysis task (Vol III, Section 7.0) by providing data to support the relative value of the user missions and the advantages of performing them using the Space Station.

1.3 GROUNDRULES AND ASSUMPTIONS

The statement of work to Contract NASW-3686 contains the following groundrules and guidelines (paraphrased and simplified):

- All facilities will be Shuttle launched and tended;
- Potential missions of interest will include domestic and foreign science, applications and commercial users as well as U.S. national security and space operations missions;
- All missions included in the study results will include the specific source of user input;
- Primary consideration should be given to the requirements for a permanent manned space station in low earth orbit;

- The Tracking Data Relay Satellite System (TDRSS) will be the primary space-to-ground communications interface for space station operations;

- Development of space station options should consider a single space station in the 1990 time frame while the evolutionary growth could require consideration of multiple stations or platforms,

- Department of Defense (DOD) Task Assignment - Consider space station interaction with the total DOD space infrastructure envisioned to be in use in the later 1980s through the year 2000,

  (A mission model delineating the military space missions for the time period specified above was provided by DOD.)

- The contractor has the responsibility to obtain all information and data necessary to conduct the study;

- NASA will provide the results of appropriate in-house studies as a primary source of information on science and applications missions,

- NASA will provide relevant results of mission analysis studies conducted in other countries.

1.4 CONSTRAINTS

Overall objectives for each science or applications discipline will be defined; next a set of user missions will be selected that will best meet the general objectives for each discipline. During this analysis, the relative affordability of these missions will be determined. This will assure a realistic mission demand so that the SS capacity is sized to accommodate these payloads and estimates of accrued benefits are provided against a realistic baseline.

1.5 DEFINITIONS

TBD

1.6 APPROACH METHODOLOGY

The process of developing the user mission requirements was accomplished in four steps as shown in Fig 1.2-1 and as described below.

1.6.1 Composite Mission Model

The first step was to issue a preliminary requirements document to enable all project tasks to start. The initial requirements document was called the MMC Composite Mission Model which was a listing of all space missions from existing sources without special consideration of their applicability to the SS or any attempt to tailor the concepts to take advantage of the SS. Parameters such as size, weight, power and orbit selection were roughly estimated. This provided the basis for all initial planning activities.

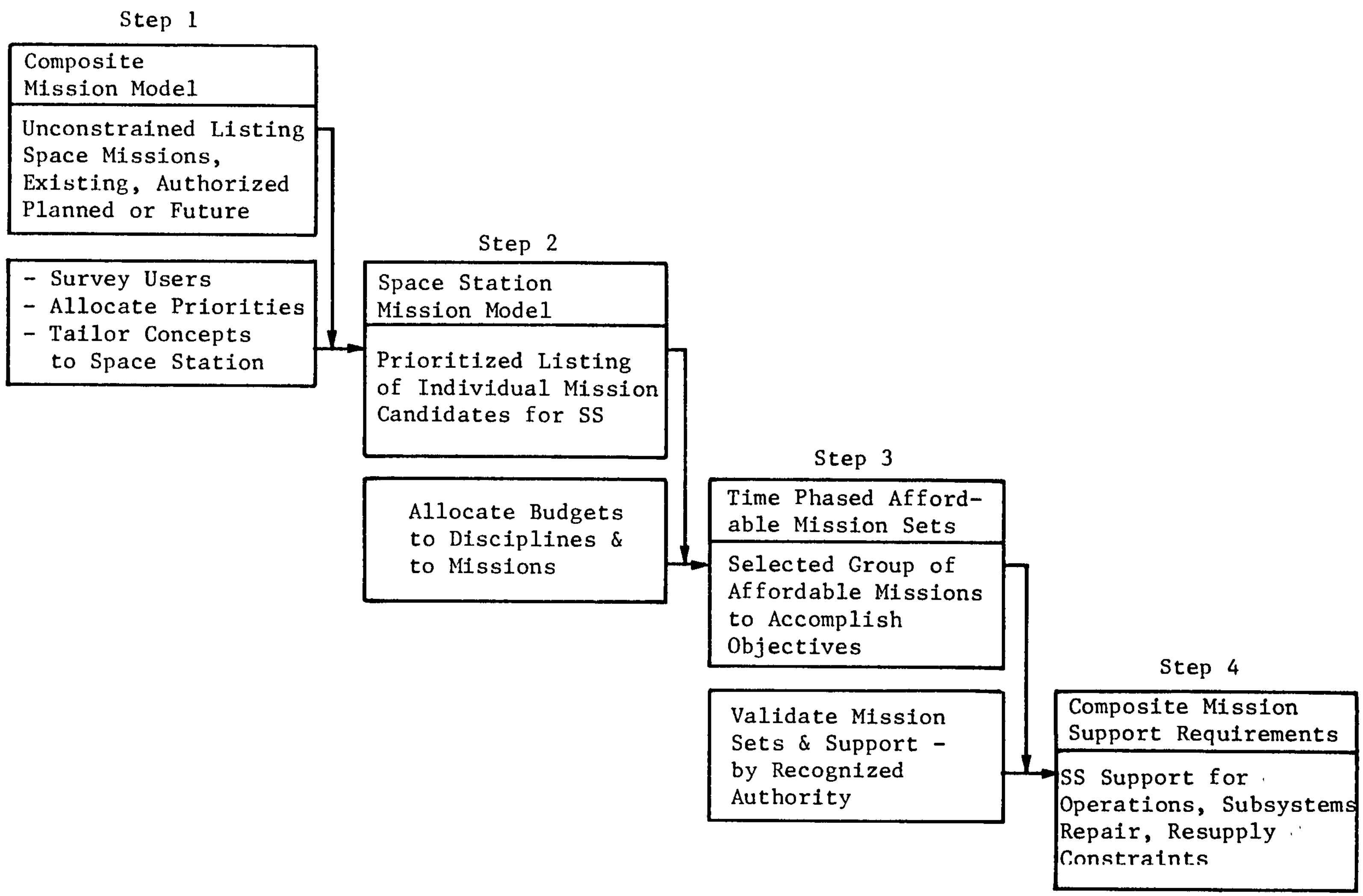

Figure 1.2-1 User Mission Requirements Development

1.6.2 Space Station Mission Model

The next step was to develop a mission model based upon mission concepts appropriate to the SS. The approach taken was to conduct a survey of potential users by making initial contacts by telecon. It was immediately apparent that few, if any, of the users had given serious consideration to a SS. It was also apparent that before they could do so, they had to be briefed on the SS and that this was too much to expect from a teleconference. It was concluded that meaningful contacts had to be made by personal interviews that would ellicit their ideas and concepts and the applications of SS capabilities. To carry out this task a training program was instituted sending our most knowledgeable personnel to interview leading researchers in each of the scientific and applications areas. In addition the Universities Space Research Association (USRA) was also contacted and asked to assist in organizing technical interchange meetings. These were arranged through Jack Sevier and involved both individual contacts and group meetings for those with common interests/specialties. These small, all day meetings proved to be invaluable as they provided useful information for those involved.

An initial, almost unanimous concern of the science oriented community was that the SS itself might use most of the available funding and leave little or no funding for the science community. The users also felt that the SS was inevitable and the best course they could take was to plan to make the best possible use of it. After briefing them on the special capabilities of the SS and conducting discussions of how they might specifically benefit from it, a generally enthusiastic belief was found to exist that the SS offers great potential. The capability of the SS for long duration operation and the availability of man to repair, resupply, and to keep the payloads operating are vital to almost all objectives.

An important element of these discussions was to establish overall objectives for each discipline and to determine the role and time phasing for each proposed mission. This approach enable us to evaluate priorities and eliminate obsolete and redundant mission concepts.

A Space Station Mission Model (SSMM) was then compiled that contains a listing of the missions that we feel are the prime candidates for the SS. The model also contains a tabulation of critical parameters. Upon completion of the SSMM, it was issued to the project to replace the MMC Composite Mission Model. Detailed SS users concept definition writeups were also prepared for each of these user missions and are included as Appendix C to this Volume.

1.6.3 Time Phased Affordable Mission Sets

The next step was to select, for each discipline, a mission set, or complement of missions from the mission model. An "Initial Phase" set was determined to initiate each discipline's planned program and an "Evolutionary Set" to provide for growth during the program through the year 2000. The mission sets were chosen to form a coherent combination of mission concepts, which would be compatible and could enhance each other by providing correlative and complementary data. Further, they were chosen to simultaneously share subsystems, operational support facilities, and support equipment.

Each mission set had to meet the consideration of affordability. In selecting the "Time Phased Affordable Mission Sets", a projection of the NASA budget was made and a projection of funding for each discipline was derived from this. Program costs were estimated for each mission and these were integrated into the discipline funding allocations. Affordability is discussed in detail in Section 4 of Volume IV. Since all missions could not be accommodated, benefits and costs were also considered in selection process. Final mission sets were selected for each discipline through the year 2000.

For most disciplines, a set for the "Ultimate" phase beyond the year 2000 is shown. We recognize that the SS must endure well beyond the year 2000 but mission planning beyond this time for most disciplines is tentative at best and often non-existent. We have, however, where possible defined mission concepts for this phase. While no specific provisions will be made for their accommodations, they do provide a basis for flexibility in design for future accommodations.

After the Mission sets and concepts for accommodation are defined, it was required that we validate our approach methodology. We have done this by going to some of the foremost authorities, usually people who have assisted us earlier, to review our approach and results. We have then incorporated their further suggestions.

1.6.4 Composite Mission Support Requirements

While support requirements are defined for each individual mission, it is also necessary to take the mission set or complement and assess requirements which derive from the missions as a group. This activity was performed in close coordinate with the mission integration activities as described in Volume III and mission implementation activities described in Volume IV.

2.0 EXECUTIVE SUMMARY

2.1 GENERAL CONCLUSIONS

Acceptance by the community of users was surprisingly good. The willingness of almost all of those contacted to spend time with us was proof of interest in the Space Station (SS). After expressing their funding reservations, general enthusiasm developed when considering the special advantages that the SS could bring to most projects.

Long duration of operation is probably the most significant single element. Many missions are currently planned for STS/Spacelab with its extremely limited time on orbit. Most of these concepts can be used on the SS with orders of magnitude improvement in results. Most free-flyers are limited by random failure and consumables and these missions also can be greatly extended.

Man can contribute most in his capacity to repair, replace, resupply and refurbish or modify systems. Many feel he has limited use in the role of observer and operator, and prefer to keep these functions for ground control, but in some areas, such as life sciences and materials processing he can be invaluable in this role.

On orbit assembly and checkout will be critical for many large payloads of the future. Only the SS can maintain adequate crew and equipment to support this kind of operation.

Materials processing needs the kind of research laboratory facility that only the SS can provide. Industry lacks confidence in current operations but participation could be achieved through education and understanding of space station capability.

Earth observations could benefit very much from on-board SS support, but they generally need a near-polar orbit which is not likely to be directly supportable from space station.

The communications industry has a highly developed satellite system. The SS capability to reduce launch costs and prolong lifetime through repair and resupply has potential for high payoff.

Astronomy missions can generally derive very large benefits from long duration and maintenance and resupply support. Astronomers are apprehensive about being onboard because of unknown levels of contamination and disturbances. Analysis of these factors, and the capability to control them are needed so that it can be determined if missions would have to be relegated to separate platforms.

A summary of potential SS support for missions in each discipline is shown in Figure 2.1-1. The numbers indicate how many missions could benefit from the support functions listed. It can be seen, for example, that the main benefit for communications and planetary missions is the launch to orbit assist while nearly all missions can benefit from repair and resupply. Many can potentially benefit from operations/control and subsystems support. This generally requires them to be attached to the SS. This may not be possible since considerations of orbit preference preclude being aboard. Initial activation and checkout is important to materials processing, life sciences, and technology development missions which should be possible since most of these missions can be conducted onboard. This capability will materially reduce the cost of these missions. Assembly on orbit is used only for a few missions but is vital for those.

Another chart, Figure 2.1-2, is more subjective in its evaluation of the SS support potential but shows the extent to which it is felt that the user missions will benefit. The light shading indicates improvements in performance and reductions in cost over what could likely be obtained by other means. The dark shading indicates, includes these advantages and in addition, major improvements beyond what is practical by any alternate mission concepts. The cross hatched areas indicates mission concepts that would have their objectives severely reduced without the support of the SS. Life science and materials processing have large cross hatch areas because their dependence upon long durations with manned involvement is not possible by other means. Other cross hatch areas are mostly due to vital assembly on-orbit functions. Communications has large dark shading since it is felt that the boost to higher orbit and, the repair and resupply capability is very important. Likewise solar astronomy could significantly benefit from film changes and on-board data storage and processing and therefore also has a large dark shaded area. Overall, the chart expresses our belief that space station has the potential to enhance operations and reduce costs over a large majority of space missions.

SS Support Functions	Astronomy	Solar Astronomy	Space Physics	Earth Observations	Life Sciences	Materials Processing	Communications	Planetary Explorations	Technology Development	Total
Launch	2	1	6	1	0	0	62	11	0	83
Repair & Resupply	20	7	7	14	14	20	13	0	0	95
Operate, Control, Data Mgmt	4	7	4	13	14	20	1	0	23	86
SS Subsystems - Attached	4	7	3	13	14	19	2	0	23	85
Initial Activation Checkout	6	0	6	14	14	20	4	0	22	86
Assembly-Large Structures	7	0	1	1	0	0	1	0	5	15
Total	43	22	27	56	56	79	83	11	73	450
No. of Missions	20	8	11	14	14	20	64	11	23	185

Figure 2.1-1 SS Potential Support by Missions

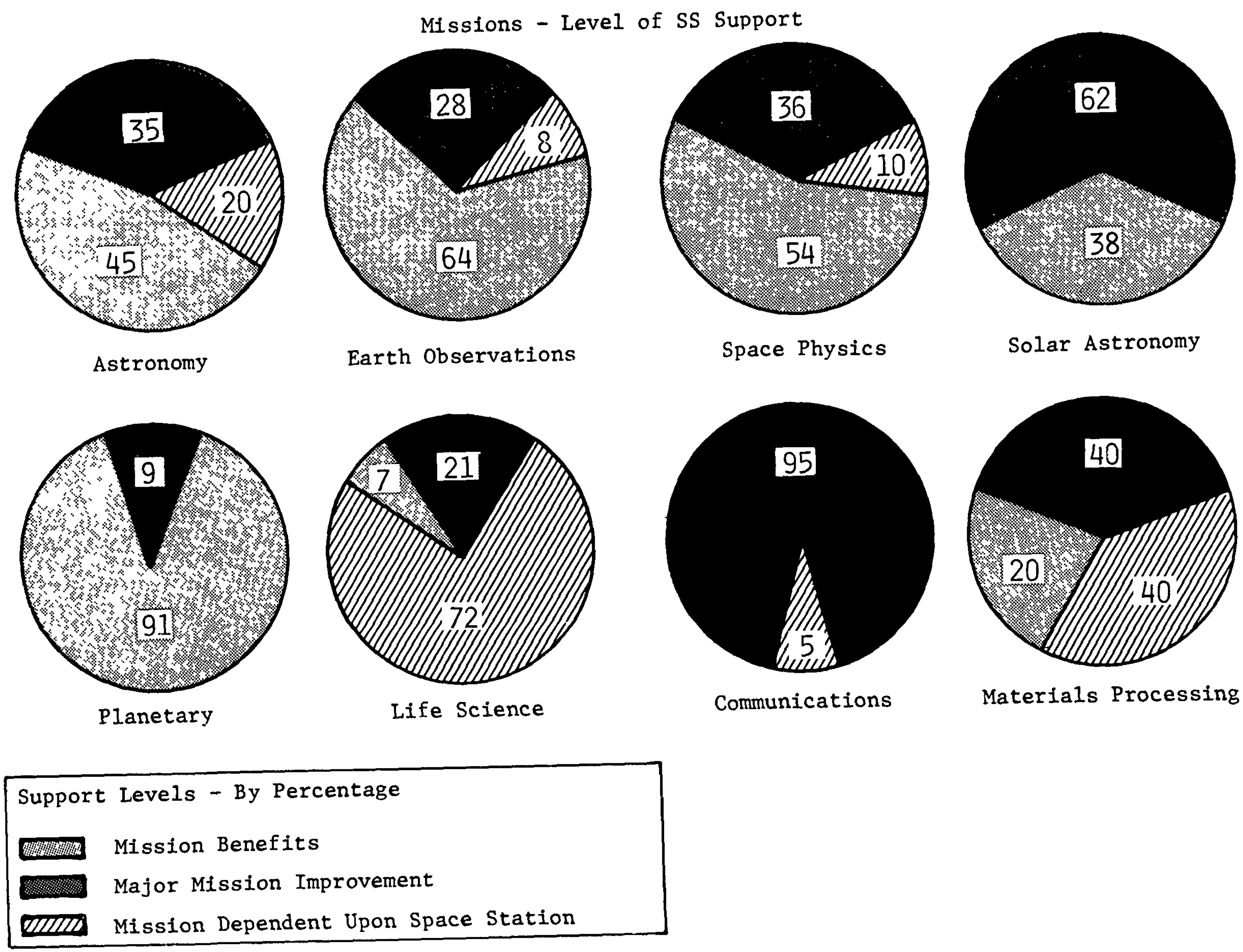

Figure 2.1-2 Mission Support Potential-Space Station

2.2 PLANETARY EXPLORATIONS

The missions selected for planetary science application are listed in Table 2.2-1 below.

Table 2.2-1 Planetary Science Mission Sets

- Galileo Jupiter and Saturn Probes
- Comet Rendezvous and Sample Return
- Venus Radar Mapper
- Mars Geo Chemistry Climatology and Aeronomy Orbiter
- Venus Probe

These missions are based on a long range systematic strategy of exploration, reconnaissance and missions to bodies in the solar system. The mission model also builds upon the experience gained from previous explorations.

The role of the SS is supporting planetary explorations of the near term will be limited to providing a launch/boost to the higher energy trajectories, if the orbital phasing can be worked out the SS will also provide a quarentine and decontamination facility for samples returned from other solar system bodies.

2.3 EARTH OBSERVATIONS

The mission sets selected for Earth Observations are shown below in Table 2.3-1.

Executive Summary

Table 2.3-1 Earth Observations - Affordable Missions

- Initial Complement
  - Imaging Spectrometer
  - Microwave Radiomewter
  - Synthetic Apeture Radar
  - Geosynchronous Satellite Sensor Intercalibration

- Evolutionary Complement
  - LIDAR - Light Detection and Ranging
  - CLIR - Cryogenic Limb Scanning Interferometer and Radiometerınd Color Scanner
  - Thermal Infrared Multispectral Imager
  - Scatterometer
  - Ocean Microwave Package
  - Stereo Visual Imager
  - LAMMR - Large Antenna Multifrequency Microwave Radiometer
  - Advanced Meterological Infrared and Microwave Sounder

- Ultimate Facility (2000+)
  - Microwave Sounder (Geosynchronous)

The recommended instrument complement was selected after a review of various mission models and extensive discussions with scientists. It was soon apparent that many instruments will aid several subdisciplines. Furthermore, instruments furnishing data to separate subdisciplines can, often if used together, have synergistic effects. Combinations of instruments were an important consideration in instrument selection.

The initial complement of instruments could be placed on the SS orbiting at a low inclination. Consideration was given to those instruments which could provide valvable, long term coverage of equatorial regions. Instruments that could observe oceanic regions, provide coverage of equatorial atmospheric regions where severe storms originate, or observe and map tropical areas as an aid to developing countries were emphasized.

The evolutionary complement, based on a near polar platform, was chosen to meet the need for long term simultaneous data on sets of geophysical parameters. These instrument observations will aid numerical forcasting models and provide a better understanding of atmospheric chemistry and circulation. The instruments chosen are balanced among the different disciplines. The ultimate complement utilizes the ability to assemble a large microwave antenna in orbit, and then launch it to geosynchronous orbit.

The work in earth observations was made possible by the help received from the people listed in Table 2.3-2.

Table 2.3-2 Earth Observations List of Contributors

- NASA HQ	- K. Ando, D. Bulter, D. McConnel, B. Schardt, S. Tilford, J. Welsh
- GSFC	- W. Barnes, E./ Mercanti, E. Speaker
- MSFC	- W. Huber, O. Vaughn
- JSC	- R. Herbert
- LaRC	- F. Huck
- JPL	- A. Kahle, R. Stewart
- NCAR	- H. Firor, J. Gille
- NOAA	- F. Hall, G. Little, J. Purdom, H. Yates
- USGS, Flagstaff	- R. Batson, H. Kieffer, G. Schaber, L. Soderblom, S. Wu
- Colorado State Univ.	- B. Marlatt, J. Smith, T. Von Der Haar, G. Wallace, M. Harvey
- Univ. of CA, Santa Barbara	- J. Dozier, J. Estes, D. Simonette, R. Smith
- Univ. of Wisconsin	- V. Suomi
- Scripps Ocean Institute	- C. Gauthier
- Texas A&M	- P. Newton
- Chevron Oil Co.	- W. Kowalik

We were further assisted by having Dr. Anne Kahle from the Jet Propulsion Laboratory and Dr. Catherine Canthier from the California Space Institute, Scripps Institution of Oceanography who reviewed the selected mission sets and made valuable constructive suggestions.

The potential capability for SS support to earth observations is shown in Figure 2.3-1. As can be seen, many vital support functions are possible, but most of these, such as operate/control, subsystems, and initial activation are only possible while on-board the space station and even the repair/resupply needs would require on orbit inclination seporation of no more than 30°. Since the majority of earth observations missions require near-polar orbits the support of these may have to be on a platform without service from the main space station.

EO SS Missions By Phase	Initial Phase				Evolutionary Phase									Ultimate
	Imaging Spect.	Microwave Radiometer	Syn. Aper. Radar	Geo Sat Calib	CLIR	LIDAR	Color Scanner	Therm IR MS Imager	Scatter-ometer	Ocean MW Package	Stereo Vis Imager	LAMMR	Adv Meterol. IR & MW	MW Sounder Geosyn.
SS Support Functions														
Launch/Boost														X
Repair/Resupply	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Operate/Control/Data	X	X	X	X	X	X	X	X	X	X	X	X	X	
Attach/Subsystems	X	X	X	X	X	X	X	X	X	X	X	X	X	
Initial Activation	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Assy-Large Struct.														X
Total	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Objectives														
Atmospheric Circ		2		2	1	2			2	2		2	2	2
Global Chem Cycles		1		1	2	2								1
Atmos. Chem				2	2	2								
Global Climate		2		2	1	2			1			2	1	2
Global Ice & Hydrol.	2	2	2	2								2		
Ocean Dynamics		1		1		1	1		2	2		1		1
Land Cover Dynam.	2		2											
Agriculture	2		2											
Global Biomass	2		2				1							
Continental Geol.	2		2					2			1			
Archeology			2								1			
Cartography	1		2					1			2			
Fisheries							2							

Note
2 = Primary Role
1 = Support Role

Figure 2.3-1 Space Station Mission Support Potential for Earth Observation

2.4 SPACE PHYSICS

The mission selected for space physics are shown in Table 2.4-1 below.

Table 2.4-1 Space Physics Mission Sets

A. Initial Complement

- o Space Plasma Effects Upon Large Spacecraft
- o Large Spacecraft Impact Upon Proximate Space Plasma
- o Initial Solar Terrestrial Observatory (STO)
- o Upper Atmosphere Research Satellite (UARS)
- o Origin of Plasma in Earths Neighborhood (OPEN)
- o Space Lab (SL) - X Experiments
- o Chemical Release Module Facility (CRM)
- o AMPTE

B. Evolutionary Complement

- o Active Plasma Facility
- o Advanced Solar Terrestrial Observatory (ASTO)
- o Plasma Turbulance Explorer (PTE)
- o Advanced Interplanetary Explorer

C. Ultimate Phase Complement

- o Very Large Radar (VLR)
- o Geostationary Solar Terrestrial Observatory (GEO-STO)
- o Advanced Active Plasma Facility

The rationale for this selection is based upon the general objective which is to understand the fundamental physical processes involved in mans global and universal environment. It has also been subjected to limitations of the budget projections.

The work in Space Physics was made possible by contributions of the people listed in Table 2.4-2.

Table 2.4-2

TBD

The role of space station in support of Space physics is illustrated by Figure 2.4-1.

Figure 2.4-1

TBD

2.5 ASTRONOMY - ASTROPHSICS

The missions selected for astronomy are shown below in Table 2.5-1.

Table 2.5-1 - Astronomy Mission Sets

- o Initial Complement
  - EUVE - Extreme Ultraviolet Explorer
  - COBE - Cosmic Background Explorer
  - XTE - X-Ray Timing Explorer
  - GRO - Gamma Ray Observatory
  - ST - Space Telescope
  - Starlab
  - SIRTF - Shuttle IR Telescope
- o *Ultimate Complement (2000+)*
  - COSMIC - Coherent Optical Sys. of Modular Imaging Collectors
  - TAT - Thinned Aperture Telescope
  - LWA Long Wavelength Antenna
- o Evolutionary Complement
  - AXAF - Advanced X-Ray Astrophysice Facility
  - OVLBI - Orbiting Very Long Baseline Interferometer
  - GTE - Gamma Ray Timing Explorer
  - FUSE - Far Ultraviolet Spectroscopy Explorer
  - LAMAR - Large Area Modular Array of Reflectors
  - HNE - Heavy Nuclei Explorer
  - OIST - Orbiting IR Submillimeter Telescope
  - XRO - X-Ray Facility
  - CRO - Cosmic Ray Facility
  - LDR - Large Deployable Reflector

This complement was selected based on scientific priorities identified in the "Astronomy Survey Committee Report (1982)". The combination addresses the major scientific questions and objectives as defined in this report. It provides a broadbased approach using the full electromagnetic spectrum for both exploration and detailed study. Many of the programs are currently funded and will be developed during the 1980s and it is felt that the entire complement will be accommodated by funding projected through the 1990s. These mission sets are in accord with the recommendations of several astronomers actively pursuing major work in key areas.

The work on astronomy was made possible through help of both individual astronomers and a panel convened by USRA. These people, listed in Table 2.5-2, contributed to the astronomy mission concepts.

Table 2.5-2 - List of Contributors for Astronomy

- o Contributors, Reviewers
  - S. Holt, NASA/GSFC
  - H. Smith, U Texas
  - R. McCray, U Colorado
  - F. Kerr, U Maryland
  - B. Burke, MIT
  - R. Haymes, Rice U
  - S. Ulmer, Northwestern U
  - H. Gursky, NRL

We were further assisted in review of the selected mission sets by Dr. Harlan Smith (U Texas) and Dr. Karl Henize (JSC) who made important constructive suggestions.

The support which the SS is capable of providing to astronomy missions is shown in Figure 2.5-1. For some of the early free flyers and explorer classes, the main function can be repair or resupply only. For some later missions that could be conducted on-board, resupply of cryogens and quenching gasses can be vital - SIRTF and LAMAR are examples. For some future missions requiring assembly and activation on-orbit, the SS support could be the only practical means of accomplishment. The support extent of the SS to astronomy can be substantial, bringing programs into the realm of practicality and affordability, to an extent not possible otherwise.

SS Missions By Phase	Initial								Evolutionary to 2000									Ultimate		
	EUVE	ST	Star Lab	SIRTF	COBE	GRO	OVLBI	XTE	FUSE	AXAF	GTE	LAMAR	LDR	HNE	XRO	OIST	CRO	COSMIC	TAT	LWA
S S Support Functions																				
– Boost							X						X							
– Repair Resupply	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
– Op Control, Data Mgmt			X	X								X					X	X	X	X
– Attach Subsystems			X	X								X					X			
– Initial Activate							X						X			X		X	X	X
– Assy Large Struct							X						X			X		X	X	X
Objectives																				
Cosmology																				
– Large Scale Structure		2	1	2						2		2	2		2			2	2	2
– Evol Of Galaxies	1	2	1	2		1	1		1	2		1	2		2	1		2	2	2
– Missing Mass	2	2	2	2		1	1		2	2		1	1		1	2		2	1	1
– Quasars/Act. Galaxies	1	2	1	2		1	2	1	1	2	1	2	2		2	1		2	2	2
– Background Radiation	2			1	2	1				2		2			1	1				1
Stellar Evolution																				
– Star Formation	1	1	1	2			1		1				2			2		1	1	1
– Supernovae Reminants		2	1			1	2	1	1	2	1	2	1	1	2		2	1	1	1
– X-Ray/Bursters						2		2		1	2	1			1					
– Binaries;Accretion		1	1	1			1	1	1	2	1	1	1		2			2	2	
– Superstellar Medium	2	1		1	1		1		2	1			2	1	1	1	1			1
Planets Life, Intelligence																				
– Extra Solar Planets		2	1	1									2					2	2	

Note
2 = Primary Role
1 = Support Role

Figure 2.5-1 Astronomy-Space Station Mission Support Potential

2.6 Solar Astronomy

The missions selected for the solar physics program are shown below in Table 2.6-1.

Table 2.6-1 - Solar Astronomy Mission Sets

- o Initial Complement
  - SSF-Solar Shuttle Facility
  - SIS-Solar Interplanetary Satellite
  - SIDM-Solar Internal Dynamics Missions
  - SCDM-Solar Coronal Diagnostic Mission
- o Evolutionary Complement
  - ASO-Advanced Solar Observatory
  - SOT-Solar Optical Telescope
  - P/OF-Pinhole Occulter Facility
  - SSXTF-Solar Soft X-Ray Telescope Facility
  - SEXTF-Solar EUV/XUV Telescope Facility

This proposed program essentially builds on the STS/Spacelab programs which precede the SS. The individual instruments would be flown as they are available and eventually integrated into the Advanced Solar Observatory (ASO). The ASO will have flexibility to evolve through configurations of increasing capability as new instruments become available. With the SS support, these changes can be accomplished on-orbit.

The concepts defined in Solar Physics were assembled and defined by Ball Aerospace Corporation. This work was made possible by help received from the people listed in Table 2.6-2.

Table 2.6-2 - List of Contributors and Reviewers - Solar Physics

- Richard Fisher (HAO)
- Richard Munro (HAO)
- Werner Neuport (GSFC)
- A. Poland (GSFC)
- Robert McQueen (HAO)
- G. Timothy (U Colo)
- L. B. Dunn (Sac Peak)
- J. D. F. Bartoe (NRL)
- A.B.C. Walker (Stanford)
- J. D. Bohlin (NASA-HQ)
- E. Rhodes (CIT)
- W. T. Roberts (MSFC)
- D. Sime (HAO)
- E. Hildner (MSFC)

The support which the SS has the potential to provide to solar astronomy is shown in Figure 2.6-1. If the payload was attached it could operate much as ATM did on Skylab including the use of film for some data, and direct support from SS subsystems. Solar astronomy could best benefit from an orbit which maximizes sun view time, the ultimate being sun synchronous at the terminator. This would not be a likely orbit for space station and would require a platform facility. The viewing time advantages of this will have to be traded against the advantages of long duration, high level support available at the SS in a less desirable orbit.

Missions by Phase	Initial SSF	SIS	SIDM	SCDM	Evolutionary ASO SOT	P/OF	SSXTF	SEXTF
SS Support Functions								
Launch/Boost		X						
– Repair/Resupply	X		X	X	X	X	X	X
– Ops/Control/Data Mgt	X		X	X	X	X	X	X
– Attached/Subsystems	X		X	X	X	X	X	X
– Activation/Checkout								
– Assembly-Large Systems								
Objectives								
1 Structure Dynamics and Processes of Suns Interior	1	1	2	1	1	1	1	1
2 Mass and Energy Transport in Solar Outer Atmosphere	1	1	1	1	2	1	2	
3 Structured Dynamics and Evaluation of the Visible Corona	1	1	1	2	1	2	1	2
4 Structure and Magnetohydro-Dynamics of the Solar Wind	1	2	1	1	1	1	1	1
5 Variation in Photon and Fluxes on Earth during Solar Cycle	1	1	1	1	1	1	1	1

Note
2 = Primary Role
1 = Support Role

Figure 2.6-1 Space Station Mission Support Potential for Solar Astronomy

2.7 LIFE/BIOLOGICAL/MEDICAL SCIENCES

All of the conceptual experiments proposed by the instigator contacts and resource documents were considered to be affordable an are listed in Table 2.4-1.

All of the human research will be performed in the Health Maintenance Facility (HMF) which is to be located in the crew habitability module. A number of the equipment items required for routine and contingency medical support will have dual utility in basic biomedical research. The HMF is anticipated to evolve through four levels of support capability. Category I is provided by the Shuttle during buildup. Category II will be fully operational at the time longer duration manned missions are implemented. Categories III and IV (2000+) will be characterized by expanded research and medical support capabilities.

The non-human research activities will require a vivarium for non-human specimen support and a Life Sciences Laboratory Facility (LSLF) both of which will b contained in the Life Sciences Research Module (LSRM).

Table 2.7-1 Life Sciences Mission Set

Initial Complement

- o Health Maintenance Facility Category II
  Analysis & Diagnostics Laboratory
  Computer Diagnostics System, Recompression

Evolutionary Complement

- o Health Main Facility Category III
  Expanded Medical and Exercise Instrumentation
  Expanded Research; Quarantine

- o Life Sciences Research Module
  Vivarium - Small Animals, Large and Small Primates, Plants
  Life Sciences Laboratory Facility
  Large General Purpose Centrifuge

Ultimate Complement (2000+)

- o Health Maintenance Facility Category lV
- o Controlled Environment Life Support System Demonstration
- o Large Plant Growth Module

A number of the equipment items for the non-human research, such as the Large general Purpose Centrifuge and the Large Primate Holding Facility, are planned or are currently being developed for Shuttle spacelab.

The investigators who provided invaluable assistance in defining research objectives, experiment concepts, and implementation requirements for the Life Sciences discipline are listed below in Table 2.7-2.

Table 2.7-2 Life Sciences Contributors

Individual	Organization	Individual	Organization
C. Arnaud	UCSF	M. Correia	UT, Galveston
B. Haverlin		G. Pascuzzon	USA-MRICD
C. Cann		J. French	Cornell Univ
G. Musgrave	VCU	J. Levinson	CU, Denver
J. Duke	UT, Houston	G. Harris	
C. Ward	Rice Univ	K. Baldwin	UC-Irvine
C. Dunn	Byalor Univ	J. Sevier	USRA
M. Reschke	NASA/JSC	C. Huber	BYU
C. Leach-Huntoon		E. Alberqueque	UM-Baltimore
J. Rummel		W. Alexander	Brooks AFB (USRA)
B. Williams	NASA/ARC	W. Harvey	
N. Daunton		M. Ross	UM-Ann Arbor
L. Kraft		D. White	Florida St. Univ
R. Johnston	Texas Med. Ctr, Inc	D. Daphne	UT-Dallas
D. Radmer	MML		

The final Life Sciences data, mission sets and requirements were reviewed by Dr. Bill Williams (NASA/ARC), Dr. W. Carter Alexander (USR-Brooks AFB), and Richard S. Johnston (Texas Medical Center, Inc.).

While it has been shown that man can effectively live and work in the space environment, a number of potentially health threatening phisiological effects have been documented in previous spaceflights. Recent data on Shuttle have indicated that the vestibular-induced sickness and perceptual changes may prove to be hazardous with changes in the acceleration forces during landing of the craft. In addition, the postflight orthostatic intolerance has been more severe in both astronauts and cosmonauts than previously believed. With the longer missions proposed for SS, it is necessary to determine the extent of these effects as well as the nature and extent of the nusculoskeletal deconditioning in order to establish the limitations of human habitation and operational efficiency for the SS era. Physiological effects which require greater than 30 days to manifest cannot be adequately studied on shuttle. The SS will provide the research capability and mission durations necessary to study the etiological mechanisms of these effects and to assess appropriate countermeasures including the potential need for a means of inducing artificial-g in future SS architecture.

2.8 MATERIALS PROCESSING IN SPACE

The missions selected for Materials Processing in Space (MPS) are shown below in Table 2.8-1.

Table 2.8-1 - Materials Processing in Space-Mission Set

Initial Phase

SS Materials Processing Laboratory

Acoustic Containerless Furnace	Directional Solidification Furnace
Electrostatic Containerless Furnace	Gradient Furnace
Electromagnetic Containerless Furnace	Isothermal Furnace
	Fluide/Chemical Process Facility
Vapor Crystal Growth Facility	Fluid Experiment System
Crystals From Solution Facility	Electrophoresis Separation Facility
Floating Zone Furnace	Combustion Research Chamber

MDAC/J&J Electrophoresis (EOS)
Lehigh Monedisperse Latex Reactor

Evolutionary Phase
Commercial Development Units

Ultimate Phase
Commercial Production Units

We are convinced that the early emphasis of space station in the area of Materials Processing should be basic research. This country's knowledge base of processing phenomena in low-gravity environments is not broad enough to allow accurate prediction of those commercial processes that might prove effective in space. We have, therefore, proposed an extensive complement of research facilities to be included within the laboratory, and have included the laboratory module as one of the early components in the space station buildup.

Also included in the MPS Initial Phase complement are the two commercial ventures that are farthest along in their development. We are not excluding other commercial applications from the initial phase, and some could well be ready by the early 1990s.

The Evolutionary Phase complement consists of commercial development hardware for the processes whose feasibility will have been demonstrated by STS-based and SS laboratory experimentation. These are hardware units provided by private industry intended to develop a successful experiment process into a large scale production capability. The generic title is used because we cannot predict which of the processes might exhibit the best commercial viability.

The ultimate phase complement consists of commercial production units. These have been included in the mission set to assure that SS planning includes the servicing capabilities that will be required by successful MPS manufacturing operations.

The mission set described in the MPS area represents a compilation of the thoughts and comments that we received from the individuals listed in Table 2.8-2.

Table 2.8-2 - Materials Processing in Space Contributors

J. Williams, NASA, MSFC, MPS Experiments Development Office
Dr. R. Snyder, NASA-MSFC, Separation Process
H. ATkins, NASA-MSFC, MPS Commercial Applications Office
Dr. T. Wang, NASA-JPL, Containerless Processing Program Manager
Dr. J. Singh, NASA-LeRC, Electronic Materials Processing
Dr. G. Rindone, USRA, Pennsylvania State University
Dr. D. Uhlmann, USRA, Massachusetts Institute of Technology
Dr. D. Day, USRA, University of Missouri - Rolla
Dr. N. Kreidl, USRA, University of Missouri - Rolla
J. Venables, MMC Laboratories, Materials and Surface Science
R. Greenwood, Ball Aerospace, MPS Carrier Program
K. Hughes, Battelle-Columbus Labs, Biomedical Space Research

We were further assisted by having Dr. D. Uhlmann review a preliminary version of our selected mission set and appreciate his comments.

The early application of SS for MPS emphasizes the laboratory experimentation capability. Experimentation will continue throughout the SS era, however, emphasis will shift toward the development and implementation of production hardware for MPS products. Commercial MPS facility servicing then becomes a significant operational requirement for the mature SS. It is felt that the research laboratory aboard SS will provide a capability that can truly bring MPS into commercial viability, and further that no other approach can do this.

2.9 COMMUNICATIONS

The Space Station mission selected for communications are shown below in Table 2.9-1.

Table 2.9-1 Communications Mission Set

<u>Initial Phase</u>

Search and Rescue Program (SARSAT)
Commercial Communication Satellite Launches

<u>Evolutionary Phase</u>

Experimental Geostationary Platform (XGP)

The search and rescue program payload can be easily accommodated by either the initial SS or on a polar-orbiting Earth Observations Platform. Commercial communication satellite launch operations can be accomplished after the implementation of SS Reusable Orbital Transfer Vehicle (OTV) capabilities. The OTV launch operations become a significant SS benefit and are therefore incorporated into the mission set as early as possible. The Experimental Geostationary Platform is shown in the Evolutionary Phase because of its additional SS operational requirements for antenna alignment along with launch operations. The Orbiting Deep Space Relay Station is omitted here because it is not presently considered to be affordable nor technically advantageous.

This Communications mission set was determined after reviewing the thoughts and comments that we received from the individuals listed in Table 2.9-1.

Table 2.9-2 Communications Mission Contributers

T. McGunigal, NASA/HQ, Search and Rescue Program
G. Knouse, NASA/HQ, Mobile Satellite Program
H. Fosque, NASA/HQ, Orbiting Deep Space Relay Station
T. Carey, NASA/NSFC, Experimental Geostationary Platform
J. Schwartz, NASA/GSFC, Tracking and Data Relay Satellite, and Tracking and Data Acquisition System
J. Blankenship, RCA Astroelectronics, Advanced Program Director
J. Schwarze, RCA American Communications, Space Systems Director
Dr. H. Rosen, Hughes Aircraft Co., Engineering Vice President
L. Cuccia, Ford Aerospace, Space Advisory Committee
Dr. G. Gordon, COMSAT General Comp., Senior Staff Scientist

Reusable OTV geosynchornous orbit transfer and servicing operations are the important contributions for Space Station to the communications community. These benefits include the reduced launch costs associated with the reusable OTV, the extended mission life gained from GEO satellite servicing and refueling, and the operational advantages gained by deploying and aligning antennas at the SS. The eventual development of communications antenna platforms will provide yet another demonstration of the SS's utility in meeting the world's communications needs.

2.10 TECHNOLOGY DEVELOPMENT

The technology development missions selected are shown in Table 2.10.1.

Table 2.10-1 - Technology Development Missions

Technology Area	Title
Structures	- Large Structures Technology - Structural Strain Monitoring - Thermal Driven Shape Control
Power Systems	- Large Space Power System Technology Demonstration - Low Cost Solar Panel Technology - Solar Array Plasma Effects
Attitude Control	- Attitude Control System Development - Tether Dynamics Technology
Propulsion Systems	- Fluid Management Technology - Low Thrust Propulsion
Communications/Tracking	- Laser Communications and Tracking - Antenna Range Facility - Large Antenna Development
Materials	- Spacecraft Materials Technology
Servicing Technology	- Satellite Servicing - OTV Servicing
Safety	- Fire Safety
Advanced Energetics	- Large Solar Concentrator - Solar Pumped Lasers - Laser-to-Electric Energy Conversion - Laser Propulsion Test - Solar Sustained Plasmas

These missions have been selected to cover a variety of space technology disciplines to illustrate the range of adaptability of the SS to these development endeavors.

The missions selected for the technology development discipline are based on the inputs to the set of Candidate Technology Development Missions compiled by S. V. Manson of NASA Headquarters staff. The authors of the Candidate Missions that were consulted are listed in Table 2.10-2.

Table 2.10-2 - Candidate Mission Authors

Title	Author(s)	Center
Large Structures Technology	J. Randolph	JPL
	B. LR. Hanks	LRC
	W. Wales	MSFC
Structural Strain Monitoring	J. Heyman	LRC
Thermal Driven Shape Control	H. M. Adelman	LRC
Large Space Power System	M. Valgora	LeRC
Low Cost Solar Panel	L. Slifer	GSFC
Solar Array Plasma Effects	J. Stevens	LeRC
	C. Purvis	LeRC
Attitude Control System Development	J. Randolph	JPL
Tether Dynamics Technology	A. Potter	JSC
Advanced Radiator Technology	T. Mroz	LeRC
Fluid Management Technology	T. Labus	LeRC
Low Thrust Propulsion	D. Byers	LeRC
Laser Communications & Tracking	J. Randolph	JPL
Antenna Range Facility	J. Randolph	JPL
Large Antenna Development	W. Grantham	LRC
Spacecraft Materials Technology	D. R. Tenney	LRC
Satellite Servicing	W. Wales	MSFC
OTV Servicing	W. Wales	MSFC
Fire Safety	T. Labus	LeRC
Advanced Energetics (5)	E. J. Conway	LRC

The role of the SS in support of technology development can be very broad in scope. The generalized benefits are derived from the availability of a test bed approach which permits alternate design approaches to be evaluated before commitment to a program. Most of the technology missions selected can only be demonstrated and studied in the space environment and with the operational capabilities provided by the SS. Some of the unique capabilities are: zero gravity environment; human operator participation prior to automation; extended duration operations; space exposure environment; and the capability to assemble and to accommodate large unwieldy objects. These unique capabilities will support the development of a wide range of space technologies and can substantially reduce development schedules and costs.

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3.0 PLANETARY EXPLORATION/OBSERVATION

3.1 SCIENCE OBJECTIVES

The underlying motivation for the conduct of a long range, coherent program of planetary astronomy consists of the attainment of new insights and understanding of key scientific questions concerning the origin and development of the solar system. Among these major questions are:

(1) What were the physical conditions leading to the formation/origin of the solar system,

(2) What evolutionary paths do the various planets follow, and how stable are the planetary environments?

(3) What were the physical conditions leading to the origin and development of life,

(4) Can we perform experiments on cosmic phenomena, in the solar system environment, that cannot be properly addressed in our laboratories? and

(5) Do extra solar planetary systems exist?

The scope of these questions proceed somewhat beyond the more immediate goals of planetary science, but place these studies in perspective with other long range astronomical goals.

Various committees of the National Academy of Sciences (NAS) and the National Aeronautics and Space Administration (NASA), such as the Solar Systems Exploration Committee (SSEC) have been chartered with the task of developing a systematic approach and the development of a program which will address these basic questions. The results of their efforts have been documented in various reports and are summarized under the Mission Model, Section 3.2. The summary presented in Table 3.1.1, indicating the scientific objectives, and identifies those missions that support the specific objectives.

Table 3.1-1 Planetary Science - Scientific Objectives/Required Missions

Objectives	Recommended Missions
o Origin of solar system	o Galileo Jupiter/Saturn Probes o Comet Rendezvous/Sample Return
o Evolution/Stability of Planets	o Venus Radar Mapper o Mars Geo Chemistry/Climatology/ Aeronomy Orbiter o Venus Probe

Table 3.1-1 continued

o Origin of Life	
o Planetary Systems/Cosmic Phenomena	o Galileo Jupiter/Saturn Missions o Comet Rendezvous/Sample Return
o Extra Solar Planetary Systems	o Space Telescope; Large Deployable Reflector (LDR)

3.2 MISSION MODEL

The Solar Systems Exploration Committee (SSEC) has developed a long range plan for future explorations in planetary science. The highest priority for the planetary program is the development of a core program consisting of two major elements:

(1) On-going basic activities including fundamental laboratory research and theoretical studies, mission operations, technology development and advanced planning activities, and

(2) A cornerstone set of planetary missions/programs to proceed into the next century.

With a modest annual sustained budget funding level, the core program of planetary missions could be carried out with sufficient frequency to permit continuity and adequate inheritance of spacecraft technology and commonality of systems, thus yielding a very cost effective approach.

The projected planetary core program considers four major areas for exploration:

(1) The inner-planet surfaces,

(2) The inner-planet atmospheres,

(3) The "primitive" small bodies of the solar system, and

(4) The outer planets.

The means to implement these missions would be drawn from present and previous planetary spacecraft technology including, Galileo-type hardware, Pioneer-class spacecraft, and Mariner Mark II type spacecraft. Instruments to be flown on these spacecraft for the proposed missions would be geared to address a more specific, and limited, set of scientific measurements than employed on previous spacecraft missions.

Among the missions identified, the following list represents a prioritized set of missions for the conduct of planetary science into the next century:

(1) Venus Radar Mapper (VRM); (See Figure 3.2-1),

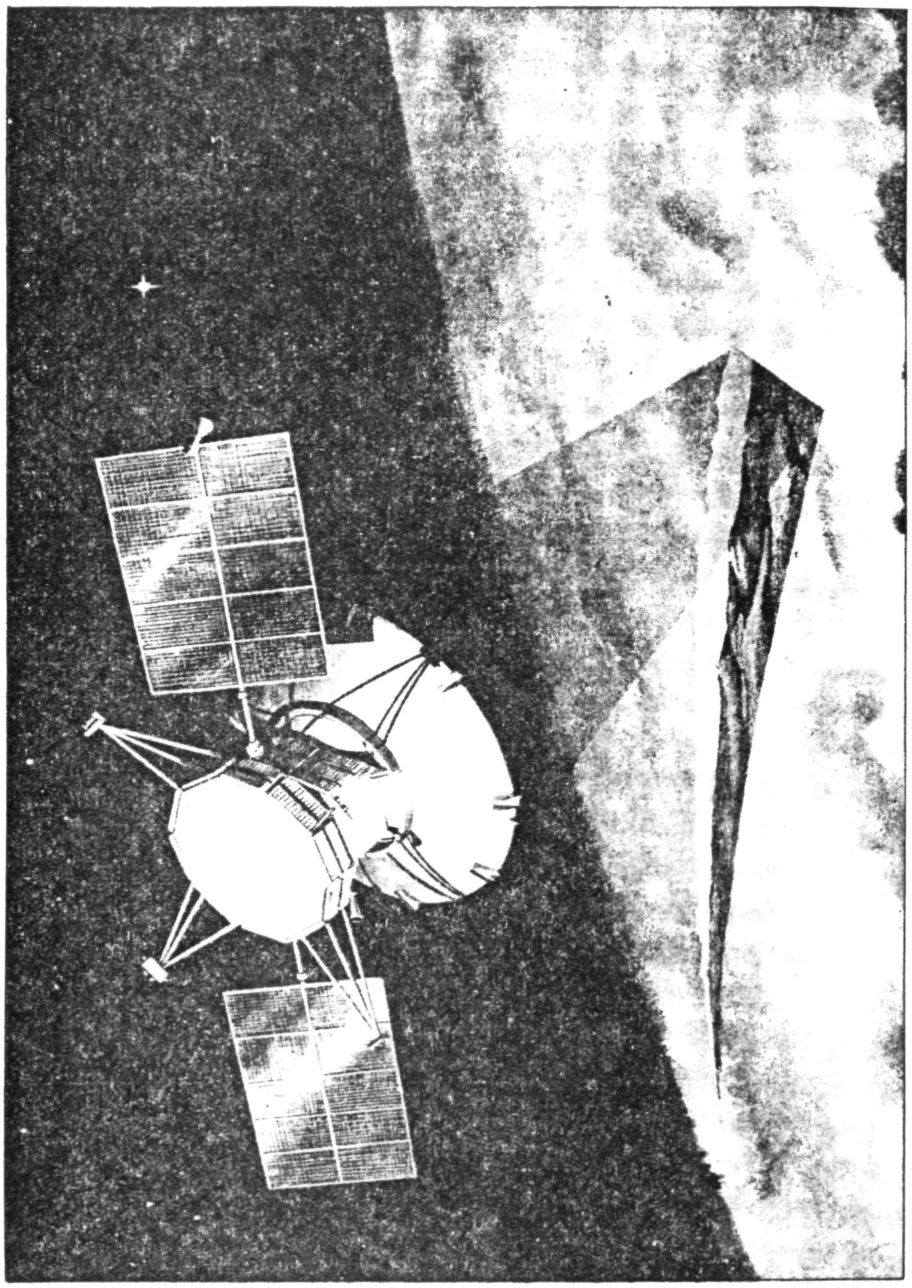

Figure 3.2-1 Planetary-Venus Radar Mapper

(2) Comet-rendezvous mission employing a plasmatized sample return,

(3) Orbiter fly-by mission to the main-belt asteroids,

(4) Mars geochemistry/climatology orbiter,

(5) Mars Aeronomy orbiter,

(6) Mars surface-network of probes,

(7) Atmospheric probe to Venus,

(8) Lunar-geochemistry orbiter,

(9) A near Earth asteroid rendezvous mission, and

(10) A Saturn/Titan Galileo type probe.

In the long term, these missions would form a natural progression leading to future missions such as a lunar research base, a Mars sample return, a Titan lander, and a comet sample return mission. The complete listing of the Planetory Mission Model is presented in Table 3.2-1.

3.3 USER MISSION DATA

The data for developing a plan for planetary studies over the next twenty year time period has been collected from various sources. These include discussions from NASA and NAS panel and working groups, chartered to develop a long range strategy for the systematic exploration of the solar system. Details of the reports of these working groups and, in particular, the Solar System Exploration Committee (SSEC) final report, have only recently been made available.

These recommendations together with other inputs collected from senior strategists in planetary science form the basis for the mission model discussed in subsequent sections. Rather then conduct a detailed survey of the entire user community, we have employed the recommendations of the SSEC. We regard this as representative, and due to the high-level structure of this body, we also regard the recommendations as validated data for use in our mission models. Details of specific missions may be found in Appendices C and D.

Table 3.2-1 Planetary Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV.: RETREV	SERV.: REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Venus Radar Mapper JPL MMCX-0101	S1A	DH					S1F	High	Initial 1988 Affordable 1989	Exploration	720	1	X									X		1000 KG
Comet Rendezvous JPL MMCX-0102	S1B	DI					S1H	High	Evol. 1992 Affordable 1992	Recon		1		X								X		Desired Plasmatized Sample Return Sample Quarantine May Be Necessary 2000-2200 KG
Mars Geochemistry/Climatology Mapper JPL MMCX-0103	S1C	FR					S1E	High	Initial 1989 Affordable 1991	Study	548	1	X									X		500-1000 KG
Titan Probe JPL MMCX-0104	S1D	GV						High	Evol. 1989 Affordable 1994	Exploration	1278	1		X								X		
Mars Probe Network JPL MMCX-0105	S1E	GW					S1C	Med	Evol. 1993 Affordable After 2000	Study	1095-2190													
Venus Atmospheric Probe JPL MMCX-0106	S1F	GX					S1A	Med	Evol. 1994 Affordable 1999	Exploration	365	1		X								X		
Lunar Orbiter JPL MMCX-0107	S1G	FS						Med	Evol. 1993 Affordable 1996	Study	365	1		X								X		300 KG
Comet Sample Return JPL MMCX-0108	S1H	FU					S1B		Evol. 2001 Affordable 1997	Explora-		1		X								X		May Be Combined with Comet Rendezvous 3500 KG

Table 3.2-1 Planetary Science - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g		POINTING				POWER & DURATION			DATA/COMM		THERMAL		PHYSICAL CHARACTERISTICS				MAINT/REPAIR CREW REQMTS			SPECIAL CONSIDERATIONS
	SUST	TRANS	VIEW DIRC	FOV DEG	ACCUR ARC-SEC	STABL ARC-SEC/SEC	PEAK POWER ω / DURATION HRS	OPER POWER ω / DURATION HRS	STDBY POWER ω / DURATION HRS	COMMAND RATE KBPS UPLINK/DNLINK	RECORDING RATE KBPS/DURATION MIN	TEMP DEG C	TOLER	LENGTH M	WIDTH M	HEIGHT M	MASS KG	CREW SIZE	SERV FREQ WKS	MAN HRS PER SERVICE	
Venus Radar Mapper MMCX-0101																	1000				
Comet Rendezvous MMCX-0102																	2000-2200				
Mars Geochemistry/Climatology Mapper MMCX-0103																	500/1000				
Titan Probe MMCX-0104																					
Mars Probe Network MMCX-0105																					
Venus Atmopsheric Probe MMCX-0106																					
Lunar Orbiter MMCX-0107														6	4		300				
Comet Sample Return MMCX-0108														70	5		3500				

Table 3.2-1 Planetary Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV. RETREV	SERV. REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Main-Belt Asteroid Multirendezvous JPL MMCX-0109	S1I	BY					S1B	Low	Evol. 1994 Affordable 2000	Recon		1		X								X		2000 KG
Earth Approaching Asteroid Rendezvous JPL MMCX-0110	S1J	FV					S1B	Low	Evol. 1999 Affordable After 2000	Recon		1		X								X		1000 KG
Saturn Probe/Orbiter JPL MMCX-0111	S1K	BU						High	Initial 1989 Affordable 1994	Exploration		1		X								X		2000-3600 KG

Table 3.2-1 Planetary Science - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER W / DURATION HRS	POWER & DURATION: OPER POWER W / DURATION HRS	POWER & DURATION: STDBY POWER W / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP DEG C	THERMAL: TOLER	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW	MAINT/REPAIR CREW REQMTS: SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Main-Belt Asteroid Multirendezvous MMCX-0109																	2000					
Earth Approaching Asteroid Rendezvous MMCX-0110														70	5		1000					
Saturn Probe/Orbiter MMCX-0111														70	5		2000-3600					

3.4 RECOMMENDED MISSION COMPLEMENT

The missions identified in the previous section have been arranged into a time-phased sequence, which spans the next twenty year time period. The missions are organized by types, such as orbiters, probes, and rendezvous, and have also been arranged for various classes of solar system bodies which are the objectives of each of these missions. In addition, projected launch dates and arrival times are indicated. The primary function of this time-phased sequence is that it permits the orderly development of a planetary program which provides the desired features: continuity; the heritage provided by earlier spacecraft technology for adapting to new missions; the cost-effective use of such spacecraft and instrument technology; and the distribution of program costs over a long time base, such that the rate permits a significant and affordable pace for planetary exploration.

This time-phased sequence is illustrated in Figure 3.4-1 and provides the basis for possible space station roles, considerations, and planning. This time-phased arrangement would thus allow the orderly development and evolution of the space station and its support functions and services necessary to augment the planetary missions.

The missions illustrated here have been subjected to a cost review and analysis. The review consists of: A study of previous NASA budgetary history; an ROM estimate of mission costs; a projection of future budget impacts based on these costs and the time associted phasing shown in Figure 3.4-1; and a final ordered/sequence based on SSEC mission priorities, consistent with an affordable annual program cost.

3.5 COMPOSITE SPACE STATION SUPPORT REQUIREMENTS

To serve the needs of the planetary missions illustrated in Figure 3.4-1, the following set of requirements, services, and capabilities have been extracted from the data provided by the user mission inputs described in Section 3.3 and Appendix C.

The primary missions could benefit from a secondary launch/boost capability. The ability to assemble/integrate additional boost stages and supply the required fuel, and to perform appropriate trajectory maneuvers for achieving optimum launch configurations to the desired, planets/objects, would constitute a significant advantage to the planetary science program.

A second function which the station could provide, consists of a possible temporary quarantine facility for any sample returns obtained from planets, asteroids or comets. Adequate isolation, and diagnostic facilities would be required for analysis/assessment before the samples are delivered to Earth.

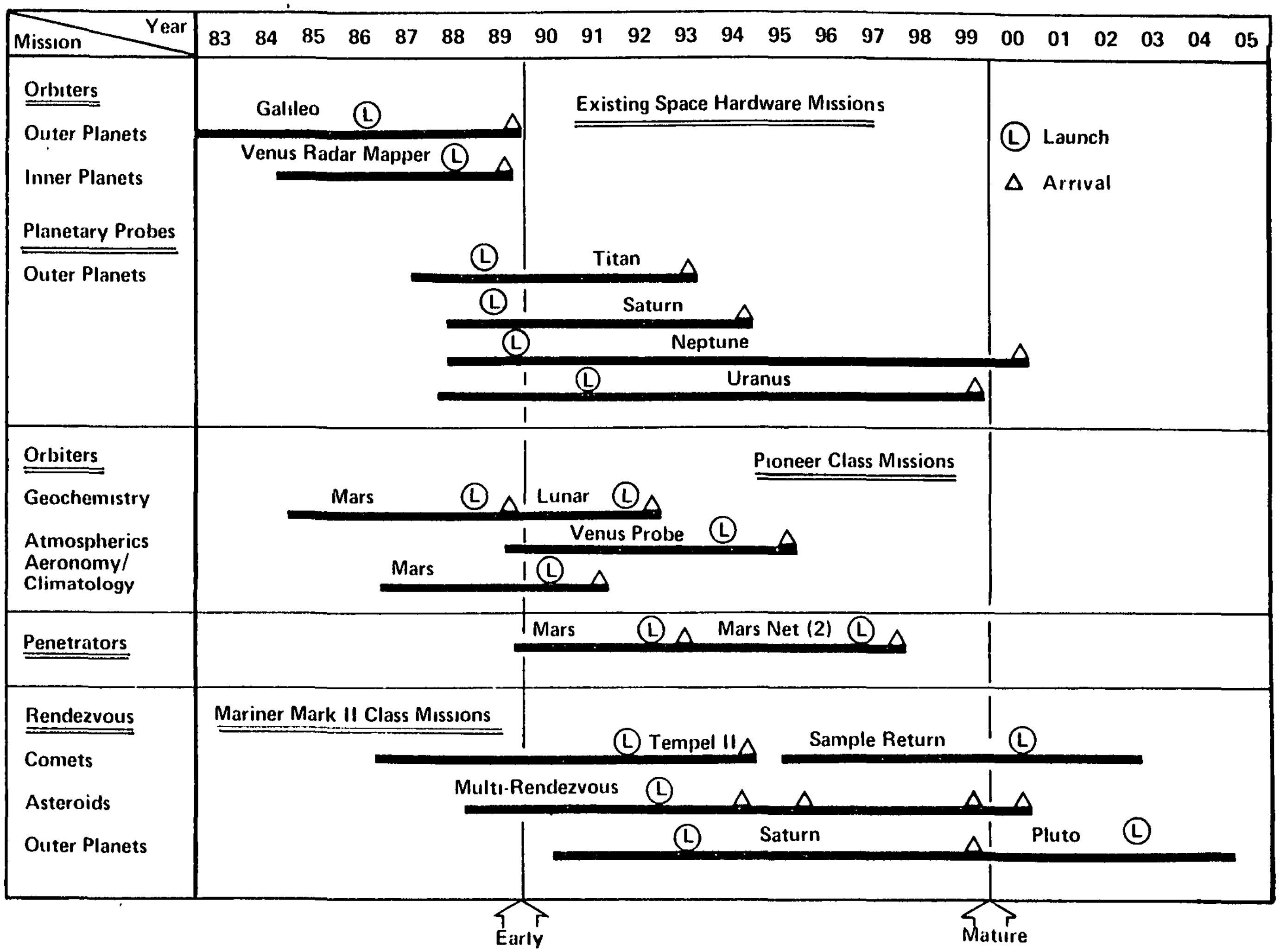

Figure 3.4-1 Recommended Mission Complement - Planetary Sciences

The space station could also serve as an additional communications link for deep-space missions in order to provide improved time coverage, particularly, for missions that require complex and critically timed maneuvers.

As other planetary missions are identified, greater direct support may be required from a space station.

3.6 BENEFITS ASSESSMENT

Direct and cost-saving benefits are not readily apparent for the planetary missions discussed. The requirements for support and capabilities could be provided by space shuttle based operations if adequate shuttle launch capabilities and launch frequency are available.

Scientific benefits, in the form of increased understanding and new knowledge concerning our solar system will of course be provided. A determination of the value and benefits provided are subjective and difficult to quantify in every day returns.

Finally, the continued advances required in the technology to implement these missions will provide spin-offs to both civilian and military concerns, which in turn could provide other unpredictable returns.

In summary, the space station offers the potential advantage of serving as a secondary launch facility, as a vital communications link for deep space missions, and as a possible quarantine facility for sample return missions.

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4.0 EARTH OBSERVATIONS

4.1 SCIENCE OBJECTIVES - EARTH OBSERVATIONS

Scientific Objectives and Measurement Needs

The measurement needs for earth observations are discussed for the present, near and far term in Table 4.1-1. Notice that the far-term needs (space station era) emphasize simultaneous measurements made over long time periods. Given the ability to make these measurements, what scientific objectives can be fulfilled in the space station era with these more accurate, simultaneous long-term measurements? The following paragraphs discuss the scientific objectives for the atmospheric sciences and observations of the Earth's surface.

a. Atmospheric Sciences - The scientific objectives for upper and lower atmospheric research are quite different. The present goal of upper atmospheric research is to understand the physical processes of the upper atmosphere that are affected by chemical species introduced into the upper atmosphere by human activities. These chemicals can include anthropogenic chlorocarbons, nitrogen based compounds present in fertilizers, and airplane and space shuttle exhaust gases. In short, any of a variety of particulates, aerosols, and gases introduced by human activity can perturb the delicate and not well understood balance of the upper atmosphere. To some extent, instruments aboard the Upper Atmosphere Research Satellite (UARS) will help us understand the chemistry, dynamics, and energetics of the upper atmosphere. However, because of the complexity of the coupling of upper atmospheric processes, it is unlikely that the effect of human perturbations will be understood in the years preceeding the space station era. The measurement of the concentrations of as many chemical species as possible, with vertical resolution of about 1 km is an important goal for the 1990s.

   Lower atmospheric scientific objectives are designed to improve the data used by the National Meteorological Center in numerical these models. Vertical temperature profiles, so important to these models, are currently provided by infrared and microwave sounders. However, these data sets are limited to cloudless or partly cloudy areas of the earth. A future scientific objective is to obtain temperature profiles in cloudy regions and in storm systems using multichannel microwave sounders in the 10-90 GHz region. These sounders will provide the continuity required to fully utilize numerical forecasting methods.

b. Earth's Surface - One of the prime objectives is to be able to make long term observations of sea surface temperature and surface wind speed. Additionally, ocean rainfall measurements are important for an understanding of sea-air interaction. Measurements of salinity, ocean color, and ocean pollution are quite important, as is the mapping of large ice features and the determination of the ice's age.

Table 4.1-1 Evolution of Earth Observation Measurement Needs

	Current	Near-Term	Far-Term
Upper Atmosphere	– Aerosols – Ozone – Minor Species	– Simultaneous – Winds	– Simultaneous – Long-Term – Calibration – Lidar
Global Chemical Cycles	– None	– Sensor Testing (Maps)	– Lidar -- High Spatial Resol
Weather	– Soundings – Clouds	– Geostationary – Sounding (Microwave)	– Lidar – Precipitation
Climate	– Solar Const – Radiation – SST – Currents	– Surface Winds – Global Radiation	– Long-Term – High Precision – Calibration
Oceanography	– Winds – Topography – Color – Temperature	– Wave Spectra	– Simultaneous – Microwave
Geology and Geophysics	– Geodesy – Crustal Dynamics	– Mapping	– Multispectral – Synthetic Aperture Radar

Scientific objectives related to continental land masses include the need to remotely measure rainfall over land areas, improve multispectral mapping of regions for land cover dynamics and planning, make global biomass measurements to look for dynamic processes, and making accurate moisture measurements. Another geomorphic and archeologic objective is to map hyperarid regions in a search for Tertiary Period fluvial features. Artifacts associated with human settlements are now buried a few feet under the sand and are present at sites of prehistoric stream flows and floodplains. Space observations using radar provide a unique way to probe through the omnipresent sandy surface to underlying bedrock. Another scientific objective is to map unexplored regions (particularly cloud covered areas) to a few tens of meters in horizontal position and a few meters vertical resolution. These measurements allow accurate maps to be constructed of unexplored and unmapped regions, at a cost considerably less than ground surveys or aerial mapping. The resulting maps can be very important to developing countries for land use planning, and could also be used in mineral exploration. In fact, geologic mapping of surface geology using a multispectral sensor (thermal infrared) could be very valuable to geologists worldwide. From a geophysical viewpoint, more precise mapping of the earth's gravitational and magnetic field is also important and a priority.

From the objectives and measurement needs some common themes emerge. First, despite the tremendous amount of data already taken by space-borne instrumentation, the field is data limited. Very sophisticated data reduction and analysis programs are available, so transferring satellite sensor data into numerical models or image analysis programs can be a relatively efficient process, even though it has not been in the past. What is now necessary, and will be particularly important in the space station era, is sufficient data on a set of geophysical parameters (such as wind speed, temperature, and pressure at different altitudes) taken with good spatial and temporal resolution. Furthermore, these sets, for climatological analysis, must extend over a period of years, preferably over an eleven year sunspot cycle or longer. This long-term atmospheric data, coupled with studies of solar variability and solar-terrestrial relationships, will play an important role in climate prediction. This in turn will play a significant role in perhaps the most important task of the space station era-feeding the world's hungry people.

Long-Term Observations

One prime scientific objective in the earth observations field centers on the ability to make long term observations of the earth and atmosphere in order to make simultaneous measurements of a set of geophysical parameters. Included in this set of parameters are wind speed, wind direction, and pressure at different atmospheric levels, as well as precipitation and ocean temperature. By combining data sets from several instruments, a powerful synergistic effect is produced. This effect is presently lacking. Comparisons of data from different geosynchronous satellites carrying nearly identical instruments is often difficult because of calibration differences.

The long-term nature of the data sets is particularly important for an understanding of the earth's climate. The long term aspect is important due to the dependence of atmospheric variation on short and long-term solar variability. Observations over an 11 year or even 22 year cycle would be an important beginning to an understanding in this area. Solar and solar-terrestrial physics data need to be combined with atmospheric data over many years before any cause-effect relationships can be finally delineated.

Transient Events

The second prime need for earth observation instruments is to be able to respond to targets of opportunity, transient phenomena such as a volcanic eruption or an unusual, severe storm. An event such as a volcanic eruption presents a unique opportunity to each scientific area. Changes in landform can be mapped as well as changes in vegetation. The gases and particulates vented can be analyzed for volume and composition. These plumes can be followed as they serve as tracers of atmospheric circulation. The long-term effect of the eruption can be studied and modeled from a climatological perspective. Thus transient phenomenon can be valuable to several disciplines and require pointable instruments so that these unusual events may be observed.

4.2 MISSION MODEL - EARTH OBSERVATIONS

The space station mission model as shown in Table 4.2-1 describes space activities from the present to the space station era. Not included in our mission model are polar orbiting and geosynchronous weather satellites that are already in orbit, even though new versions of these satellites may be launched in the near future and in the space station era. For example, the TIROS and GOES satellites are not included.

Our mission model centers around the instruments required to make a given set of observations. For the missions described in Table 4.2-1, Martin Marietta data sheets describing each mission in detail were filled out. A summary of those data sheet descriptions is found in the Appendix of this report. Figure 4.2-1 describes the phased earth observations activities projection from 1980 to 2000. Note that missions are fairly balanced between scientific disciplines and usually incorporate shuttle test flights for new instrument designs or technology. For example, a Synthetic Aperture Radar (SIR-A) was tested on the Shuttle and will be tested again in a modified form (SIR-B) again on the Shuttle. Later in the decade the free Flying Imaging Radar Experiment (FIREX Satellite) will be flown and will incorporate the knowledge and experience gained in SIR-A and SIR-B. Also, the cooperative international research programs, such as the International Satellite Cloud Climatology Program (ISCCP) are expected to play more important roles in the future. From this listing of possible missions, instruments were selected to go on board a space station and polar platform.

Table 4.2-1 Earth Observation Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV.: RETREV	SERV.: REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
FILE-Feature Identification and Location Exp MMA MMCX-0700		EI	90	Any	500			Operational	1982 Affordable	Research		5	X		X	X	X							30 KG
LAMMR-Large Antenna Multifreq. Microwave Radiometer NASA-GSFC MMCX-0701		JK	90		500			Planned	1991 Affordable	Research				X			X							318 KG
Stereo Visual Imager US Geolog Survey MMCX-0702	S2E	BZ	90	90		200-450	S2A	Opportunity	Initial 1991 Affordable 1995	Application	1800	2		X		X	X	X	X	X				
ERB-Earth Radiation Budget NASA, NOAA MMCX-0703	S2D	AW	46		704		S2G	High (Operational)	Initial 1984,1988 1992 Affordable1991	Research	3285 (9 Yrs)	3	X			X	X	X	X	X				50 KG
CZCS-Coastal Zone Color Scanner NOAA MMCX-0704	S20	FJ	90	Above 70	800		S2B	Operational	Initial 1990 Affordable 1991	Research & Application	1825	1	X			X	X	X	X	X	X			
Ocean Microwave Package MMCX-0705		JL			500			Opportunity	Affordable	Research				X			X							200 KG
Scatterometer NASA-GSFC MMCX-0706		JM			400			Planned	Affordable	Research			X				X							160 KG
THM-Tethered Magnetometer (Mag. Gradiometer) US Geolog Survey MMCX-0707	S2L	JC	90	Above 70		200 w/100 km tether	S2M	Planned	Evol. 1990 Affordable 2000	Research	720	1		X		X	X		X					

Table 4.2-1 Earth Observation Science - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER w / DURATION HRS	POWER & DURATION: OPER POWER w / DURATION HRS	POWER & DURATION: STDBY POWER w / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
FILE-Feature Identification and Loc. Exp. MMCX-0700			Earth					100				12.5 ±12.5	1	0.5	0.5	30				
LAMMR-Large Antenna Multifreq Microwave Radiometer MMCX-0701			Earth	100°				300		64/200			4	1	1	318				Requires counter-rotating mass so net angular. Momentum is zero. 6-50 GHZ
Stereo Visual Imager MMCX-0702			Earth										2	2	2					Needs open FOV both fore and aft
ERB-Earth Radiation Budget MMCX-0703			Solar Earth					55		1 3		25 ±10				50				
CZCS-Coastal Zone Color Scanner MMCX-0704			Earth					11.4												Sun synchronous orbit preferred
Ocean Microwave Package MMCX-0705			Earth		1100			200		20			0.5	0.5	0.25	200				
Scatterometer MMCX-0706			Earth		1000			215		4			1.15	0.55	0.31	160				3 1 X 1 X 0.15 m Deployed
THM-Tethered Magnetometer (Mag. Gradiometer) MMCX-0707			Earth									-270	1	1	1		1			LHe cooled Requires 100 km tether

Table 4.2-1 Earth Observation Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE: LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ONBOARD	ATTACHED	PLATFORM	FREE SAT	SERV.: RETREV	SERV.: REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
GG-Gravity Gradiometer US Geolog. Survey MMCX-0708	S2M	JD	90		300	LEO	S2L	Planned	Evol. 1990 Affordable 2000	Research and Application		1		X				X	X	X	X			
TOPEX-Ocean Topography Exp. NASA, JPL MMCX-0709	S2N	BH	63.43	± 65	1300		S2A	Planned	Initial 1989 Affordable 1993	Research	1800	2	X					X	X	X	X			
Geosyn Satellite Sensor Intercalibration MMCX-0710	S2H	JB	90			ANY	GOES Sats.	High (Opportunity)	Initial 1990 Affordable 1991	Research	365	3		X	X	X	X		X	X	X			250 KG
Thermal Infrared Multisp. Imager NASA, JPL MMCX-0711	S2J	BM CZ	98		700-830	300-830	S2B	Opportunity	Evol. 1992 Affordable 1998	Research and Application	1800	1		X			X	X	X	X				833 KG
LIDAR NOAA MMCX-0712	S2I	DW FI	90		400-800	400-800	S2C	High (Planned)	Evol 1993 Affordable 1994	Research	365	1	X				X	X	X	X	X			
CLIR-Cryogenic Limb Scanner NCAR MMCX-0713	S2C	FK	90	Above 60	500-600		S2B	Opportunity	Initial 1989 Affordable 1989	Research	1800	1		X			X	X	X	X				
Imaging Spectrometer NASA, JPL MMCX-0714	S2B	BL CD CE CY EG	90	Above 70		LEO	S2C	High (Opportunity)	Initial 1989 Affordable 1989	Research and Application	3600	1	X			X	X	X	X	X				55 KG
Microwave Radiometer NASA-GSFC, NOAA MMCX-0715	S2G	DY	90			LEO	S2F	Operational	Initial 1989 Affordable 1988															

Table 4.2-1 Earth Observation Science - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS PER DAY	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/ONLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP DEG C	THERMAL: TOLER	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW	MAINT/REPAIR CREW REQMTS: SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
GG-Gravity Gradiometer MMCX-0708			Earth																	52		Grav. Gradiometer uses LHe for cooling
TOPEX-Ocean Topography Exp MMCX-0709			Earth																	52		Orbital position needs to be known to 5 cm
Geosyn. Satellite Sensor Intercalibration MMCX-0710			Earth					200/5						1	1	1	250			4		Geosyn satellite parameters will depend on instrument being calibrated
Thermal Infrared Multispectral Imager MMCX-0711			Earth									-197					300			52		2π SR pointable cryog. cooled detector
LIDAR MMCX-0712			Earth					2123-2346	209		6400w/o process 84 w/ process						833			13		Changeout of flash tubes at 3 month intervals
Cryogenic Limb Scanning Interferometer and Radiometer MMCX-0713			Earth Limb				600	120						4.8	0.96		800			104		LHe cooled detector very sensitive to contaminants
Imaging Spectrometer MMCX-0714			Earth					2000		300,000							500					2π SR pointable cryog. cooled detector
Microwave Radiometer MMCX-0715			Earth	$\pm$25	$\pm$0.5			65		2				0.49	0.15	0.2	55					FOV is $\pm$25 either side of sub-satellite track

Table 4.2-1 Earth Observation Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ONBOARD	SS SUPPORT FUNCTIONS: ATTACHED	SS SUPPORT FUNCTIONS: PLATFORM	SS SUPPORT FUNCTIONS: FREE SAT	SS SUPPORT FUNCTIONS: SERV. RETREV	SS SUPPORT FUNCTIONS: SERV. REMOTE	SS SUPPORT FUNCTIONS: RESUPPLY	SS SUPPORT FUNCTIONS: LAUNCH	SS SUPPORT FUNCTIONS: ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Synthetic Aperture Radar NASA, JPL, USGS MMCX-0716	S2A	CW CX	90	Above 70		LEO	S2E	High (Opportunity)	Initial 1989 Affordable 1986	Research	1800	1		X		X	X	X	X	X				125 kg
Active Microwave NOAA	S2F	JA	90			LEO	S2G		Initial 1989 Affordable 1998	Research	3600	1	X			X	X	X	X	X				
Microwave Passive 100m NOAA	S2K	DY	Equatorial		GEO	GEO	S2G		Evol. Affordable 1998	Research and Application	3600	1		X				X	X	X		X	X	

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5.0 SPACE PHYSICS

5.1 GENERAL OBJECTIVES

The overall goal of the space physics program is to understand the fundamental physical processes involved in mans global and universal environments. Although the main thrust of the program is the advancement of space physics, an improvement in monitoring and prediction capabilities in the study of solar-terrestrial relationship is also very desirable.

Space physics for the next two decades is focused on near earth space physics, due to the coupling of the earth's magnetosphere with the solar wind. The interest in space physics goes beyond science for science's sake, since it also involves understanding the natural processes which may allow long-term climatology/weather forecasting prediction over the solar cycle, and furthermore, provide warning of episodic events which give rise to disruption of RF communications and electrical power distribution systems. The knowledge gained in the long run may even provide a possibility to control some aspects of our environment, such as the weather.

5.2 SPECIFIC OBJECTIVES

To achieve such goals requires a coordinated scientific undertaking due to the complexity and breadth of the relationships. Solar terrestrial physics requires the simultaneous investigation of both solar and earth physics to understand the cause and effect relationships.

Some specific space plasma physics objectives include the study of plasma interactions with space structures in LEO; the study of naturally occurring acceleration processes; and the effects of plasma interactions on materials properties based on recent STS flights. Indeed, possible answers to these questions may arise in the investigation of fundamental space physics processes such as spacecraft charging. Table 5.2-1 below, summarizes the major elements and identifies a number of key scientific objectives for the space physics program.

Table 5.2-1 Space Physics Objectives

Major Elements	Key Investigative Objectives
o Space Plasma Physics	o Characterize Solar System Plasmas
	o Understand Plasma Interactions and Confinement
	o Investigate Plasma Instabilities

Table 5.2-1 (concluded)

o Solar Terrestrial Relationships	
- Solar Variability	o Solar Variability Effects on Earth
- Magnetosphere Physics	o Remote Magnetospheric Diagnostics
	o Wave-Particle Processes
	o Magnetosphere-Ionsphere Mass Transport/Coupling
	o Global Electric Circuits
- Atmospheric Sciences	o Upper Atmospheric Dynamics
	o Middle Atmospheric Chemistry & Energetics
	o Lower Atmospheric Turbidity
	o Planetary Atmospheric Waves

5.3 MISSION MODEL

In order to identify appropriate missions to meet the needs of space physics for the next 1 or 2 decades, various sources of data and reports were studied and scientific investigators working on present generation experiments were contacted for their views and advice. An extensive collection of scientific missions has been suggested and documented. These have been collected and summarized in Table 5.3-1. This data has then been studied further to prepare a time-phased sequence of these missions, which would service the needs of space physics investigation over the next 20 year time period. The resulting mission sequence is illustrated in Figure 5.3-1. There are three major classes of investigations shown:

1) Collection of active experiments which have been started in early STS flights and that evolve into an Active Plasma Facility,

2) Set of passive in-situ plasma experiments employing translational techniques and tethered devices,

3) Synergistic array of remote sensing devices designed to probe inaccessible regions in space or on earth and the sun.

Table 5.3-1 Space Physics Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV.: RETREV	SERV.: REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Space Plasma Effects Upon Large Spacecraft NASA MMCX-0400	S3A	JE	SS Incl.		SS Alt.	LEO	S3B S3C S3D	Opportunity	Initial Affordable 1990	Research	Perm.			X	X									Measurements Should Begin Upon SS Construction Results May Serve to Impact SS Operations Over Long Term
Large Spacecraft Impact Upon Proximate Space Plasma NASA MMCX-0401	S3B	GB	SS Vicinity		SS Vicinity	LEO	S3A S3C S3D	Opportunity	Initial Affordable 1991	Research	Perm.			X				X	X	X	X			Several Subsatellites (3 Classes) Above 500 KG
ISTO - Initial Solar Terrestrial Observatory NASA-MSFC MMCX-0402	S3C	AZ	57	57-70	400	300-400	ABD EFG HJ S5E	Candidate	Initial Affordable 1995	Research	1800 Minimum			X	X	X	X	X	X	X	X	X	X	Solar Physics Adv. Solar Observatory May Be Integrated on Same S/C 20,000 - 60,000 KG
ASTO - Advanced Solar Terrestrial Observatory NASA-MSFC MMCX-0403	S3D	AZ	90	80-100	250	200-250	ABC EFG HJK S5E	Candidate	Evol. Affordable 2001	Research	1800 Minimum			X	X	X	X	X	X	X	X	X	X	30,000 - 80,000 KG
GEOSTO - Geosynchronous Solar Terrestrial Observatory NASA- MMCX-0404	S3E	AZ	0		GEO		CDE FJK S5E	Opportunity	Evol. Affordable 2004	Research	1800			X			X	X		X	X	X	X	10,000 - 20,000 KG
Very Large Radar NASA MMCX-0405	S3F	JH	0		GEO		S3C S3D S3E	Opportunity	Ult. Affordable 2006	Research	1800			X			X	X		X	X	X	X	Above 20,000 KG
OPEN - Origin of Plasma in the Earth's Neighborhood NASA-GSFC MMCX-0406	S3G	BI		0-80		2-240 R_E	S3C S3D	Planned	Initial Affordable 1993	Research	1460	4	X					X				X		(Manned) In-Space Use of Space-Based Interception of Open Data May Facilitate STO Program Objectives 1000 KG
AIE - Advanced Interplanetary Explorer NASA-GSFC MMCX-0407	S3H	EU	L_1 Libration Approximately	15°x 500°			S3C S3D S3E	Opportunity	Evol. Affordable 1998	Research	1460	1		X				X				X		

Table 5.3-1 Space Physics Science - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER W / DURATION HRS	POWER & DURATION: OPER POWER W / DURATION HRS	POWER & DURATION: STDBY POWER W / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Space Plasma Effects Upon Large Spacecraft MMCX-0400																				
Large Spacecraft Impact Upon Proximate Space Plasma MMCX-0401								100-1000			1,000		1.5	1.5	1.1	7,500				1.5x1.5x10-100 m Deployed
ISTO - Initial Solar Terrestrial Observatory MMCX-0402			Inertial Solar Earth		10	0.02	25,000	10,000		32,000		-100 +100	80	15	9	20,000-60,000	1-3		24	
ASTO - Advanced Solar Terrestrial Observatory MMCX-0403			Inertial Solar Earth		10	0.02				32,000		-100 +100	80	15	9	30,000-80,000	1-5		36	
GEOSTO - Geosynchronous Solar Terrestrial Observatory MMCX-0404			Inertial Solar Earth													10,000-20,000				
Very Large Radar MMCX-0405	0.05-0.1	0.1 +TBD	Inertial					25,000					2,000	2,000	2,000	Above 20,000				L, W, H Deployed
OPEN - Origin of Plasma in the Earth's Neighborhood MMCX-0406			Inertial		0.6			15		600	100		3.0 (Cylinder)		3.5	1,000				
AIE - Advanced Interplanetary Explorer MMCX-0407			Solar Inertial							6										

Table 5.5-1 Space Physics Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV. RETREV	SERV. REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Plasma Turbulence Explorer NASA, JPL MMCX-0408	S3J	DR	TBD		TBD		S3D S3E	Planned	Evol. Affordable 2002	Research				X				X	X	X	X	X		
Chemical Release Module Facility NASA-MSFC MMCX-0409	S3K	DP	Many		Many		S3C S3D S3E	Approved	Initial 1985 Affordable 1990	Research	180 Min.	Many	X					X	X	X	X	X	X	Continuation Throughout 1990's Required to Meet STO Program Objectives 2700 KG

Table 5.5-1 Space Physics Science - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIR	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Plasma Turbulence Explorer MMCX-0408			Inertial																	
Chemical Release Module Facility MMCX-0409			Inertial				180	20			1.0		3 (Cylinder)		2	2,700				

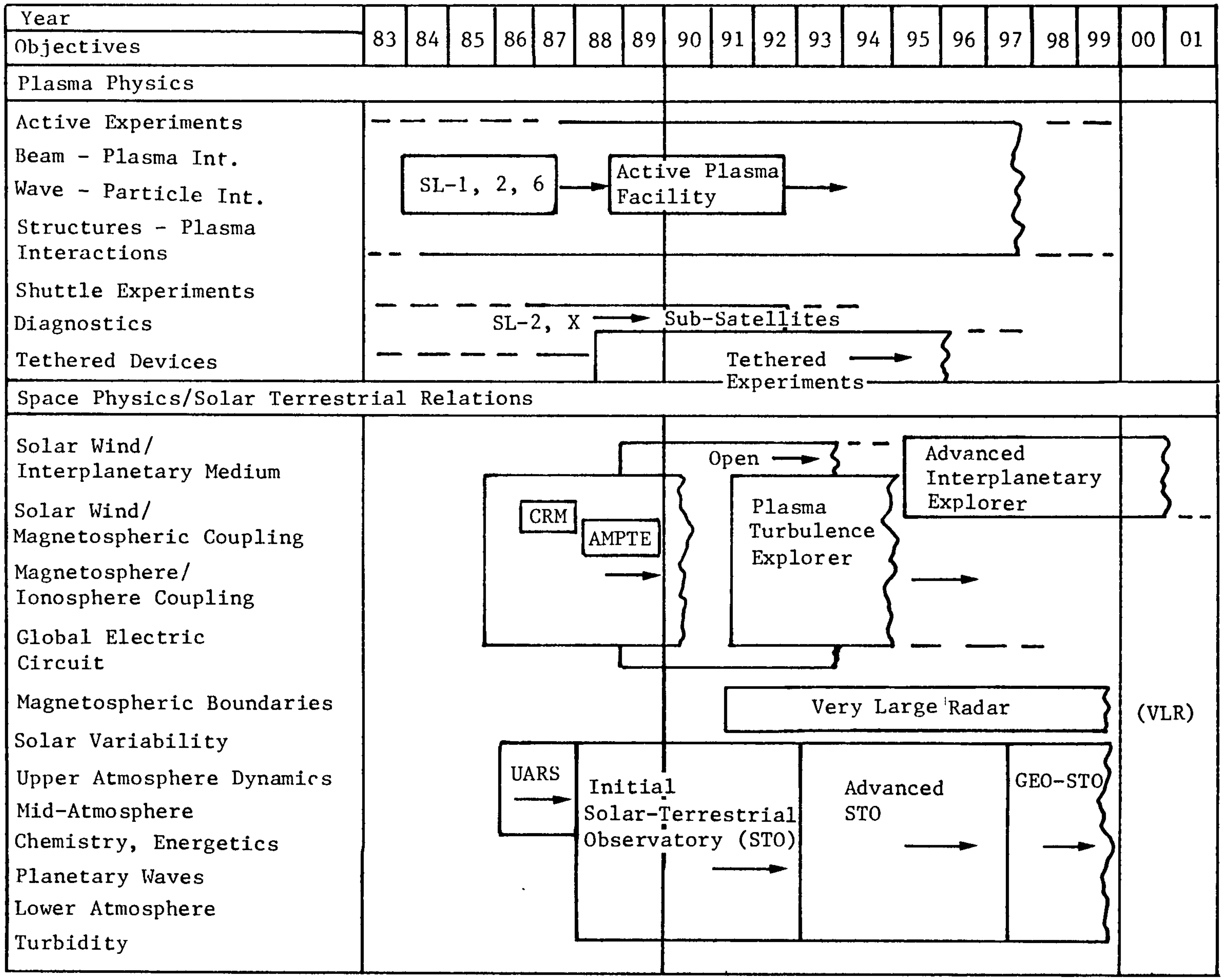


Figure 5.3-1 Space Physics Mission Sequence

These investigations also employ several types of platforms for development and implementation. These include: STS experiments such as Spacelab 1 (SL-1), SL-2, and SL-6, with appropriately developed interfaces; explorer-class spacecraft such as Active Magnetospheric Particle Tracers Experiment (AMPTE), Plasma Turbulance Explorer (PTE), and Advanced Interplanetary Explorer (AIE), for housing in-situ plasma experiments; large platforms such as the proposed Solar Terrestrial Observatory with considerable support and growth capability provided to a synergistic collection of active and remote sensing instruments; and large, deployed free-flyers on platforms which operate independently from other facilities, to perform specific detailed diagnostic observations, such as the Very Large Radar (~Km size array).

Collectively, these missions provide a powerful, and varied approach to the key science objectives, following several, independent investigative paths, in order to satisfy these objectives and continue the advancement of space physics for the next decade.

5.4 RECOMMENDED COMPLEMENT

All facility class missions previously identified prior to 1989 have received some level of funding; e.g., Chemical Release Module (CRM) facility, AMPTE, and Subsatellite Facility. The CRM facility program continues throughout the 1990s primarily in support of the Solar Terrestrial Observator (STO) program requirements. In the early 1990's, a maneuvering capability for the CRM coupled with TMS and OTV support, will allow reuse via on-orbit refurbishment and resupply.

Programs such as Upper Atmospheric Research Satellite (UARS) and Origin of Plasma in the Earths Neighborhood (OPEN) are awaiting further go ahead funding.

The STO program, (Figure 5.4-1) consists of two stages, Initial Solar Terrestrial Observatory (ISTO) and Advanced Solar Terrestrical Observatory (ASTO), with a GEO-STO mission implemented later in the program. The mission sequence shows some extension in mission duration for several missions, most notably the STO missions. However, listed missions can actively use the services of a space station to remain operational over extended periods via on orbit refurbishment and instrument change out. The overall STO program requires an 11 to 22 year operational period to do thorough research over a solar cycle, and to begin experiments relating to modification of ionospheric heating/cooling properties. The OPEN program is included to satisfy program requirements for companion spacecraft for auxilliary measurements. Subsequent to OPEN, the Advanced Interplanetary Explorer and the Plasma Turbulence Explorer Missions would continue to satisfy this need.

Due to similarities among the scientific objectives, the advanced solar observatory (ASO) may be consolidated on the same spacecraft with the ISTO.

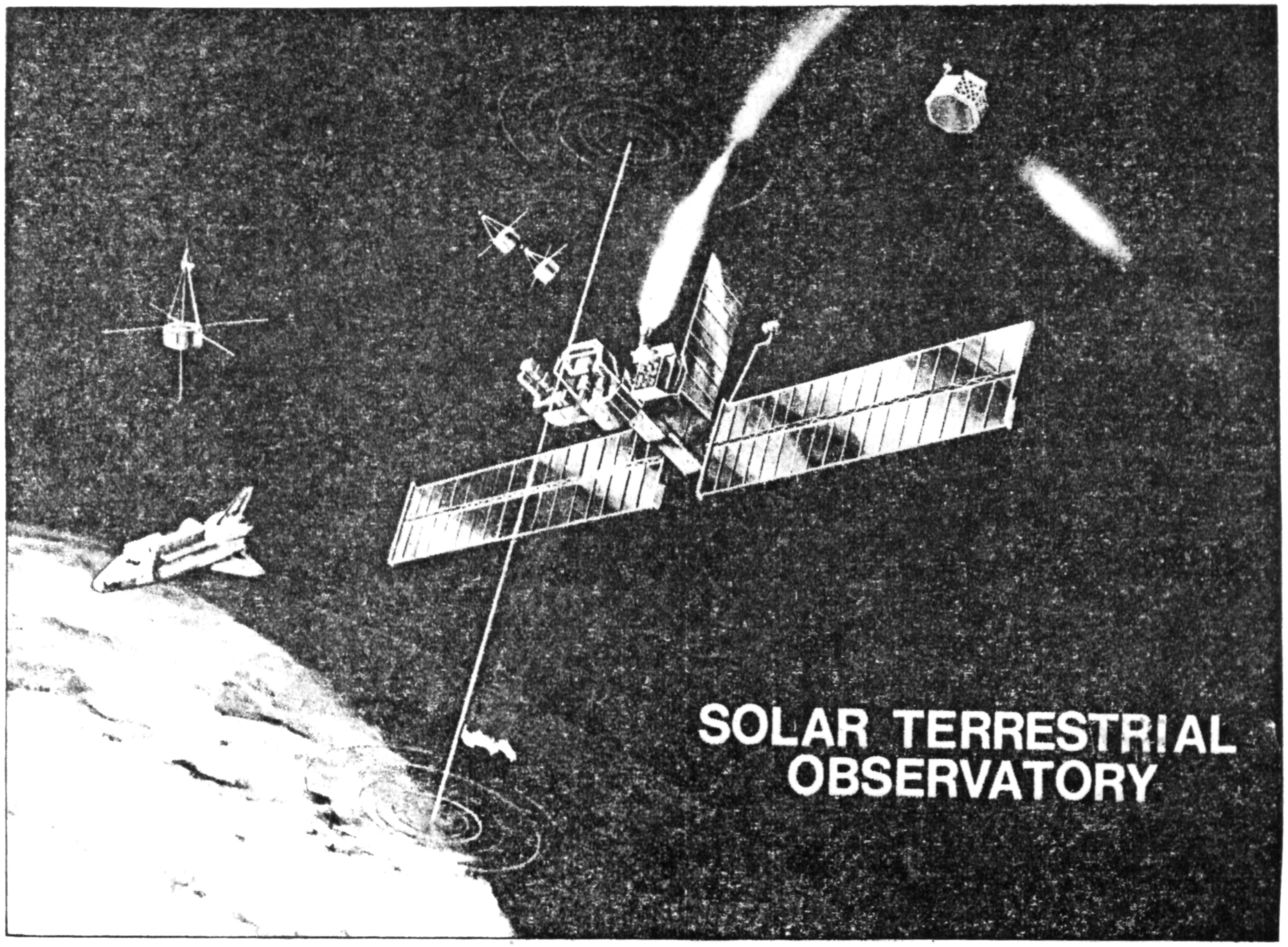


Figure 5.4-1 Solar Terrestrial Observatory

Two additional experiments are identified which are both of basic research interest and which also bear on large spacecraft technology. A mission to study Space Plasma Effects upon Large Spacecraft involves extended exposures of large space structures for possible degradation effects. A second mission to study the inverse problem of the effect of a Large Spacecraft Impact upon Proximate Space Plasma would be a continuation of investigations currently underway on shuttle missions. As various spacecraft grow in size and complexity it will become increasingly important to assess the impact of the physical presence of the spacecraft on the local space plasma.

A mission concept for the mature phase of the Space Station is the Very Large Radar (VLR). A one to two kilometer aperture radar would be located approximately in GEO, outside the plasmasphere in order to perform remote diagnostic measurements on the plasmaphere and various boundaries of the magnetosphere. Table 5.4-1 summarizes the recommended mission complement.

Table 5.4-1 Recommended Complement

A. Initial Phase

- o Space Plasma Effects Upon Large Spacecraft
- o Large Spacecraft Impact Upon Proximate Space Plasma
- o Initial Solar Terrestrial Observatory (STO)
- o Upper Atmosphere Research Satellite (UARS)
- o Origin of Plasma in Earths Neighborhood (OPEN)
- o SL-X Experiments
- o Chemical Release Module Facility (CRM)
- o AMPTE

B. Evolutionary Phase

- o Active Plasma Facility
- o Advanced Solar Terrestrial Observatory (ASTO)
- o Plasma Turbulence Explorer (PTE)
- o Advanced Interplanetary Explorer

C. Mature Phase

- o Very Large Radar (VLR)
- o Geostationary Solar Terrestrial Observatory (GEO-STO)
- o Advanced Active Plasma Facility

5.5 COMPOSITE SUPPORT REQUIREMENTS

Some major requirements placed on the space station systems and operations by the space physics program are discussed below.

First, there is a need to understand the in-situ plasma and its effects on the Space Station due to the changing spacecraft configuration and flight attitudes during its buildup. This will require a very early implementation of instrumenting the system for measurements during the assembly period.

One of the major facilities, the Solar Terrestrial Observatory (STO), requires considerable platform subsystems support. The STO incorporates a large number of instruments for the coordinated operations. This will be a challenge for both ground and on-board crew, particulary for real time response to episodic events.

Additional support requirements, such as control and operation, and maintenance, of both free-flying platforms and tethered subsatellites will also challenge the on-board crew, both for satisfactory operation and for safety.

Also, some of the extremely high data rates will require a sophisticated information handling system.

Manned STO operation is highly desirable. Real-time response to episodic events such as magnetospheric storms and solar flares is essential and can best be handled by an on-board observer due to the rapid response time required.

Finally, facilities such as the STO will need on-board assembly, integration, and test capability of complex groups of scientific instrumentation. As an example, Table 5.5-1 summarizes the STO instrumentation and other facilities and instruments to be used for the space physics missions. Also, calibration, alignment adjustments, and routine maintenance for instruments such as the LIDAR and Plasma Wave Injector are essential. There can be significant cost savings if these functions can be performed by man.

Finally, contamination must be controlled. Releases of water and/or cryogen effluents must be contained. Active monitors for outgassing in the space station vicinity are required. The contamination consideration may require that the STO instrumentation be located on a separate platform. An extensive analysis of space station contamination and control is needed in order to make such tradeoffs.

5.6 BENEFITS ASSESSMENT - TBD

Table 5.5-1 Consolidated ASTO Equipment

Instrument	Function	Specifications	Solar Variability	Wave-Particle Processes	Magnetosphere-Ionosphere Interaction	Global Electric Circuit	Upper Atmospheric Dynamics	Middle Atmospheric Chemistry & Energetics	Lower Atmospheric Turbidity	Planetary Atmospheric Waves
			Overall STO Program Objectives Compatability & Time Phased Utilization Aboard STO Spacecraft							
Total Irradiance Monitor (Solar Constant Monitor)	Integral of Solar Irradiance over Full Spectrum	0.1% Uncertainty, 0.01% 27-Day Precision	X					X	X	
Spectral Irradiance Monitor	Spectral Irradiance in X-Ray, EUV, & UV Spectral Ranges	Spectral Interval / Spectral Resolution / Uncertainty / 27-Day Precision: 10-120 nm / 0.1 nm / 5% / 0.5% 120-200 nm / 0.5 nm / 5% / 0.5% 200-450 nm / 0.5 nm / 1% / 0.5% 900-4000 nm / 100 nm / 1-2% / 0.5%	X			X	X	X	X	X
Soft X-Ray Telescope	Magnetic Field Morphology of Inner Corona, Coronal Holes, Active Regions	∿3 sec Spatial Resolution; ∿5-10 R_s FOV; 5-60 Å Broad-Band Filters	X							
White Light Coronagraph	Magnetic Field Morphology of Outer Corona, Electron Density, Transient Eruptions	∿5-10 sec Spatial Resolution; ∿1.2 R_s to 5-10 R_s FOV	X							
Resonance Line Coronagraph	Corona Radial Motion Amplitude & Morphology, Temperature Distribution	∿10-20 sec Spatial Resolution; ∿1.2 R_s to 5-10 R_s FOV	X							
EUV Spectrograph	LOS Velocity at Coronal Hole Base	10-20 sec Spatial Resolution; 3 min FOV; 10 km/sec Velocity Resolution	X							
XUV Doppler Spectroheliograph	Velocity, Temp, Density, Composition, Configuration, Timing of Flares & Eruptions	∿3 sec Spatial Resolution; Full Sun FOV; ∿10 km/sec Velocity Sensitivity	X							
Hard X-Ray Spectrometer	No. & Spectrum of Sun Proximate Accelerated Electrons	Full Sun FOV; $E/\Delta E \approx 10\text{-}100$; 10-300 keV	X							
Radio Spectrograph	LOS Velocity at Coronal Hole Base	$f < 20$ MHz; Full Sun FOV; Moderate Spatial Resolution								
Chemical Release Module	Perpendicular & Parallel E-Field Determination & Conductivity Modification	⩾1 Maneuverable Reusable Release Module with Set of Release Canisters using Ba, Li, O, SF_6			X	X				
Particle (Electron/Ion) Injector	Modification of Local Plasma & Injection of Electrons & Ions	Variable Energy, Density, Species: H^{++}, N^+ O^+, Xe^+; Elect. Energies 100 eV to 100 keV; Ion Energies 100eV to 100 keV Variable Pitch Angles & Controlled Pulse Pattern		X	X	X				
Plasma Wave Injector	Wave-Particle Processes Simulation via Injection at Various Wave Normal Angles WRT B	1 Hz to ⩾30 MHz Transmitters & Antennas; Variable Power		X						
Low Light Level TV	Auroral Imaging: Visible, UV, Vacuum UV	10m x 10m/Pixel, 10 sec/Frame		X	X	X	X	X	X	
X-Ray Telescope	Imaging of Backscattered X-Ray	X-Ray (10-500 keV) Imaging Capability		X	X	X	X	X	X	
Coherent Scatter Radar	2-D & 3-D Ion Drift Fields	Based on Ground-Based Concept (1-500 MHz), Desired Ion Velocities of 10 m/s at $\geq 10\ cm^3$ Densities				X	X			

Table 5.5-1 (concl)

Instrument	Function	Specifications	Solar Variability	Wave-Particle Processes	Magnetosphere-Ionosphere Interaction	Global Electric Circuit	Upper Atmospheric Dynamics	Middle Atmospheric Chemistry & Energetics	Lower Atmospheric Turbidity	Planetary Atmospheric Waves
			Overall STO Program Objectives Compatability & Time Phased Utilization Aboard STO Spacecraft							
Multiple Subsatellites	Multipoint Auroral & Ionospheric Characteristics Determination (In-Site Measurement)	Ions/Electrons 0-100 MeV; Ion Drift > 10 m/s, Ion Comp Density 10^1 to 10^6 cm^{-3}; Magnetic Field > 1 nt		X				X	X	
Maneuverable Subsatellite(s)	Plasma & Plasma Wave Characteristics Measurement (Remote & In-Situ)	Plasma Waves 1-10^7 Hz; Ion & Electron Composition & Distribution 0-100 MeV; Neutral Density & Mag Field with Propulsion Capability		X	X				X	X
Tethered Particles & Fields Probe	Low-Altitude In-Situ Measurements & Ionospheric Pertubations	Magnetometers (> 1nt); E-Field Probes (> .1 mV/m); Ion Mass Spectrometer (1-56)			X					
LIDAR	Aerosol Layer & Thin Cloud Height Thickness, & Distribution in Tropospheric & Lower Stratosphere	NADIR Pointed· 1m Receiver ; ∿20w Transmitted at 2 or 3 λs (∿ 0.33-1.5 μm); Verticle Resolution < 1 km						X		
Radiation Balance Monitor	Meas. Outgoing Reflected Solar & Emitted Radiation Reaching S/C from Below	Earth Radiation Budget Sensor: 2-Channel Radiometer 0.3-3.0 μm						X		
IR Emission Spectrometer	Verticle Profiles & Latitude of Minor & Trace Species; Mesasphere & Lower Thermosphere Energetics	Limb Viewing; Cryogenic Interferometer Spectrometer 2-20 μm (500-500 cm^{-1}), 0.1 cm^{-1} Spectral Resolution, Scan Time ⩽ 10 sec				X	X		X	
IR Absorption Spectrometer	—Same as Above— Plus Mesosphere & Lower Thermosphere Dissociaton Levels	High Resolution Interferometer 2-16 μm (600-5000 cm^{-1}), 0.01 cm^{-1} Spectral, Solar Acq & Trk, 1 sec Scan Time				X	X			
UV & Visible Spectrometer	Spatibl Distribution & Variability of Ion-Spatial Excited-State Species Down to 80 km (Thermosphere) Excited-State Species 10 ∿40 km (Mesosphere/ Stratosphere)	Multichannel Grating Spectrometer -20-1200 nm, 0.5 Å Spectral Res., 1 km Imaging Field Resolution					X	X		
Upper Atmospheric Wind Sensor	Horizontal Wind Field Components: Upper Stratosphere, Mesosphere, & Lower Thermosphere	Zonal & Meridional Wind Velocity to 4 m/s 2 m/s; 25-100 km Altitude Range, 2 km Verticle Resolution				X	X		X	
Upper Atmospheric Temperature Sounder	3-D Temp Field Meas (Tropopause to ∿120 km)	Temp Uncertainty = 3k, Precision 1k, Vert Resolution < 2 km, 100 km Horiz Sampling Limb Emission Radiometer to 60 km PM or Advanced Temp Sounder to 30 km, Combination of Emission or Absorbtion Spectrometer & PMR Above LTE Limit				X				
Lightning Mapper	Global Lightning Intensity & Distribution	0.001 sec Time Resolution, 5-10 km Spatial Resolution			X					

6.0 ASTRONOMY/ASTROPHYSICS

6.1 SCIENCE OBJECTIVES

The major motivation for the continuation of astronomical research in space lies in the continual quest for a deeper and more comprehensive understanding of our universe. A survey of the current status of the major problems in astronomy is provided in the report of the Astronomy Survey Committee (July 1982). This report also provides a projection of astronomical needs for the next decade, which will furnish the resources and facilities to address these problems and to advance our knowledge on a broad front. A rather detailed program was outlined and prioritized in this report and provides the basis for our astronomy mission model.

Some of the major scientific questions confronting astronomers today, and most likely into the next 1 or 2 decades include:

1) What is the large scale structure of the universe?,

2) How do galaxies evolve?,

3) What is the role of violent events in the evolution of galaxies and the universe?,

4) How do stars and planets form?,

5) What causes solar and stellar activity?,

6) How widespread is life and intelligence in the universe?, and finally

7) What is the connection between astronomy and the fundamental forces of nature?

Each of these questions has been carefully considered and expanded into more detailed and specific subsets of questions which can be addressed by a variety of observational techniques and programs. These detailed questions are summarized into a collection of scientific objectives and are listed in Table 6.1-1.

Table 6.1-1 Astronomy-Scientific Objectives

Categories of Study	Key Questions
o Cosmology - Galaxies and the Universe	o What is the large-scale structure/ geometry of the universe?
	o What is the nature and sources of relativistic cosmic jets?
	o How do galaxies evolve and what is the nature of the hidden mass?
	o What powers the active galactic nuclei and quasars?
o Stellar Evolution	o How do stars and planets form, and what is the relationship of star formation to molecular/dust clouds?
	o What is the role of supernova explosions in producing collapsed objects, cosmic rays, and heavy element synthesis?
	o What causes activity (disturbances) on the surface of the sun and stars?
o Origin of Planets, Life, Intelligence	o Do extra solar planets exist?

6.2 ASTRONOMY MISSION MODELS

Quite a large number of missions have been developed and planned to provide a means for answering some of the fundamental, scientific questions in astronomy. These missions have arisen from sources of data for outlining a research program in astronomy for the next 1 or 2 decades may be found in the following reports:

1) National Academy of Sciences, Astronomy Survey Committee: Astronomy and Astrophysics for the 1980s, 1982.

2) NASA: Space Systems Technology Model, Vol. 1, 2, 3 Sept 1981.

3) Technology for Space Astrophysics: The Next 30 Years Conference Proceedings, (AIAA, SPIE, OSA), Danbury, CT; Oct 1982.

4) National Academy of Sciences, Committee on Space Astronomy and Astrophysics: A Strategy for Space Astronomy and Astrophysics for the 1980s 1979.

In addition to these reports, a number of astronomers who are prominent in astronomical research were consulted for their views, recommendations, and inputs. The data derived from these reports and individual contacts, form the basis for the astronomy mission model presented in Table 6.2-1.

6.3 MISSION MODEL

The sources of data listed in 6.2 have been revised and evaluated to provide a series of approximately 40 missions. These were studied in greater detail, and those missions showing redundancy or duplicity were eliminated, resulting in a smaller more concise set, consisting of approximately 25 missions. Based on the priorities provided by the Astronomy Survey Committee, the missions were arranged in the time phased sequence depicted in Figure 6.3-1.

The missions are arranged by the segment of the electromagnetic spectrum employed for observation. This mission set also follows a natural progression in the sophistication of the type of study:

1) survey,

2) exploratory,

3) detailed study, and

4) application of specialized techniques.

Finally, the mission model considers three classes of spacecraft to be employed:

1) relatively small, inexpensive Explorer-class spacecraft,

Table 6.2-1 Astronomy Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV. RETREV	SERV. REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
COBE-Cosmic Background Explorer NASA-GSFC MMCX-0001	S4A	DU	99 Sun Synch		900	800-1000	SIRTF LDR	High (Approved)	Initial 1985 Affordable 1989	Research	720	1	X					X	X	X	X			Design incorporates accessibility for servicing. 1500 kg
FUSE-Far Ultraviolet Spectroscopy Explorer NASA-GSFC MMCX-0002	S4B	FA	28.5		GEO		ST FOT	High (Opportunity)	Evol. 1992 Affordable 1993	Research	1800	1		X				X	X	X				" 1000kg
XTE-X-Ray Timing Explorer NASA-GSFC MMCX-0003	S4C	AM	28 5	28-57	300	300-400	LAMAR AXAF	High (Planned)	Initial 1989 Affordable 1989	Research	720	1		X				X	X	X				" 850 kg
EUVE-Extreme Ultraviolet Explorer NASA-GSFC MMCX-0004	S4D	AP	28.5	28-57	500	400-800	FUSE	High (Planned)	Initial 1987 Affordable 1989	Research	720	1	X					X	X	X				" 400 kg
GTE-Gamma Ray Transient Explorer NASA-GSFC MMCX-0005	S4E	EY	28.5	28-57	450	400-800	GRO	Med (Opportunity)	Evol. 1993 Affordable 1993	Research	720	1		X				X	X	X	X			" 3000 kg
HNE-Heavy Nuclei Explorer NASA-MSFC MMCX-0006	S4F	EV	57	28-57	400	400-800	CRO	Med (Opportunity)	Evol. 1995 Affordable 1997	Research	720	1		X		X								" 4000 kg
STARLAB NASA-GSFC MMCX-0007	S4G	AT	28.5	28-57	450	300-800	ST	Med (Planned)	Initial 1989 Affordable 1990	Research	3600	4 (14 days each)	X				X	X		X				" 2000 kg
SIRTF-Shuttle Infrared Telescope Facility NASA-ARC MMCX-0008	S4H	AU	28.5	28-57	400	300-800	COBE LDR	High (Planned)	Initial 1989 Affordable 1990	Research	1800	6 (14 days each)	X				X	X		X	X			" 10,000 kg

Table 6.2-1 Astronomy Science - Space Station Mission Model

MISSION / LaRC CODE	ACCEL SENSITIVITY, g: SUST	ACCEL SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER w / DURATION HRS	POWER & DURATION: OPER POWER w / DURATION HRS	POWER & DURATION: STDBY POWER w / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS/DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
COBE-Cosmic Background Explorer MMCX-0001			Inertial	7	900	90		385				-268 ±3	4.8	4.8	4.4	1421	1	26	4	Contamination Sensitivity is extreme.
FUSE-Far Ultraviolet Spectroscopy Explorer MMCX-0002			Inertial	0 5	2	1 0	2000	1000				0±40	2	2	4	1000	1	52	4	Contamination Sensitivity is high.
XTE-X-Ray Timing Explorer MMCX-0003			Inertial	1 0	360	72	1000	300			61	0±20	2	2	4	850	1	52	4	
EUVE-Extreme Ultraviolet Explorer MMCX-0004			Inertial	5	10,500	1050	110	70			3.2	0±20	2.1	2.1	1	400	1	52	4	Contamination Sensitivity is high.
GTE-Gamma Ray Transient Explorer MMCX-0005			Inertial	1.0	360	72	2000	1500			61	0±20	2	2	2	3000	1	52	8	2X2X6 m deployed.
HNE-Heavy Nuclei Explorer MMCX-0006			Earth	30	120	12		500				0±20				4000	1	52	4	
STARLAB MMCX-0007			Inertial	0 5	2	0.02		1000				0±20	1.5	1.5	5	2000	2	52	16	Contamination Sensitivity is high.
SIRTF-Shuttle Infrared Telescope Facility MMCX-0008			Inertial	0.5	2	0.2		400		Spacelab Rate		-258 ±5	3.1	3.1	8.7	10,000	2	4	16	Contamination Sensitivity is extreme

Table 6.2-1 Astronomy Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV. RETREV	SERV. REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
LAMAR-Large Area Modular Array of Reflectors NASA-GSFC, SAO MMCX-0009	S4J	AL	0	0-28	300	300-400	AXAF GRO XTE	Med (Candidate)	Initial 1992 Affordable 1996	Res.	1800	4 (14 days each)	X			X		X		X	X		X	5200 kg
OVLBI-Orbiting Very Long Baseline Interferometer NASA-MSFC, MIT MMCX-0010	S4K	CF	45	40-57	800	500-5000	OIST	High (Candidate)	Initial 1991 Affordable 1993	Res.	1800	4 (14 days each)	X				X	X		X	X		X	10,000 kg
OIST-Orbiting Infrared Submillimeter Telescope NASA, CIT MMCX-0011	S4L	EN	57	28-57	800	400-1500	LDR OVLBI	Med (Opportunity)	Evol. 1994 Affordable 1999	Res.	3600	4 (14 days each)		X				X	X		X	X		10,000 kg
FOT-Faint Object Telescope NASA, JHU MMCX-0012	S4M	JF	28.5	28-57	800	400-800	Starlab ST FUSE	Med (Approved)	Initial 1985 Affordable 1985	Res.	1800	5 (14 days each)	X					X		X				1000 kg
ST-Space Telescope NASA-MSFC MMCX-0013	S4N	AK	28.5	28-57	450	400-800	Starlab FUSE FOT	High (Approved)	Initial 1985 Affordable 1986	Res.	3600	1	X					X		X	X			11,070 kg
AXAF-Advanced X-Ray Astrophysics Facility NASA-MSFC MMCX-0014	S4P	AN	28.5	28-57	400	400-800	XTE GRO LAMAR	High (Planned)	Evol. 1992 Affordable 1995	Res.	3600	1		X				X		X	X			10,000 kg
LDR-Large Deployable Reflector	S4Q	AJ	57	28-57	750	400-800	SIRF COBE OIST	High (Candidate)	Evol. 1995 Affordable 2002	Res.	3600	1		X			X	X		X	X		X	25,500 kg
GRO-Gamma Ray Observatory NASA-GSFC MMCX-0016	S4R	AR	0	0-28	400	400-600	AXAF GTE	High (Planned)	Initial 1989 Affordable 1989	Res	1800	1	X					X		X	X			11,000 kg

Table 6.2-1 Astronomy Science - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIR	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER W / DURATION HRS	POWER & DURATION: OPER POWER W / DURATION HRS	POWER & DURATION: STDBY POWER W / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
LAMAR-Large Area Modular Array of Reflectors MMCX-0009			Inertial	1	60	30		1050					4	4	6	5200	1	52	4	
OVLBI-Orbiting Very Long Baseline Interferometer MMCX-0010			Inertial	0.5	2	0.5		10,000					50	50	10	10000	3	52	24	
OIST-Orbiting Infrared Submillimeter Telescope MMCX-0011			Inertial	0.5	20	20		1000					15	15	6	10000	3	52	24	Contamination Sensitivity is high.
FOT-Faint Object Telescope MMCX-0012			Inertial	0.25	2	0 5		350				0±20	1	1	3	1000	1		4	Contamination Sensitivity is high.
ST-Space Telescope MMCX-0013			Inertial	0.25	1	0.007		2100				0±40	4.3	4.3	13.6	11070	2	52	16	Contamination Sensitivity is high.
AXAF-Advanced X-Ray Astrophysics Facility MMCX-0014			Inertial	0.5	15	1		1000			1500	0±40	3.1	3.1	11.5	10000	2	52	16	Contamination Sensitivity is high
LDR-Large Deployable Reflector MMCX-0015			Inertial	0.25	0.1	0.03		2000				-125 ±5	20	20	5	25500	3	52	24	Contamination Sensitivity is high.
GRO-Gamma Ray Observatory MMCX-0016			Inertial	10	1800	180		2000			32		4.5	4.5	6	11000	2	52	16	

Table 6.2-1 Astronomy Science - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV.: RETREV	SERV.: REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
COSMIC-Coherent Optical System or Modular Imaging Collectors NASA-MSFC, NRL, SAO MMCX-0017	S4S	EQ	28.5	28-57	450	400-800	ST TAT	Med (Opportunity)	Ult. 2001 Affordable 2001	Res.	3600	1		X			X	X		X	X		X	67,000 kg
TAT-Thinned Aperture Telescope NASA-MSFC, NRL, SAO MMCX-0018	S4T	ER	28.5	28-57	450	400-800	ST COSMIC	Med (Opportunity)	Ult. 2005 Affordable 2005	Res.	3600	1		X			X	X		X	X		X	85,000 kg
CRO-Cosmic Ray Observatory NASA-GSFC MMCX-0019	S4U	AX	0	0-28	400	400-600	AXAF GRO	Med (Candidate)	Ult. 1993 Affordable 2001	Res.	1800	1		X		X						X		18,000 kg
XRO-X-Ray Observatory NASA-GSFC MMCX-0020	S4V	AS						Med (Candidate)	Evol 1998 Affordable 1999	Res.	1800	1		X		X	X	X			X	X		3500 kg

Table 6.2-1 Astronomy Science - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIR	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
COSMIC-Coherent Optical System of Modular Imaging Reflectors MMCX-0017			Inertial	0.25	1	0.0005		20,000				0±20	50	7	5	67,000	6	8		Contamination Sensitive. Onorbit Assembly, Alignment, Test Required.
TAT-Thinned Aperture Telescope MMCX-0018			Inertial	0.25	0 1	0.0005		25,000					100	100	25	85,000	12	8		Contamination Sensitive. Major onorbit Construction/ Assembly, Alignment, Test Req'd
CRO-Cosmic Ray Observatory MMCX-0019			Earth	180				2000					5	5	15	18,000	2	52	16	
XRO-X-Ray Observatory MMCX-0020			Inertial	1		30		1000			200		6	6	6	3500	2	52	16	

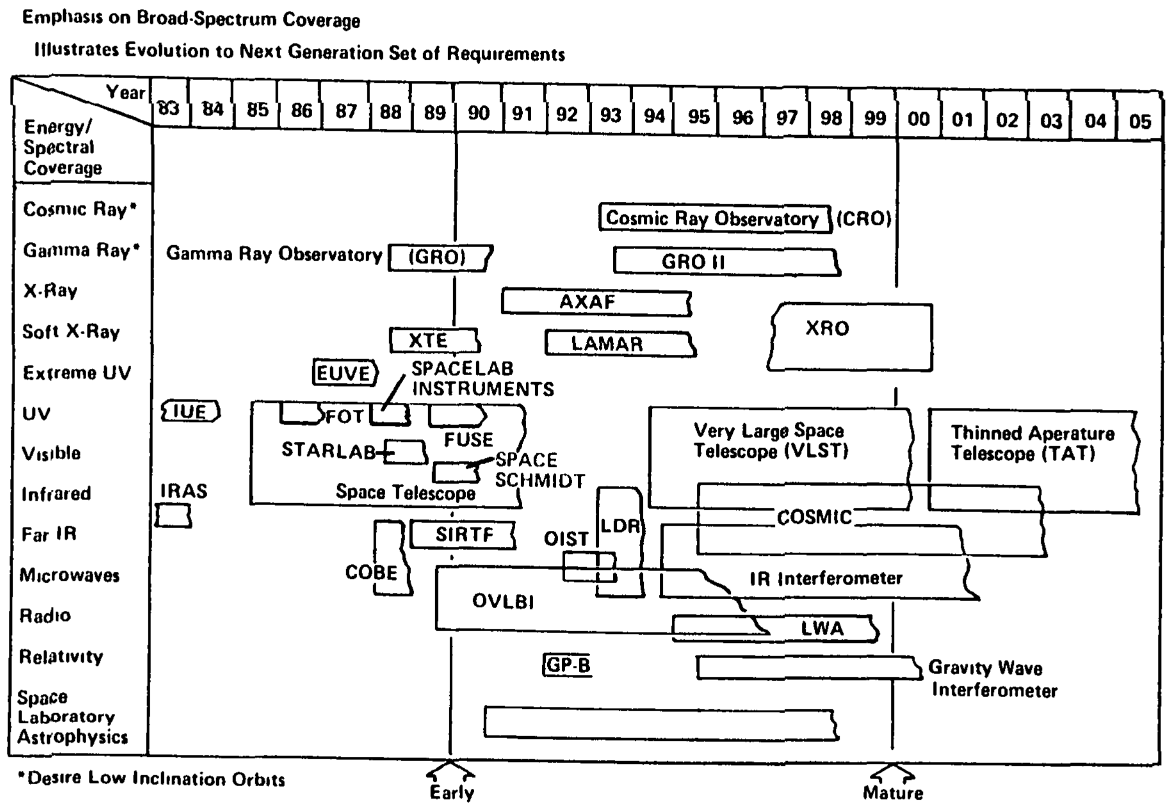


Figure 6.3-1 Astronomy Mission Sequence

2) Spacelab-type experiments, and

3) major observatory, free-flyer facilities. Examples of these classes of missions are shown in Figures 6.3-2 and 6.3-3, showing a set of missions considered for early phases of the space station, and a more futuristic set to be considered by space station in its mature stages.

6.4 RECOMMENDED COMPLEMENT

The recommended affordable mission model for astronomy is shown in Figure 6.4-1. This model includes a considerable portion of the mission model described in section 6.3. Missions shown in Figure 6.4-1 incorporate the following guidelies and constraints:

1) Highest scientific priority given by the Astronomy Survey Committee,

2) Previous NASA budget history, with very modest extrapolations,

3) estimated ROM mission costs,

4) anticipated technology readiness, and finally

5) determination of an "affordable" mission set matched with priorities.

In this manner, missions are accommodated at a later future date rather than dropped from the mission set.

6.5 COMPOSITE REQUIREMENTS

The major operational requirements imposed on a space station by the astronomy mission model follow a sequential development.

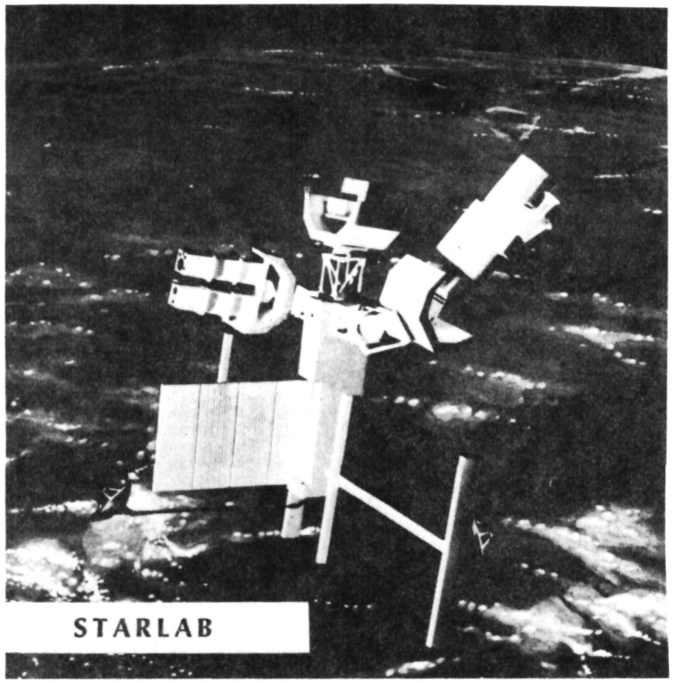
Early time phases of the model require support and services consisting of deployment/retrieval functions; routine servicing, maintenance and repair; and finally consummable replenishment and focal plane instrument changeout.

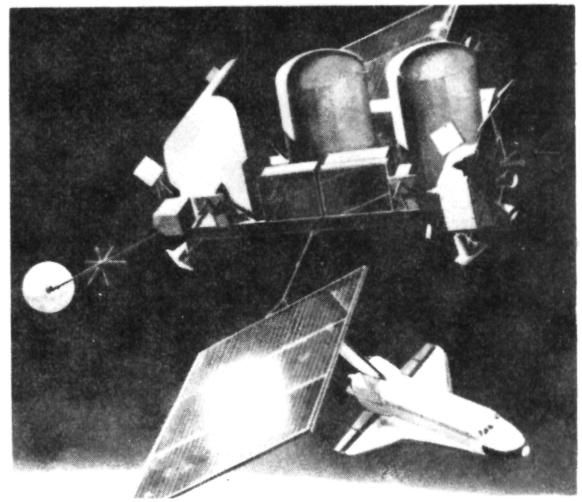
In later, more mature time phases of the mission model, considerably more complex services and capabilities would be expected. These would consist of:

1) attached platforms for small instrument operation in an undisturbed, contamination free environment,

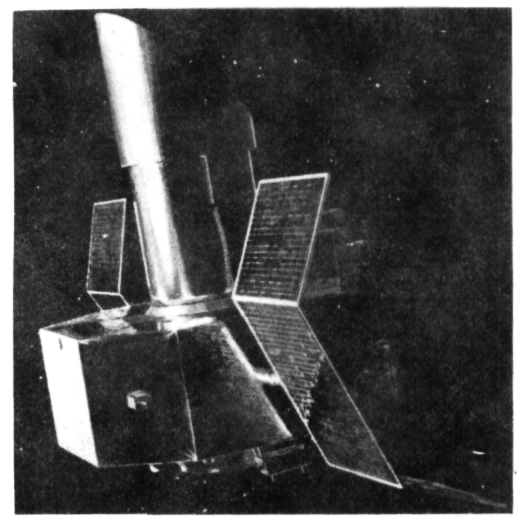
2) a facility for instrument/module repairs/refurbishment including electronic and optical components,

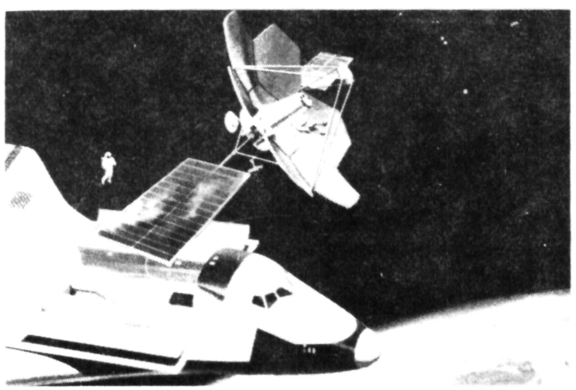
3) a more advanced facility to perform instrument integration/assembly, alignment, calibration and test functions, and





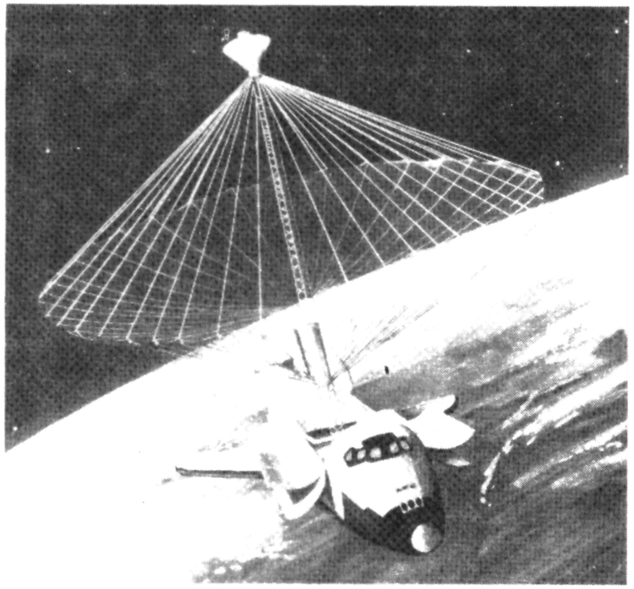
The Gamma Ray Observatory (GRO) will investigate compact sources and cosmic background at energies from 0.05 to 50 MeV.



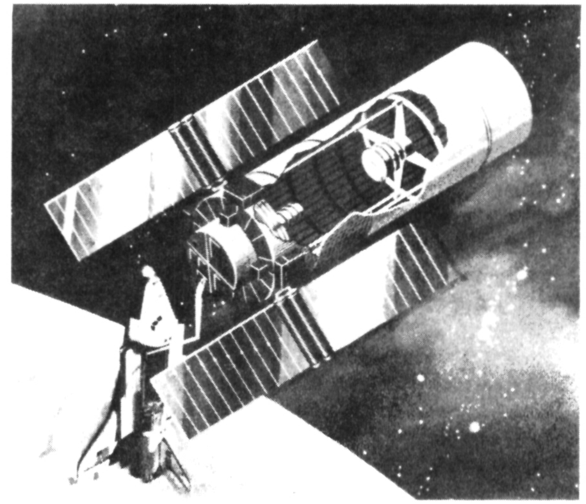


Large Deployable Reflector will perform infrared and millimeter-wave astronomy.

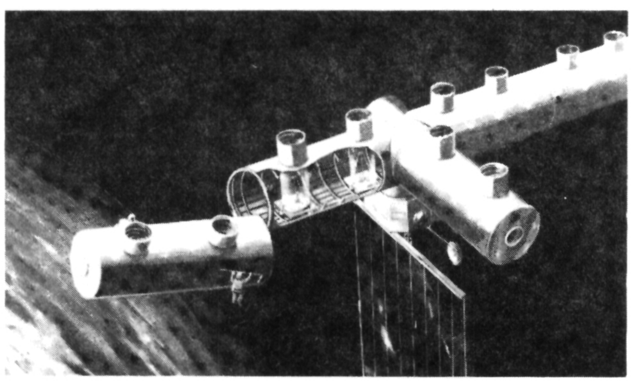
Figure 6.3-2 Astronomy—Early Concepts



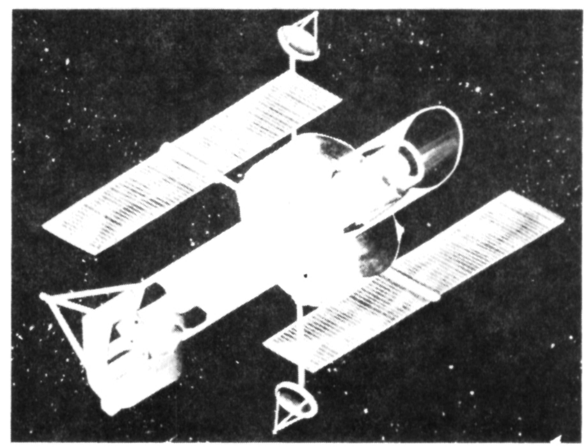
OVLBI - 50 Meter Deployable Antenna



Very Large Space Telescope (VLST) concept involves transforming the modified interstage section of the Shuttle External Tank into a telescope spacecraft.



The COSMIC two-dimensional coherent array of optical telescopes is capable to resolve starspots on nearby stars.



Advance X-Ray Astrophysics Facility (AXAF)

Figure 6.3-3 Astronomy—Mature Concepts

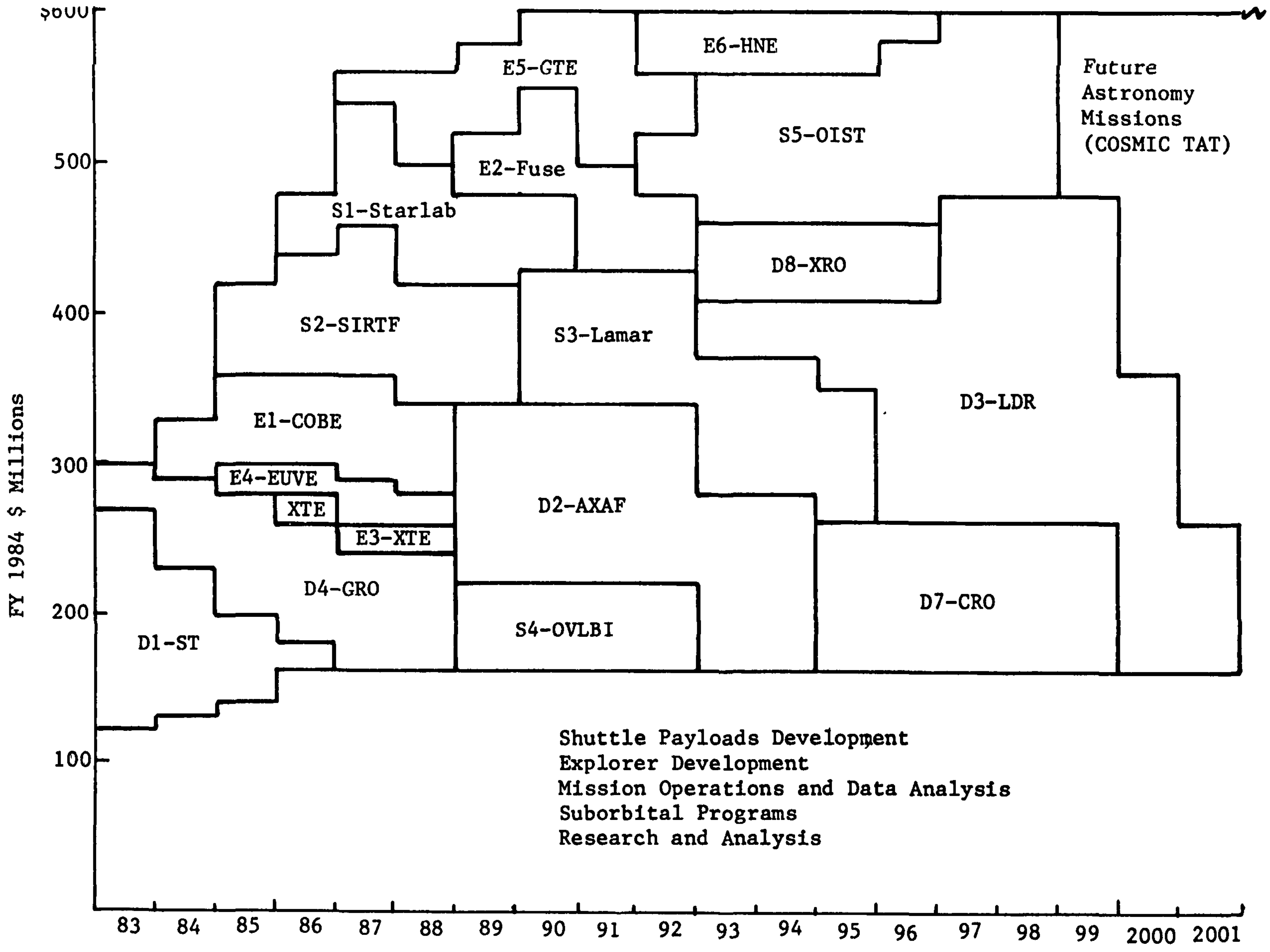


Figure 6.4-1 Recommended Mission Model - Astronomy

4) a construction/assembly base for the build-up and integration of large space structures incorporating multi-element, large scale optical systems using active optical control/alignment techniques.

Accommodations, services and capabilities, such as these provided by a space station would permit astronomy to move forward in the most effective manner in the next decade.

With those capabilities, Astronomy could then address the major scientific questions with full concurrent spectrum coverage; with capability for extremely high angular resolution (10^{-3} to 10^{-4} arc sec), greatly increased limiting sensitivity, and high spectral and temporal resolution.

The programs of the astronomy mission sequence, identified in Figure 6.4-1, indicate specific needs for a wide variety of facilities to provide the above services. These services and capabilities would be provided by the following facilities:

1) TMS type vehicle to retrieve and redeploy small instruments and explorer-type spacecraft,

2) a storage/transfer facility for consummables such as liquid helium,

3) centralized information handling facility which would provide a real-time function for critical data screening and interactive control of various instruments,

4) collection of several pointing platforms providing relatively course (1 arc min) to relatively fine pointing (1 arc sec) capability for attached instruments,

5) optical integration/refurbishment module which would provide services for repair, replacement, realignment and recalibration of instruments removed from space observatories such as AXAF or LDR, and

6) a major module to provide on-orbit assembly nd integration, alignment, and test checkout services for large optical observatories.

These facilities have been addressed in the space station architecture and design, by providing dedicated modules for these functions. These same services and capabilities could also serve the needs and requirements of other scientific disciplines such as solar physics, earth observations and space physics. Thus, a major benefit to a more effective utilization of the Space Station toward meeting the combined scientific goals of these disciplines, is provided.

6.6 BENEFITS ASSESSMENT

Since much of todays astronomy must be done above the Earth's atmosphere, the resources demanded by such investigations become substantial. Ways must be explored in which space astronomy can be carried out with greater flexibility and at lower cost. The currently developing concept of a space station offers considerable promise in these respects.

In addition to important aircraft and balloon facilities for observations above most of the Earth's atmosphere, there will be in operation by the early 1990's three distinctly different types of space-science vehicles, each providing observations on a different time scale. Sounding rockets will still be important for space exposures requiring only a few minutes duration. They offer great flexibility in providing location, launch timing, payload content, and valuable opportunities for developing satellite instrumentation at low cost. The Space Shuttle will augment space-astronomy capability by offering orbital exposures on Spacelab ranging effectively from hours to a few days,while also accommodating large payloads. Among the larger experiments, only a few can carry out their missions with maximum cost-effectiveness within such relatively brief exposure times. Large free-flying satellites present the most advantageous means for carrying out major scientific programs, permitting dedicated, noninterfering payloads and observing lifetimes ranging up to several years. However, each individual spacecraft is expensive and (except for major observatories such as ST and AXAF) not normally accessible for refurbishment, modification, or recovery after launch.

In terms of exposure times provided, there is a large gap in capability between Spacelab missions and those carried out on free-flying satellites. Many areas of space astronomy require long-duration, relatively low-cost exposure, together with large payload capacity and accessibility for replenishment of expendable materials, repair/replacement of components, and return to Earth for reconfiguration.

A space station can appear to offer many potential advantages; specifically, platforms optimized for astronomical use must offer unmanned operation, simplicity and economy of both construction and operation, and the convenient servicing and replacement of experiments.

Several areas of astronomy could profit substantially from dedicated platforms. For example, a cluster of experiments could fill a platform with capability for imaging, spectroscopy, and studies of time variation in the gamma-ray, x-ray, ultra-violet, and the infrared regions. Some types of astronomical research, such as cosmic-ray studies, would be expected to place few constraints on platform characteristics and the choice of neighboring experiments.

Many astronomical missions would appear to be substantially more cost-effective if flown with a space station, rather than on Spacelab or a free flying satellite. The platform concept should include, for astronomy, consideration of the simplest and least expensive system able to carry out the basic platform functions.

The primary benefits accuring from the above research programs consist of new knowledge about our nearby and distant universe; and the new technology development arising from the new facilities and instruments which must be built to implement the missions and observational programs. Additional benefits, arising from operating these missions/programs in conjunction with the space station, include the cost effective increase in useful operating lifetime of all major facilities due to the availability of space station services. In some cases, particularly for programs intended for the early 2000 time frame, some of the proposed missions can be accomplished only by the presence and services/capabilities provided by the space station. Finally, the flexibility in operations provided by the presence of space station and the ability to support concurrent missions which employ the full electromagnetic spectrum for observations, provide immeasurable benefits and advantages for the conduct of astronomical research.

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7.0 SOLAR ASTRONOMY

"Specifically, platforms optimized for astronomical use must offer unmanned operation, simplicity and economy of both construction and operation, and the convenient servicing and replacement of experiments."

Astronomy and Astrophysics of the 1980's
Volume 1: Report of the Astronomy
Survey Committee, Appendix A

This quotation summarizes the findings of the MMC/BASD Mission Analysis Study for the discipline of solar astronomy. Operations by man _in situ_, man on the ground or automatic operation may depend on the instrument to be operated and the observations to be made; however, the servicing and replacement of experiments can be most conveniently performed by man and it seems most likely that maintenance by man also offers simplicity and economy compared to maintenance by machines. Solar astronomy will benefit by the development of a permanently manned space station including the development of a space based solar observatory.

7.1 SCIENCE OBJECTIVES

Dr. J. D. Bohlin, Solar and Heliospheric Physics branch chief, NASA headquarters, has defined five general scientific objectives for solar astronomy.[a] These are the study of:

(1) Structure, dynamics and processes of the suns interior,
(2) Mass and energy transport in and through the solar outer atmosphere,
(3) Structure, dynamics and evolution of the suns visible corona,
(4) Structure and magnetohydrodynamics processes of the solar wind, and
(5) Variation of solar photon and plasma fluxes on earth during solar cycle

Dr. Bohlin explains that these current objectives are rather specific in nature as opposed to the more general and exploratory objectives of solar astronomy prior to the Skylab mission (1973-1974). Specific objectives are characterized by specialized missions designed to observe specific phenomena. Eight such specialized missions were considered in this study; section 7.2 describes each mission in terms of one or more of the five science objectives.

Just as solar astronomy objectives have evolved from general to specific, the science observing requirements for solar astronomy have evolved from brief glances to long and deliberate stares at solar phenomena. Dr. Richard Fisher, Solar Optical Telescope (SOT) facility scientist, describes the transition as going from a research and development phase into a production phase. The overwhelming majority of the solar scientists surveyed during this study endorse the concept of a long duration, stable platform in space to serve as an operational base for conducting solar astronomy observations. The benefits increase greatly when two full solar cycles (22 years) can be continuously studied from an observatory in orbit.

[a] "Solar and Heliospheric Physics Space Missions for the 1980s" AIAA-83-0516

It it obvious that the space station can meet the general science requirements of solar astronomy. Whether or not mans permanent presence is required for routine operations, the servicing and maintenance of a space based solar observatory over a period of two decades will require a major commitment of resources. This commitment could be in one of two forms; multiple shuttle launches to service and maintain the observatory or possibly fewer launches to construct a permanently manned space station from which to service the solar observatory and to perform numerous other service and maintenance tasks. The outcome of this study indicates that the use of the space station is most effective.

7.2 MISSION MODEL

The eight solar astronomy missions used in this study to derive space station requirements are summarized in Table 7.2-1. Each mission is described in the following paragraphs and the relationship between objectives, requirements and evolutionary development are discussed.

7.2.1 Solar Optical Telescope

The SOT is a 7.0 m by 4.0 m diameter telescope facility containing a 1.25 m diameter primary mirror with a 3.0 m focal length. A gregorian pod directs the focused energy to any of several instruments located at the gregorian focal plane. The SOT will also accommodate co-observing instruments which do not make use of the primary mirror and optical subsystem. An early SOT concept is shown in Figure 7.2.1-1.

SOT is the first of the eight proposed solar astronomy mission to receive hardware development funding. SOT is currently scheduled to fly as a Spacelab payload in 1988, than be reflown as an attached payload or a free-flyer and ultimately to be incorporated into the Advanced Solar Observatory (ASO).

The SOT objectives are to observe details of the sun, from 0.1 to 0.5 arc seconds in size, in the wavelength range of 1175A to 1.2μ. The interaction between solar magnetic and hydrodynamic processes will be studied.

Observations in this wavelength range will show details in the solar atmosphere; therefore, the SOT objectives are most closely related to science objective number 2, section 7.1. Resolution requirements can only be met by providing a very stable pointing platform.

7.2.2 Solar Soft X-Ray Telescope Facility (SSXTF)

The SSXTF is a 6.15 m x 1.3 m diameter telescope containing an 80 cm Wolter 1, grazing incidence, nested mirror with 0.5 arc second resolution capability. The SSXTF definition team has identified a number of candidate focal plane instruments which will operate in the 1.5 A to 300 A wavelength region. The conceptual SSXTF is depicted in Figure 7.2.2-1.

Table 7.2-1 Solar Astronomy - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV.: RETREV	SERV.: REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
SOT - Solar Optical Telescope NASA-GSFC MMCX-0200	S5A	BA	57		460	400-500	S5D S5E	Approved	Initial 1988 Affordable 1988	Research	3600	3	X		X	X	X	X	X	X	X			Spacelab/Shuttle Sortie Prior to S5D, S5E 6600 KG
SSXTF - Solar Soft X-Ray Telescope Facility NASA-GSFC MMCX-0201	S5B	BB	57		430	400-500	S5D S5E	Planned	Initial 1989 Affordable 1990	Research	1800	3	X		X	X	X	X	X	X	X	X		Spacelab/Shuttle Sortie Prior to S5D, S5E 1875 KG
P/OF - Pinhole/Occulter Facility NASA-MSFC MMCX-0202	S5C	DO	97		400	400-500	S5D S5E	Candidate	Initial 1989 Affordable 1991	Research	360-720	3	X		X	X	X	X	X	X	X	X		Spacelab/Shuttle Sortie Prior to S5D, S5E 3600 KG Min
ASO - Advanced Solar Observatory NASA MMCX-0203	S5E	AQ	Sun Synch Polar	Above 57	Full Sun		All S5 S3C S3D S3E	Candidate	Initial 1992 Affordable 1995	Research	360-720	6		X	X	X	X	X	X	X	X	X	X	
Solar Shuttle Facility NASA MMCX-0204	S5D	JG	Sun Synch	Above 57	Full Sun	400-500	S5A S5B S5C S5E	Opportunity	Evol. 1990 Affordable 1992	Research	7920	3		X	X	X	X	X	X	X	X		X	Cluster of 4 Instruments S5A, S5B, S5C, S5E
SIS - Solar Interplanetary Satellite NASA,JPL MMCX-0205	S5G	BJ	80 Solar		1 AU From Sun		S5E	Candidate	Initial 1986 Affordable 1989	Research	1620	1	X					X	X	X	X	X		
SIDM - Solar Interior Dynamics Mission NASA MMCX-0206	S5H	AO	Sun Synch		Full Sun		S5C S5E S5J	Candidate	Initial 1990 Affordable 1990	Research	720	3		X	X	X	X	X	X	X	X	X	X	Follow On to Solar Max Msn 400 KG
SCE - Solar Corona Explorer (Coron. Diag. Msn.) NASA-GSFC MMCX-0207	S5J	AV	Sun Synch	57	600	Above 400	S5E S5H	Planned	Initial 1988 Affordable 1988	Research	1080	1		X	X	X	X	X	X	X	X	X	X	May Use Film 400 KG

Table 7.2-1 Solar Astronomy - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP DEG C	THERMAL: TOLER	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
SOT - Solar Optical Telescope MMCX-0200			Solar	0.5	10	1	2000	2000						3.8 (Cylinder)		7.3	6600				
SSXTF - Solar Soft X-Ray Telescope Facility MMCX-0201			Solar	2.5	1	0.1-0.3	350	350		1				1	1	7	1875				
P/OF - Pinhole/Occulter Facility MMCX-0202			Solar	3	10	0.05	500	500		500				20	20	1000	3600 Min				L, W, H Deployed
ASO - Advanced Solar Observatory MMCX-0203			Solar	2.5		10															
Solar Shuttle Facility MMCX-0204			Solar	2.5	10	2															
SIS - Solar Interplanetary Fxplorer MMCX-0205			Solar					60													
SIDM - Solar Interior Dynamics Mission MMCX-0206			Solar	2.5	10												400				
SCE - Solar Corona Explorer MMCX-0207			Solar	2.5	10	2		300	90		600						400	1-2			

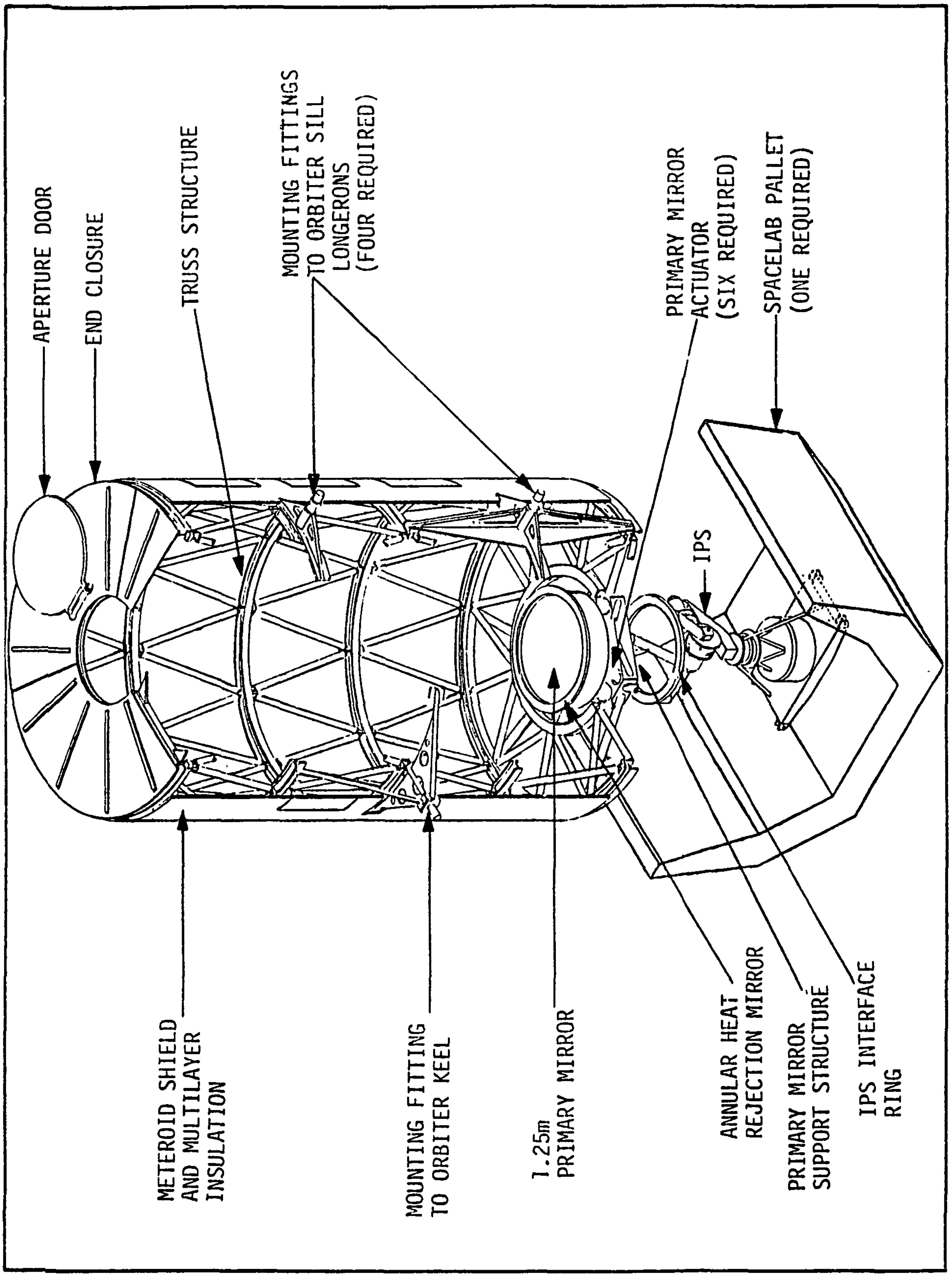


Figure 7.2.1-1 Early SOT Concept

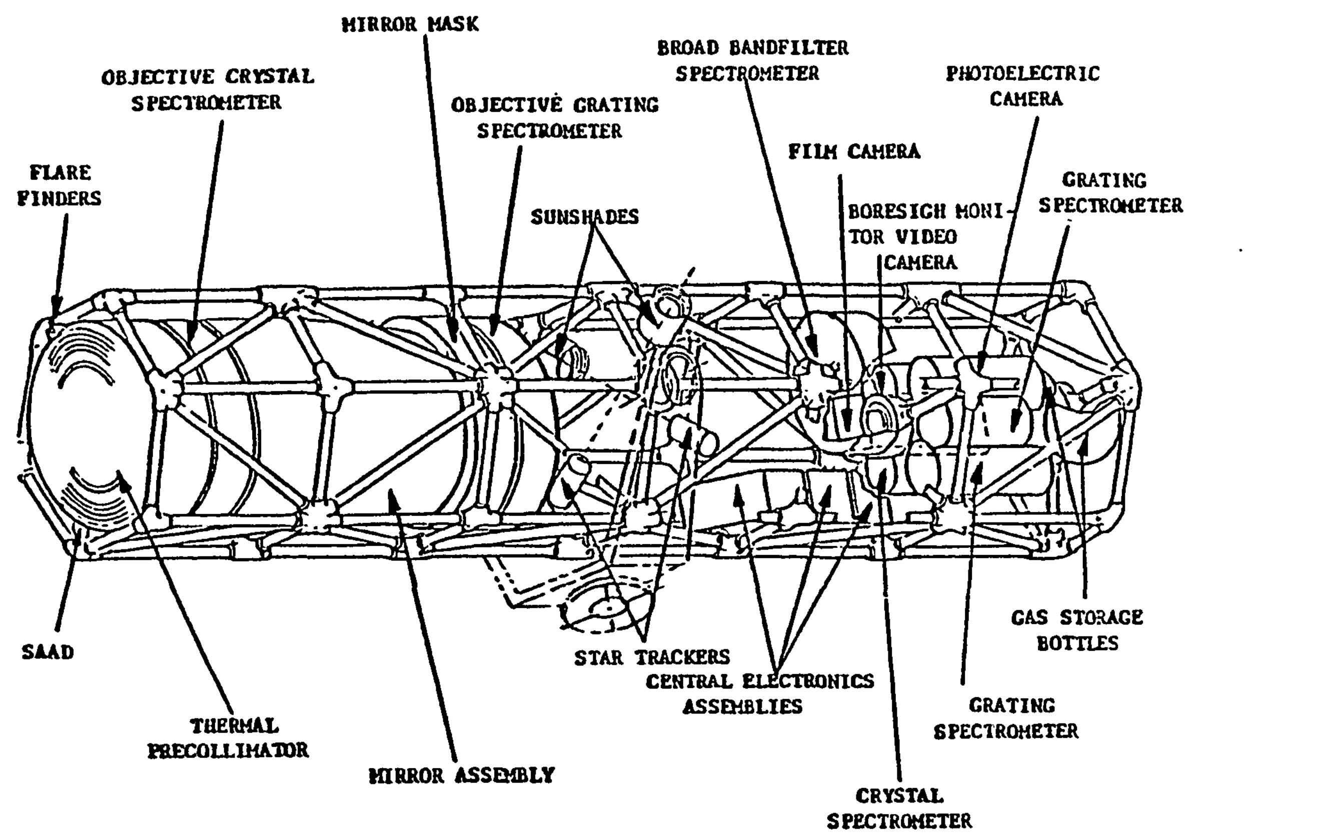


Figure 7.2.2-1 Solar Soft X-Ray Telescope Facility

The SSXTF objectives are to provide a diagnostic capability for the study of solar corona and transient events, such as solar flares, which are predominantly high temperature phenomena.

The SSXTF specific objectives, like the SOT objectives, are most closely related to science objective number 2, section 7.1. SSXTF has been identified as a potential SOT co-observing instrument. Phase A studies of the SSXTF have been completed. In order to study solar flare events, the SSXTF must be accurately pointed and setup to observe solar flares whenever they occur.

7.2.3 Pinhole/Occulter Facility (P/OF)

The P/OF consists of a 50 m boom that separates an occulting mask from an array of detectors and telescopes. The name "pinhole" derives from the use of a remote occulter (for coronagraphic studies) containing an array of small apertures to obtain high angular resolution of hard X-radiation. Figure 7.2.3-1 shows a P/OF conceptual configuration.

The P/OF objectives are to study nonthermal phenomena of plasma dynamics in the solar corona and to observe the acceleration of nonthermal particles in solar flares and in coronal disturbances with both x-ray and coronagraphic instruments.

These objectives are similar to those stated in science objective number 3, section 7.1. The emphasis here is to observe solar corona out to 10 solar radii while remaining stable to within a few seconds of arc.

7.2.4 Solar Shuttle Facility (SSF)

The SSF may be considered as a shuttle based fore runner of the Advanced Solar Observatory (ASO). Some of the facilities for inclusion in this cluster are the Solar Optical Telescope (SOT), Solar Soft X-Ray Telescope Facility (SSXTF), European developed Grazing Incidence Solar Telescope (GRIST) and the Pinhole/Occulter Facility (P/OF).

The SSF objectives are to understand the fundamental plasma processes underlying cyclic activity and transient high-energy phenomena on the sun and other stars.

As the SSF consists primarily of instrument which will ultimately become incorporated into the ASO, it is not surprising that these objectives and those of ASO given below are similar. The SSF has been recommended for development by the Astronomy Survey Committee.

7.2.5 Advanced Solar Observatory (ASO)

The ASO minimum configuration consists of four major instrument groupings:

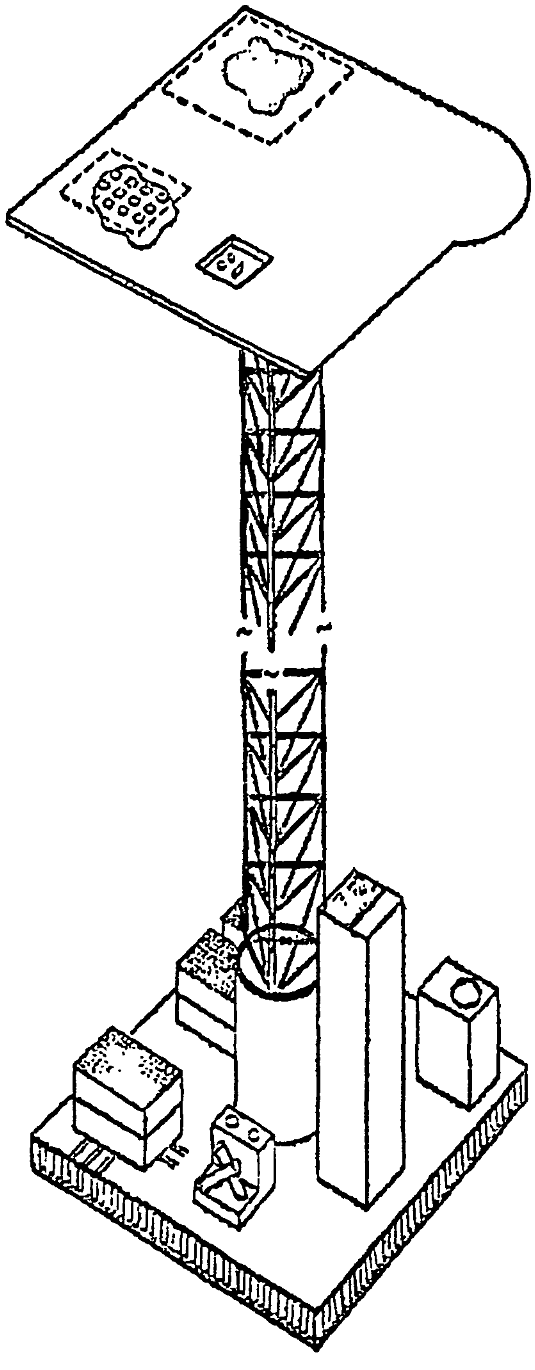


Figure 7.2.3-1 Pinhole/Occular Facility

(1) Solar Optical Telescope (SOT)
(2) Pinhole/Occulter Facility (P/OF)
(3) Solar Soft X-Ray Telescope Facility (SSXTF)
(4) Solar EUV/XUV Telescope Facility (SEXTF)

ASO is the name being given to the ultimate goal of an orbiting solar astronomy dedicated cluster of instruments and facilities. The minimum configuration complement listed above is one version of many possible combinations of instruments. The advanced solar observatory concept is depicted in Figure 7.2.5-1 and discussed further in section 7.4.

The ASO objectives are to understand the varied structures and phenomena responsible for the generation and transport of energy in the solar interior and atmosphere.

The ASO (and SSF) objectives are broader in scope than those of other missions in the solar astronomy mission model. This is partly due to the number of solar instruments which make up the ASO complement. It is also due to the overall versatile nature of the ASO concept as a true observatory in space for all aspects of the discipline of solar astronomy.

7.2.6 Solar Interplanetary Satellite (SIS)

The SIS is a boxed-shaped spacecraft containing solar viewing instruments electronics and propulsion elements. A STAR-27 solar rocket motor is located within a central circular opening in the spacecraft. Thrusters are located at the upper and lower ends of two solar panel supports. The SIS concept is shown in Figure 7.2.6-1.

SIS has been conceptually developed to support the International Solar Polar Mission (ISPM) being conducted by a consortium of European scientists. As such, the SIS will be launched before the first elements of a space station would be placed in orbit. However, the five year or longer mission lifetime of SIS makes it a candidate for space station support.

The SIS objectives are to observe the solar corona and transient events from a position 90° behind the earth in the ecliptic, following an ellipse identical to that of earths orbit but oriented 90° to it.

SIS objectives are specifically aimed at matching the intent of science objective number 4, section 7.1. The STS instruments are derived from those developed as part of the ISPM spacecraft.

7.2.7 Solar Internal Dynamics Mission (SIDM)

The SIDM is a 1 m class telescope facility containing up to five solar observing instruments which operate in the 3500 A to 7500 A wavelength region. SIDF has evolved from the Solar Cycle and Dynamics Mission (SCADM) concept which was divided into two moderate mission concepts, the SIDF and the Solar Coronal Diagnostic Mission (SCDM).

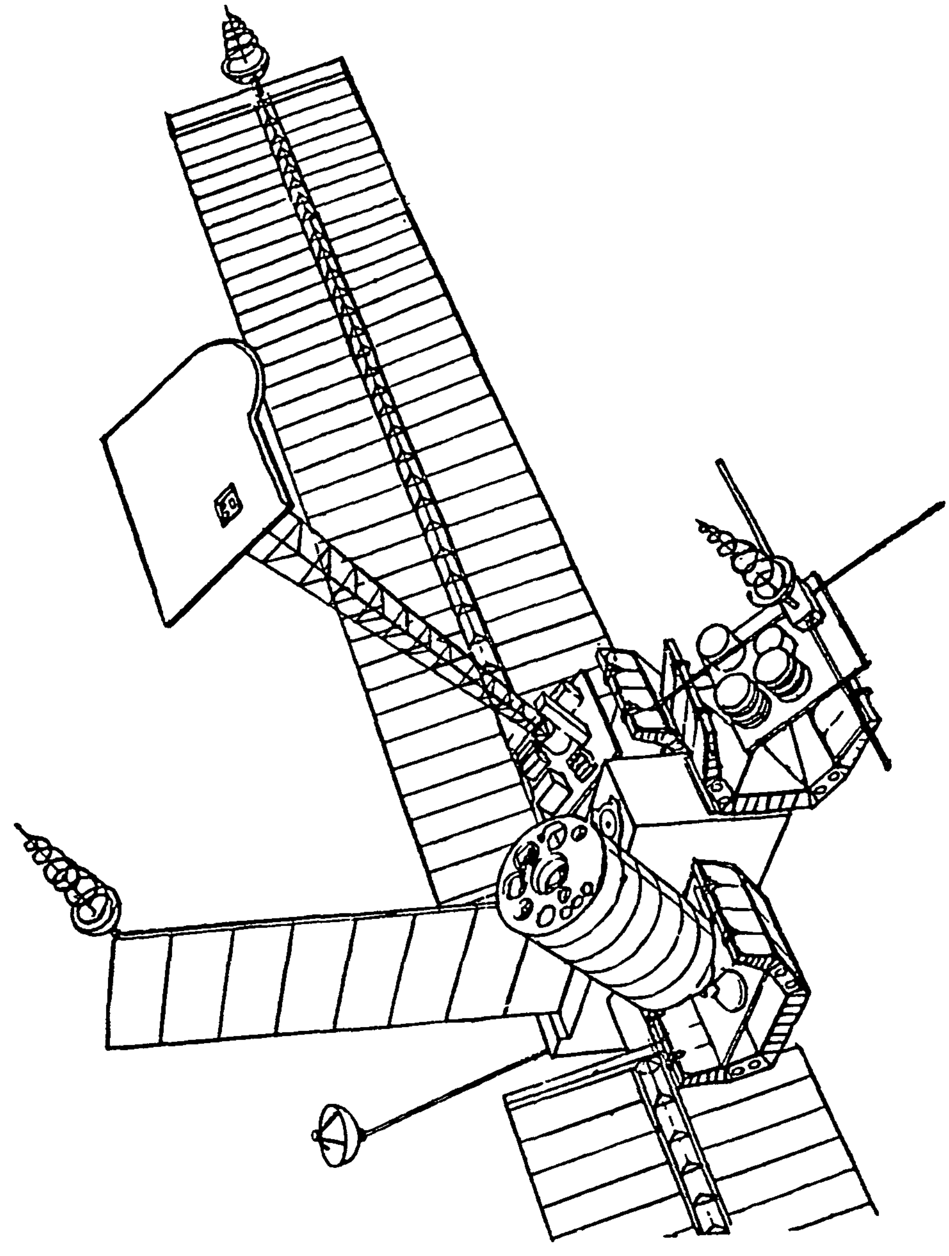


Figure 7.2.5-1 Advanced Solar Observatory

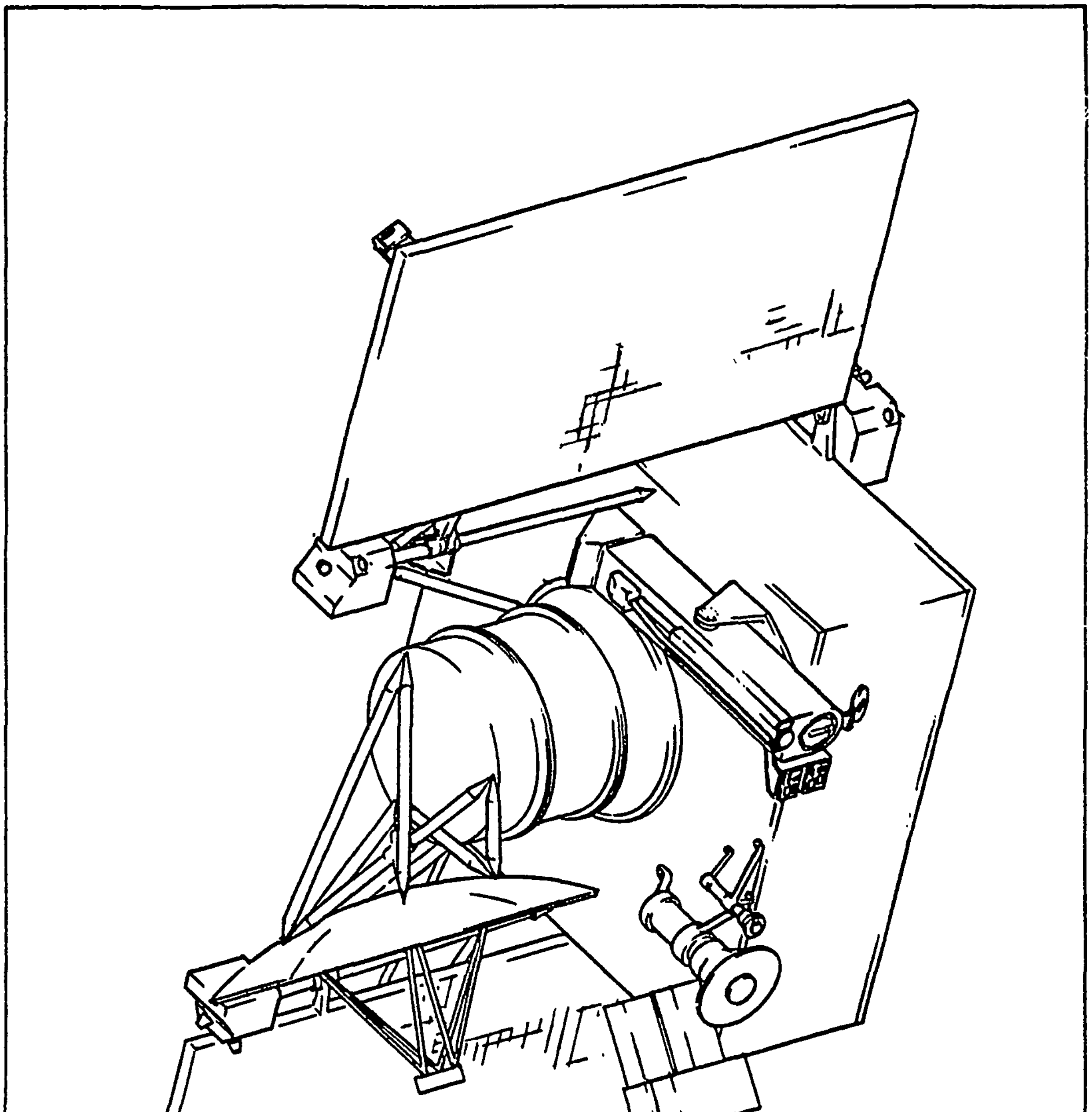


Figure 7.2.6-1 Solar Interplanetary Satellite

The SIDM objectives are to study the internal structure of the sun, solar dynamo, solar cycle, and large scale circulation and convection in the solar envelope.

SIDM is the only mission which fulfills the goals of general objective number 1, section 7.1. The SIDM concept has not been developed at the Phase A study level as of this data although some of its concepts are derived from the Solar Cycle and Dynamics Mission (SCADM).

7.2.8 Solar Coronal Diagnostic Mission (SCDM)

The SCDM is a 1 m class telescope facility containing up to five solar observing instruments which operate in the 3 A to 1000 A wavelength region. SCDM has evolved from the Solar Cycle and Dynamics Mission concept as has the Solar Internal Dynamics Mission (SIDM). SCDM was formerly called the Solar Corona Explorer (SCE).

The SCDM objectives are to investigate the structure, dynamics and evolution of the corona, globally and in the required physical detail, and to study the close coupling between the inner corona and the heliosphere.

SCDM falls into two of the science objectives, number 3 and 5. Science objective number 5, section 7.1, is closely associated with the Solar Terrestrial Observatory (STO) which is discussed in section 5.0 of this volume.

7.3 USER MISSION DATA/CONCEPTS

Each of the missions described in the solar astronomy mission model has been studied by a team of scientists. In most cases, reports prepared by these science definition teams have been made available for this study. This has been the basic for the solar astronomy requirements defintion and validation through the science teams.

Table 7.3-1 identifies the individuals contacted during this study, their respective areas of interest and their organizations. In most cases both written and verbal contacts were made and in some cases discussions were held in person.

All of the individuals contacted are either chairman of science definition teams or organized scientists on the field of solar astronomy. Their opinions are reflected in this study and the approaches used in this study were discussed with them. Information extracted from science team reports or other sources are identified in footnotes throughout this section.

As data on mission concepts were received, the data was compiled in the Mission Concept Reference Data contained in Appendix C. The final report was written based on this data and on less technical, more philosophical discussions where are expressed as possibilities.

Table 7.3-1 Solar Astronomy Mission Model Advisory and Validation Team

Organization	Individual	Areas of Interest	Address	Tel No.
High Altitude Observatory	Dr. Richard Fisher	Solar Optical Telescope (SOT)	High Altitude Obser. Boulder, CO 80302	303-494-5151 x324
High Altitude Observatory	Dr. Richard Monro	Pinhole/Occulter Facility (POF)	High Altitude Obser. Boulder, CO 80302	303-494-5151 x331
NASA/GSFC	Dr. Werner Neupert Dr. A. Poland	Coronal Diagnostic Package (CDP)	Goddard Space Flt Center Greenbelt, MD 20771 Code 682	301-344-6184 301-344-7169
High Altitude Observatory	Dr. Robert MacQueen	Solar Interplanetary Satellite (SIS)	High Altitude Obser. Boulder, CO 80302	303-494-5151 x427
Lab for Atmospheric & Space Physics	Dr. G. Timothy	Solar/Stellar Missions	Univ of Colorado LASP Boulder, CO 80306	303-492-8133 441-5056
Sacramento Peak Observatory	Dr. R. B. Dunn	Solar/Stellar Missions	Sacramento Peak Obser. Sunspot, New Mexico 88349	505-434-1390
Naval Research Laboratory	Dr. J. D. F. Bartoe	Spacelab 2 Mission Specialist SUSIM Co-Investigator	U.S. Naval Research Lab Wash. DC 20375 Code 4160	202-767-3287
Stanford University	Dr. A. B. C. Walker	Adv Solar Obser. (ASO) Member Field Committee	Inst for Plasma Research Stanford Univ Via Crespi Stanford, CA 94305	415-497-1487
NASA/HQ	Dr. J. D. Bohlin	Chief, Solar & Heliospheric Physics Branch	NASA Headquarters Wash. DC Code EZ-7	202-755-8490
NASA/MSFC	Mr. W. T. Roberts	ASO Study Mgr STO Study Mgr	NASA/MSFC Bldg 4200 Marshall Space Flt Center Alabama, 35812	205-453-3432
High Altitude Observatory	Dr. D. Sime	Advanced Solar Obser. (ASO)	High Altitude Observ. Boulder, CO 80302	303-494-5151 x417
NASA/MSFC	Dr. E. Hildner	Solar Beacon		205-453-0123

7.4 RECOMMEND COMPLEMENT FOR SOLAR ASTRONOMY

The collection of instruments, facilities and support hardware selected by the solar astronomy community to be placed in space and operated as an observatory has been given a name, the Advanced Solar Observatory (ASO). The minimum configuration ASO consists of four major instrument groupings, one version of which has been described in Section 7.2.5. This grouping is further described in reference[a]. Another possible grouping consists of the High Resolution Solar Telescope Cluster (HRSTC) which is an advanced version of the Solar Optical Telescope (SOT), the Pinhole/Occulter Facility (P/OF), the Solar High Energy Facility (SHEF) and the Solar Low Frequency Radio Facility (SLFRF). All four of these major instrument groupings and the individual instruments which make up the groupings are described in detail in a paper by Dr. A. B. C. Walker [b].

For the purpose of this and the following section, we, the ASO will be considered as a single mission element which is developed over a period of years from Spacelab instrumentation.

The Astronomy Survey Committee has made the development of ASO the major recommendation for solar astronomy. Of the four major instrument groupings which comprise ASO, the SOT is the only approved program of those named on the schedule taken from reference [a] and shown in Figure 7.4-1. Of the non-ASO missions, the SIS is given the earliest launch date and therefore the implied highest priority. Following SIS on the schedule is the SCDM and SIDM. The STO and OPEN missions are discussed in Section 5.0.

The development of solar astronomy missions shown in Figure 7.4-1 is feasible within the constraints of the MMC affordability model described in Volume 5.0 of this report.

The first element of the ASO complement to receive hardware funding is the SOT. SOT will be flown as early as 1988 as a Spacelab facility in a sortie mode. After one or two additional flights, SOT will be refurbished to accommodate one or more co-observing instruments. The most likely co-observing instrument to be incorporated into the SOT after its initial flights is the Solar Soft X-Ray Telescope Facility (SSXTF), described in Section 7.2.2. The SSXTF has been given the higher priority for development by the facility definition team [c]. Other focal plane and co-observing instruments will be added until a full up SOT becomes the HRSTC.

[a] "Solar and Heliospheric Physics Space Mission For the 1980's" AIAA-83-0516

[b] "The Advanced Solar Observatory" AIAA-83-0511.

[c] "Solar EUV, XUV and Soft X-Ray Telescope Facilities," final report, January 1982.

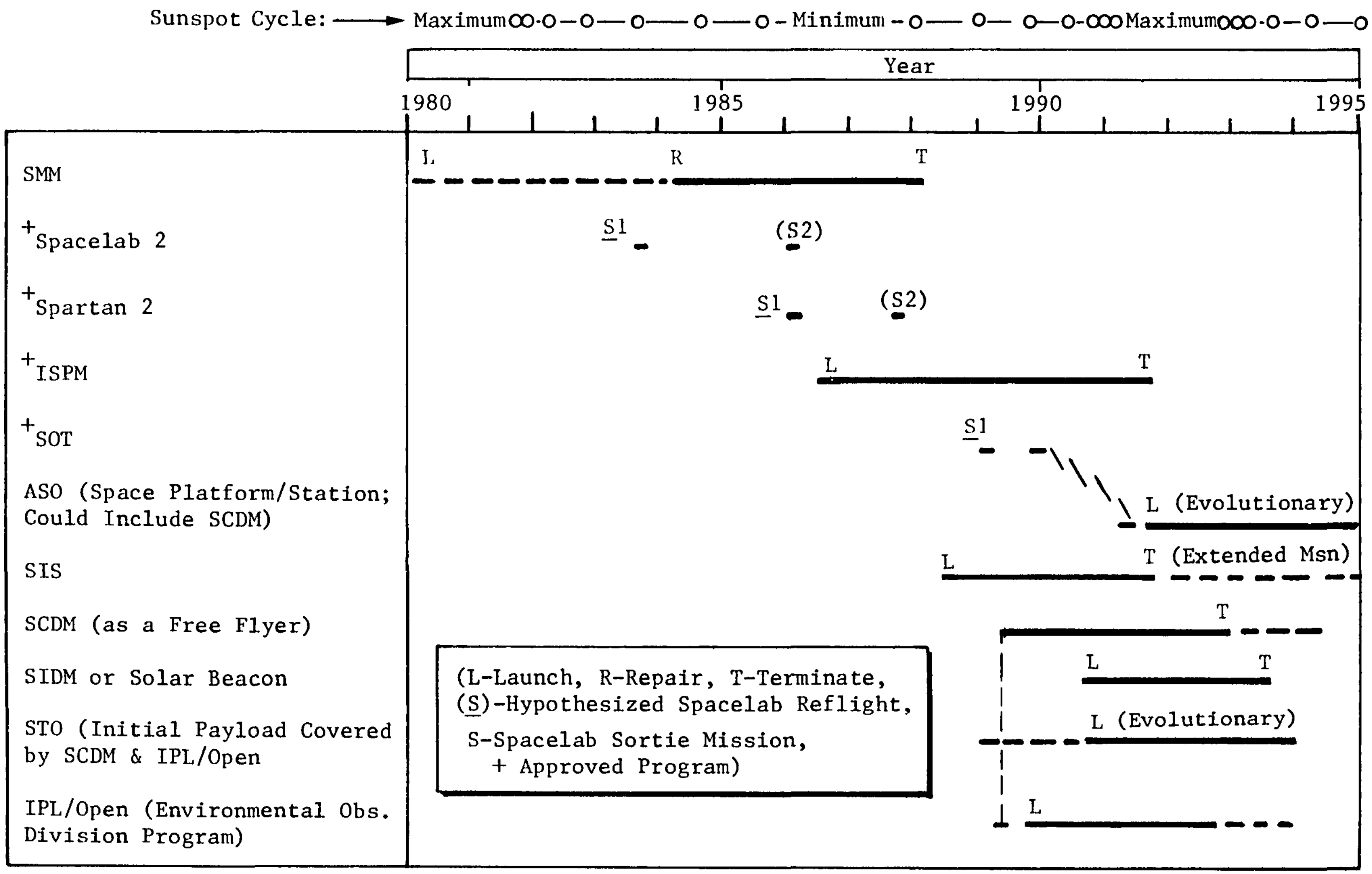


Figure 7.4-1 Desired Space Flight Program in Solar and Heliospheric Physics

The SSF, as recommended for development by the Astronomy Solar Committee, will consist of the SOT with SSXTF, the P/OF and a European instrument, GRIST. SSF will be flown as a shuttle attached payload and as such will likely remain in orbit for only seven days. SSF does not appear in any literature other than the Astronomy Survey Committee report; however, it is a logical step in the phased development of ASO. The SSF may be the same mission described as a developmental ASO shuttle sortie mission in reference [b]. Neither the SSF not the ASO developmental shuttle flights are mentioned in reference [a] or shown in Figure 7.4-1.

7.5 COMPOSITE REQUIREMENTS FOR SOLAR ASTRONOMY

Dr. Werner Neupert, a solar physicist and principal investigator at NASA/GSFC, defines five phases of space station as follows:

(1) Integration
(2) Commissioning (check-out)
(3) Routine observations
(4) Servicing and repair
(5) Retrieval and return

Of these activities, routine observations are most important solar astronomy and should, therefore, be given the largest time allotment and highest priority. Routine observations can be done by ground based observers as well as on-board observers, but the other four activities can most likely be performed best by having a man present, if for no other reason than to supervise the work of machines. However, the total time required to perform these other activities should be less than the time allocated for routine observations. Thus, while man's capabilities to perform necessary tasks are recognized, the capability to perform these observations must not depend entirely on man's permanent presence in space.

7.5.1 Integration Concepts

As the ASO is the only solar astronomy mission currently planned for space station integration, the integration task for solar astronomy should be relatively easy. The minimum ASO configuration will consist of four major groupings of instruments, all of which will have been flown numerous times prior to being incorporated into ASO. Most of these same groupings will have been integrated together during SSF or one of the ASO shuttle development flights. The integration, as well as the operation, of these instruments will have become mature procedures by the time ASO is integrated onto the space station.

[a] "Solar and Heliospheric Physics Space Mission for the 1980's" AIAA-83-0516.

[b] "The Advanced Solar Observatory" AIAA_83-0511.

A major trade study will address the question of where to locate ASO to maximize its potential benefits, for example, locating ASO on the space station at 28.5° with limited solar exposure or on an independent platform either at 57° or in sun synchronous orbit for better viewing. The added cost for the platform and its maintenance and servicing for 22 years at higher inclinations could make the choice of integration aboard the space station a reasonable compromise, especially since data management could be more effective including the use of film.

Because of its size, more than one shuttle flight may be required to transport the ASO to the space station. Additional shuttle flights, on an average once a year basis, should be anticipated in order to exchange one or more of the instruments. It is conceivable that the entire facility such as SOT could be removed and replaced by some other large solar facility during the later stages of the ASO mission.

The other space station contemporary solar astronomy mission, SIS, SIDM and a free flying SCDM, will not be integrated onto the space station but may require other support as described in the following paragraphs.

7.5.2 Operational Support

The role of man in operational support of a space based solar observatory is a controversial issue in the astronomy community in general, and in the solar astronomy community in particular. Some ground based solar observatories require very little operational support by man while others require a great deal. Even within a single observatory, operational support by man may depend on the telescope being used to make an observation and on what is being observed.

Perhaps the best way to summarize the question of the need for mans permanent presence in space to operate a space based observatory is to assume that the operational support of solar telescopes in space will not be significantly different from that operational support required by ground based solar observatories.

7.5.3 Maintenance Repair/Service

Unlike the question of operational support, the question of maintenance, repair and servicing by man in space is unanimously endorsed by the solar astronomy community. Dr. Richard Fisher, the Solar Optical Telescope (SOT) facility scientist, believes astronauts will change out SOT instrumentation and perform major servicing on-orbit after the SOT has completed several sortie type flights and been converted into a free-flyer or space based facility. Similar man tended tasks are anticipated by other solar astronomers. These needs, when combined together and with the general need for the versatility that man's presence can provide, may generate enough work to keep a space station crew fully occupied without the task of performing routine observations and operations. The capability to perform maintenance repair and servicing to a solar observatory in space will undoubtedly enhance the capabilities of the observatory in ways that cannot now be imagined.

7.5.4 Subsystem Support

Space Station subsystem support for solar astronomy can be estimated simply by knowing the subsystem support requirements for ASO. Reference [d] refers to a second volume to be subtitled "Configuration and Development of the (ASO) Instrumentation". Unfortunately, this second volume has not been published as of this writing and is not available in a preliminary or draft form. When this volume is available, the composite subsystem support requirements for ASO will be incorporated into the overall support requirements for space station.

Scheduled and/or unscheduled visits by man provides operational versatality which could enhance data acquisition. Dr. A. B. C. Walker, the Advanced Solar Observatory (ASO) facility scientist and a member of the Astronomy Survey Committee, forsees a problem with the amount of data generated by a full up solar observatory in space. Getting all of the data generated by several solar telescopes down-linked to the ground could be a significant cost and schedule driver. However, if film cameras or on-board tape recordings could be routinely changed out, this constraint could be reduced.

Combined Mass Requirements - Table 7.5.4-1, Reference [d] illustrates how the ASO development program could utilize the shuttle in four sortie missions. These developmental flights of ASO may be the same missions recommended by the Astronomy Survey Committee under the SSF name. In any case, this table serves as a convenient reference source of ASO component mass.

Combined Data Requirements - Data requirements are by far the most difficult to estimate because data rates, both uplink and downlink, are greatly influenced by the level of solar activity being observed. During quiet periods, solar observations become synoptic in nature whereas during active periods all instruments will be recording data as rapidly as possible. It seems inevitable that whatever data communication system is available to a space based solar observatory, it will prove to be inadequate during times of high solar activity. This problem and a possible solution were discussed in the above paragraph, however, as a general rule, it should be assumed that the combined data rate requirements for solar astronomy will occasionally exceed the system capability.

[d] "Report of the (ASO) Science Definition Team" Draft Copy.

Table 7.5.4-1
Developmental ABO Configuration for Shuttle Sortie Missions

Mission 1		Mission 2	
SOT	2,770 kg	P/OF	
SSXRT	1,875	Boom and Occulter	
EUV Guest Instrument	500 kg	X-Ray Sensors	450 kg
Guest Instrument	250 kg	UV Coronagraph	280 kg
ABO Control Electronics	50 kg	White Light	200 kg
Contingency	800 kg	Coronagraph	
		Support Structure	
		Contingency	
Total Mass	6,245 kg*	Total Mass	4,200 kg*
Volume	3 Pallets	Volume	1.5 Pallets
Mission 3		Mission 4	
SOT	2,770 kg	SOT	2,770 kg
SSXRT	1,875 kg	SSXRT	1,875 kg
SGRNS	260	SGRNS	260 kg
SIDF	400 kg	SEUVT	1,745 kg
Guest Instrument	250 kg	SIDF	400 kg
Guest Instrument	250 kg	Guest Instrument	250 kg
P/OF	3,600 kg	P/OF	3,600 kg
Contingency	1,400 kg	Contingency	1,700 kg
Total Mass	10,795 kg*	Total Mass	12,600 kg*
Volume	5 Pallets	Volume	5 Pallets

* Does Not Include the Mass of Pointing Systems

7.6 BENEFITS ASSESSMENTS

The benefits to be derived from a permanently manned space station cannot be fully assessed for the discipline of solar astronomy. This is primarily due to the unpredictability of nature and the relative immaturity of the science. As recently as the early 1970's, solar telescopes on board Skylab revealed details of the solar surface that had never been seen. Larger and more sophisticated telescopes, such as SOT, will reveal even more detail, some of which may be very short-lived. Mans permanent presence may allow un-interrupted observation of such phenomena with instantaneous response capability. As long as there are new discoveries to be made, man's presence and the committment necessary to make man's presence possible will benefit solar astronomy.

7.6.1 Direct Mission Benefits

The ASO mission will benefit from a manned space station in many ways, some of which have been described throughout this section. To summarize, the most obvious benefit will be that of a stable platform from which to conduct a long term ovserving program. A related benefit will be the maintenance repair and service capability which will be vital for an extended mission. The operational benefits to be derived are difficult to assess, but will undoubtedly prove to be significant.

A more subtle benefit to be derived from a permanently manned space station is described by Dr. R. Fisher in his recent paper on SOT operations [e]. He concludes that a man in orbit with the equipment he is to operate has made a committment to the collection of scientific data, and that such an individual sees scientific research as the ultimate goal of his efforts. This philosophic benefit, while difficult to describe, may be more important than the more obvious benefits discussed above.

7.6.2 Alternate Missions Evaluation

The ASO mission could be conducted from a free flying space platform, operated by ground command and serviced and maintained by frequent shuttle visits. However, all of the benefits described in this section, except that of a stable platform, would be forfeited. In addition, the cost of frequent shuttle re-visits could equal or exceed the cost of developing a permanently manned station over a two decade mission lifetime.

7.6.3 Derived/Synergistic Benefits

The capability to study the sun as an average star and/or as a part of the earth/sun system is a derived benefit which the space station can provide. This concept is developed in section 5.6 of this report with respect to the ASO and the Solar Terrestrial Observatory (STO).

[e] "Scientific Exploration and the Use of Payload Specialists" Draft Copy, Private Communication.

8.0 LIFE/BIOLOGICAL/MEDICAL SCIENCES

8.1 SCIENCE OBJECTIVES

8.1.1 General Science

While it has been established that humans can effectively travel and work in space, a number of physiological changes have been documented which may prove to be health threatening due to long duration exposure to space flight conditions. The common goal of the Life Sciences research community is to understand the complex physiological responses to the space environment. Previous research has determined that potential hazards to crew health and comfort exist. Of particular concern for missions in excess of 30 days are the cardiovascular, skeletal, and muscular systems deconditioning. Of primary importance in the space station era is the elucidation of the etiological mechanisms of these and other adaptive physiological responses to space flight and the study and implementation of countermeasures.

In addition to providing for on-orbit health maintenance, it is considered to be equally important to define the crewmembers' limiting constraints and the optimal human operational envelope within which future crew systems and manned missions would be designed.

Based upon the experience obtained in past Apollo, Gemini and Skylab programs and currently in the Life Sciences Flight Experiments Program, researchers have almost unanimously concluded that the need exists for a more totally integrated, multidisciplinary approach within the Life Sciences Research Program. This multidisciplinary approach should utilize a coordinated investigator team representing expertise in all subdisciplinary areas to study the entire living system. In establishing an integrated research approach, multiple animal species should be employed in the space station to enhance the human data and to pursue basic lines of inquiry such as plant physiology and animal reproduction.

While meaningful biomedical data has been obtained during past missions, the numbers of experimental subjects (particularly human) have been low, the methodologies employed have been diverse, and each flight has presented its own set of potentially confounding variables. The space station should provide the unique opportunity to study greater numbers of humans and non-human specimens within the same facility environment, with a longer adaptation period and with greater opportunity to control potentially confounding variables. The experimental flexibility currently employed in earth-based laboratories should be duplicated in the zero-gravity (zero-g) laboratory. As interesting data emerge, the increased flexibility in crew schedules, experimental designs and techniques should be exploited to maximize the informational return from each mission. As indicated in past space life sciences research, more questions will arise than will be answered with each experiment. It would be highly desirable to pursue such lines of inquiry expediently under guidance of the investigator team rather than to postpone highly promising experimentation until distant future flights. This rapid reflight capability had been anticipated by the research community with Shuttle Spacelab, but it has yet to be realized due to five year experiment development phases (from announcement of opportunity (AO) to flight date), tight crew schedules and constraining resource allocations.

8.1.2 Operational Medicine Objectives

The Operational Medicine Program provides for the health and safety of the crewmembers and it promotes research to improve definition of the optimal human operational envelope for spaceflight. As such, it will always remain of the highest priority within the NASA program. Representative activities in this area include medical certification, inflight biomedical observation, and postflight certification for return to duty of space station (SS) crews; contingency and emergency medical support to space station missions; development and validation of countermeasures for adverse effects of space flight; and advanced planning to refine medical selection and retention standards and improve the definition of human capabilities for space flight.

The space station era will introduce a shift in the emphasis of Operational Medicine as the SS activities shift to construction and servicing of large space structures (LSS) and commercial ventures, in contrast to the primarily scientific endeavors of the current shuttle program. As the SS evolves into longer missions with more routine industrial and extravehicular (EVA) activities, the Operational Medicine program will begin to focus upon the study of the myriad problems associated with long-duration exposure to zero-g and the emergency treatment of industrial accident traumas.

The Operational Medicine "mission" differs from the other Life Sciences missions discussed herein since it includes the actual medical support of the space station as well as the research required to develop adequate medical support. The medical support is envisioned to progress through four categories representing increasing levels of support capabilities in close conjunction with the evolving capabilities of the SS. These categories are discussed in greater detail in Section 8.4.3 "Evolutionary Approach ". The research objectives for the Operational Medicine mission include such activities as the assessment of wound healing, burn therapy, trauma treatment techniques, drug distribution and pharmakinetics, fluid therapy and surgical interventions in the space flight environment. The overriding goal of the research activities is to advance the continuing definition and development of medical support requirements for the SS.

8.1.3 Cardiovascular/Cardiopulmonary Objectives

Previous data have indicated cardiovascular deterioration occurs during space flight. Space Station studies should determine to what extent these changes are progressive/chronic during space flight and to what degree they are reversible in the postflight environment. Preliminary observations of crewmembers in the postflight environment suggest that long-term morbidity might result from excessive red cell deformation, cardiopulmonary congestion, changes in myocardial mass and contractility, and fundamental defects in neurogenic and overall cardiovascular control typical of space-induced cardiovascular changes. Experiments should be designed for the study of these changes in various species. Specific areas of investigation might include assessment of the magnitude of long-term cardiopulmonary congestion and the final disposition of early cephalic fluid shifts; myocardial muscle mass; spacial distribution of pulmonary blood flow and ventilation; myocardial contractility; investigation of interventions that maintain red cell and plasma volume; assessments of the cardiovascular response to imposed workloads; and the development of strategies to prepare the cardiovascular system for reentry to the terrestrial environment after prolonged exposure to space. It would also be desirable to determine whether an artificial gravitational force would reverse or prevent the adaptive cardiovascular changes that occur in a zero-g environment, and to determine the minimum gravitational force necessary to accomplish this objective. Information gained from this type of experiment may have a significant impact on the design of future space facilities.

8.1.4 Vestibular/Neurophysiology Objectives

Past space flight missions have indicated that space sickness has a significant impact on the well-being and operational efficiency of crewmembers particularly during the first few days of a mission. NASA has recently provided additional support to the ongoing vestibular research activities in pursuit of countermeasures for the space sickness phenomenon. About half of the investigators contacted anticipated that an acceptable intervention will be developed prior to the SS era. The remaining investigators believe that a "bandaid" may be available at that time, however, the solution to the problem lies in the understanding of the underlying mechanisms. While the SS will provide the optimal setting within which the extensive study of vestibular physiology and function could be implemented, it is believed that the vestibular subdiscipline will assume a lower priority by the end of this decade. Space sickness is most disruptive in the first few days of the mission during which adaptation occurs, therefore, it will not be perceived as such a detriment in light of the longer mission durations proposed for SS. None-the-less, vestibular function research remains a high priority within the investigator community. The issues to be addressed include neurosensory and electrophysiological function over long periods of adaption, the chronic and/or progressive morphological and biochemical alterations due to long duration zero-g exposure, and musculoskeletal deconditioning due to reduced neurovestibular inputs to postural muscles.

8.1.5 Osteology Objectives

Classical balance studies in Gemini, Apollo and Skylab missions have indicated a serious negative calcium balance. If the daily negative calcium loss recorded in Skylab crewmembers were to continue at the rates measured, a 10% loss in skeletal calcium was predicted for each year of weightless flight [a]. This could pose a serious danger to astronauts, especially during the stress of reentry following a long mission. The possibility of a vertebral compression fracture during reentry increases with the age and gender (more prevalent in female) of the astronauts. It is critical to determine whether the calcium losses continue indefinitely or whether a new equilibrium level is eventually established.

It should also be determined if induced-g fields reverse the deleterious effects of zero-g on bone loss and progressive increases in urinary calcium concentration and excretion rates. These experiments should be designed for both human subjects and species (such as rats) which also respond to weightlessness with bone mobilization and calciuria. Until this question is answered, the potential remains for recurrent renal calculi (stones) and skeletal fractures during prolonged exposure to decreased gravitational forces. Suggested areas of investigation include: analysis of bone strength as a function of weightlessness exposure time, pharmacological or other interventions that slow bone resorption; measurement of calcium precipitation; and design of interventions that prevent bone loss and/or precipitation [b].

Currently, countermeasures have been focusing upon skeletal loading, pharmacologic intervention and induced electrical events in the bone. It is possible that treatment of future crewmembers with medications prior to flight will permit long duration flights to be undertaken without adverse effects on their skeletal systems [c].

8.1.6 Musculoskeletal Physiology Objectives

Evidence was obtained during the Skylab missions indicating a progressive deterioration of muscle tissue. It is significant that the muscle catabolism continued throughout the 84-day Skylab 4 mission in

[a] S. Holt, NASA/GSFC, Draft Report, 1982.
[b] S. T. Wu and S. Morgan, Panel Reports, 1978.
[c] P. C. Johnston and J. A. Mason, NASA-TM 58248, 1982.

spite of the exercise regime and improved nutrition employed. It is necessary to determine whether such atrophy continues indefinitely or whether it stabilizes at an endpoint appropriate for zero-g. The decrease in muscle strength and endurance will be a significant factor in such things as the design of tools for inflight operations, the scheduling of mission durations and crew shift changes, and task assignments for high work load activities like satellite construction and servicing. Both human experiments and animal models should be employed to study the changes in skeletal muscle with long term exposure to hypogravity. The morphological, biochemical and subcellular changes should be documented and correlated with alterations in electromyographic (EMG) activity of the various muscle groups.

8.1.7 Hematology/Immunology Objectives

Blood analyses during Apollo and early Skylab indicated reduced red cell mass and red blood cell (RBC) deformation. During Skylab 4 (84 days) the changes were not as severe. However, it has been speculated that the exercise regimen and the improved nutrition contributed to the reduced severity of the response rather than any adaptive normalization of hematological dynamics. Of principal interest in this subdiscipline is whether the reduction in circulating hematocrit occurring in space flight is a progressive or self-limiting response, whether the response is in any way debilitating, and whether the RBC shape changes are indicative of changes in RBC metabolism and/or RBC membrane physics. Skylab and Shuttle data have also provided preliminary information indicating immunological system suppression. SS studies of the immunological system will provide data directly relevant to defining health care requirements in the space station environment. Interest has been expressed in the banking of blood samples throughout the SS activities to take advantage of future technological advancements in analyses techniques.

8.1.8 Fluid/Electrolytes Imbalance Objectives

Body fluid shifts followed by a reduction in fluid volume occurs during the first 48 hours of weightlessness. In addition, these changes are accompanied by the concurrent loss of electrolytes (sodium and potassium) continuing throughout the duration of the mission (Skylab data). Hormonal responses to counteract these changes were shown to occur, but were ineffective in preventing the fluid/electrolyte losses. Part of the fluid loss is in the form of a decreased plasma volume which appears to persist throughout flights lasting up to 84 days. This reduction in volume may be expected to reduce the astronaut's tolerance to vertical ($+G_z$) accelerations upon their return to earth, thereby impairing crew performance during the critical reentry and landing phases of the flight. The excessive sodium and potassium excretion continues throughout the mission despite increases in aldosterone secretion. The extent of the electrolyte losses in longer flights are unknown and difficult to predict. Prolonged electrolyte loss could result in dehydration and cardiac malfunction. The ability of individuals to cope with normal as well as emergency procedures may be severely compromised by the reduction in plasma sodium and potassium levels [a]. Space Station studies should address such issues as the Gauer-Henry reflex, renal hemodynamics in 0g, renal response to water/salt loads and dehydration in 0g, and the humoral mechanisms involved in the above processes.

8.1.9 Metabolism Objectives

The Skylab data indicates that a negative nitrogen balance persists throughout flight without evidence of adaptation even in the longest flight of 84 days. In addition to nitrogen, there was excessive excretion of sodium, potassium, calcium, and phosphorous. Classical metabolic balance studies should be performed over longer duration missions to determine whether changes in these and other important nutrients reach significant negative balance levels that would pose potential hazards to crew health and operational efficiency. The balance studies should be supplemented with determinations of Standard Metabolic Rates. While measurements can be obtained on the crewmembers, animal studies provide greater capability for diet, environment and activity controls and a greater amount of information can be obtained with postflight body composition studies performed on larger numbers of experimental subjects.

8.1.10 Embryology/Developmental Physiology Objectives

Experiments utilizing frog eggs have shown the importance of the gravity vector and acceleration force levels in the normal first cleavage division and in subsequent development. To date, the factors determining the plane of first cleavage division and subsequent bilateral symmetrical development in mammals are unknown. The mechanisms underlying the process of axis formation are basic to the entire process of development. Earth-based studies have shown that critical periods exist for the normal development of each organ system which can be easily disrupted by relatively small environmental changes. In light of such evidence, it is of very high priority within this subdiscipline to study the effects of spaceflight conditions, particularly hypogravity, on the fertilization, development and maturation processes in various animal species. Of particular emphasis will be the study of mammalian development in zero-g since the long range goal is to determine the ultimate feasibility of space colonization. Short-range objectives include the determination of whether animals (single and multiple generations) reared in hypogravity exhibit anatomical, physiological and behavioral patterns adaptive to the new environment. The studies envisioned for space station will require the capability to support large animal colonies and one-g controls inflight for the full duration of each generation's life cycle and ultimately multiple generations.

[a] S. Holt, NASA/GSFC, Draft Report 1982.

8.1.11 Psychology/Behavior Objectives

The Space Station itself should be designed to maximize the operational efficiency of the crewmembers. Preliminary efforts are underway to address basic habitability requirements for the SS inhabitants. Relatively little work has been done since the 1950's (army research) and the 1960's (NASA manned systems research) in the definition of the optimal human work and habitation environments. Now that a great deal more information is available in regard to the physiological changes in space flight, it is time to reassess the crew systems support requirements in light of these physiological changes. The health and sense of well-being of the crewmember necessarily affects the work performance of the individual. Ground-based research should be performed prior to the design of the station itself to further define "optimal" work and living environments. However, the study of crew interactions, and inflight capabilities over the long-term may not be possible until the actual implementation of long-duration SS missions. The types of issues which require study include changes in perception due to weightlessness; stresses of high density living quarters, isolation, environment and schedule changes, and high work loads; and the normal everyday group dynamics and personality conflicts. Research in this area will aid in developing optimal group composition (skill and personality mixes), work schedules, tools and crew support systems, and recreational provisions to achieve high inflight performance levels. Preliminary data (unpublished, personal communications) have shown promising results in the search for a solution to space sickness by preflight behavioral modification training. Continued work in these areas seems warranted.

8.1.12 Radiation Biology Objectives

Cosmic radiation is of serious concern for long-duration space flight missions. Preliminary data (unpublished, personal communications) have shown that primates exposed to 55 MeV levels have had a higher mortality rate from gliomas approximately twenty years after the time of exposure. Those exposed to 2000+ MeV levels did not exhibit the same propensity for tumor development. The ambient radiation levels during solar flare activity is in the range of 35 to 50 MeV. The risk to space station inhabitants should be addressed by first characterizing the cosmic radiation environment of the space station. determining the actual risk to living systems, and assessing the effective levels of shielding. The suggested means of assessing the radiation risks include the use of animal systems to determine tumor development, cataract incidence, mutogenic or transformation effects, life span deviations, and cell loss of non-dividing cells. This research is of very high priority, and a great deal of the work can be performed on the ground. The conceptual experiments proposed could be implemented on space station to verify the earth-based research findings.

8.1.13 Basic Space Biology Objectives

The Basic Space Biology subdiscipline is concerned with the role of gravity in shaping the form and function of living systems. The unique conditions of space flight are utilized for basic biological research such as the effects of hypogravity on growth, reproduction, behavior, morphology, biochemistry and genetics of a wide variety of organisms. Information is sought concerning the role of gravity in microscopic organisms' life processes, tissue cultures, genetics at the subcellular and molecular levels, and interspecies differences in their adaptive capabilities to the space flight environment. The basic space biology activities will allow the probing of interesting phenomena which will result in more knowledge and additional questions to be posed concerning the role of gravity in the evolution of life as we know it on earth.

8.1.14 CELSS Research Objectives

The ultimate goal of the Controlled Environment Life Support System (CELSS) research program is the development of a closed (or semi-closed) ecological life support system to be implemented aboard a future space station. Current research in this subdiscipline has been focusing upon several areas:

1) Control systems technology,

2) Waste processing including regeneration of atmospheric gases and potable water, and

3) Conventional (plants) and unconventional (algae) food production.

Most development efforts can be accommodated by earth-based research. However, plant research, technology demonstrations and concept verification will require use of the shuttle and, later, the space station. The flight experiments are envisioned to include the evaluation of plant food sources (Botany Objectives, Section 8.1.15); feasibility assessment of algae growth systems for food production; phased testing of subsystems and staged integration of control systems and waste management processes. It is hoped to test a semi-closed Controlled Environmental Life Support System (CELSS) designed for 2 to 3 crewmembers onboard the mature space station (year 2000+). Onboard food production will be implemented for this feasibility demonstration supplemented with external food sources.

8.1.15 Botany Objectives

The botany research falls into two classes:

1) Basic biological questions concerning the role of gravity in plant physiology; and

2) Development efforts oriented toward inflight food production for future incorporation into a closed, or semi-closed, ecological life support system in a future space station.

The plant experiments concerned with the role of gravity in basic plant physiology may require acceleration levels lower than 10^{-4}g in order to determine absolute intrinsic sensor thresholds, which is incompatible with manned space station concepts. Some of these experiments may have to be assigned to a freeflyer platform mission. The physiological responses of plants to the space station environment should be studied in order to establish the data-base for future development of inflight food production systems. Such issues which need to be addressed include acceleration effects (vibration and transient g forces), illumination and nutrient requirements, environmental control and monitoring requirements and systems, species selection, plant composition (edible yield), and inflight harvest and processing requirements.

8.1.16 Space Station Role/Objectives

The space station will provide the optimal environment within which to study the adaptive mechanisms exhibited by living systems exposed to space flight. The Shuttle Life Sciences Flight Experiments Program is oriented toward study of the acute adaptive responses in humans and non-human specimens which can be observed during the seven to nine day Shuttle missions. As the SS laboratory capability becomes available, the investigators will redirect their efforts to determine whether such zero-g "adaptive" responses result in an acceptable equilibrium appropriate for the new environment, or whether such changes are progressive and/or chronic and ultimately detrimental to the crewmembers.

In addition to the capability to study long-term effects, the investigators will also have the opportunity to perform complex experimentation with subjects immediately upon their arrival at the SS. It is currently difficult to schedule data collection sessions on Shuttle Spacelab mission day 1 since the crewmembers are heavily involved with Shuttle "housekeeping" activities. In addition, the Shuttle Spacelab crewmembers may suffer from space sickness during this period which could interfere with their scientific operations. In contrast, the space station crew could be previously adapted and available to perform the scientific operations immediately upon the new arrivals (human and animal) with each shift change. In this manner, the gaps in the Shuttle Spacelab data can be filled for this critical adaptive period.

In reiteration, the rapid reflight capability for promising lines of experimentation is uniquely valuable and ultimately feasible for space station. The Shuttle will eventually assume the service role for which it was intended and this frequent access to the space station will result in shorter experiment development times and interflight intervals.

8.2 MISSION MODEL

8.2.1 Model Development/Rationale

The Life/Biological/Medical Sciences Space Station Mission Model has evolved from a number of sources including the NASA Technology Models, the MMC Composite Mission Model, relevant space station/platform documentation and inputs from the investigator contact pool. The MMC Composite Mission Model was initially developed to include all conceptual and planned life sciences/biomedical research activities suggested by the source documents listed in the bibliography (Appendix B). Those conceptual experiments and programs which appeared to be feasible and/or promising for implementation aboard a space station were retained for consideration in the Space Station Mission Model.

Preliminary analysis of some programs such as the "Space Biology Research Program" were considered to be too broad in reference to develop specific requirements and were, therefore, excluded from consideration as "missions". In their place conceptual experiments were proposed by potential investigators in the subdiscipline areas and the requirements necessary to support the broad programs were based upon these representative research activities. In addition, planned equipment development programs, such as the Large Primate Facility and the Large General Purpose Centrifuge, were excluded as "missions" since they are primarily equipment items designed to satisfy experiment requirements in a number of research areas.

The resulting Space Station Mission Model is composed of 14 subdiscipline "missions." Each mission represents the requirements for the proposed conceptual experiment complement. Detailed discussion of each of these missions is provided in Appendix C of this volume. It is not anticipated that all the conceptual experiments within each "mission" will be implemented within the same time frame, but rather, phased in accordance with NASA research priorities and SS capabilities, as discussed in the "Recommended Complement," Section 8.4.

8.2.2 Model Listings and Data

The resulting Life/Biological/Medical Sciences Mission Model for the SS is provided in Table 8.2.2-1.

Table 8.2.2-1 Life/Biological/Medical Sciences - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORD-ABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV.: RETREV	SERV.: REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Operational Medicine NASA-JSC MMCX-0601		DJ						High (Planned)	Initial Evol & Mature Afford-able	Tech. Dev. Res. Med. Ops. Implemen-tation	Contin-uous		X		X									Existing STS program, planned SS program Implementation in Health Maintenance Facility in conjunction with Habitability Module Categories II, III and IV
Cardiovascular Physiology NASA-ARC, JSC MMCX-0602	S6P S6V S6W S6X	EA GK GL GM					S6A S6Q S6U S6AD S6AG S6AH	High (Oppor-tunity)	Initial Evol. Afford-able	Tech-nology Develop-ment Research	30-60			X	X									HMF Vivarium-Large Primate Facility Non-Human Laboratory Animal Centrifuge
Vestibular/Neurophysiology NASA-ARC,-JSC MMCX-0603	S6S S6T S6AJ	ED EE					S6A	Med. (Oppor-tunity)	Evol. Afford-able	Research	90-180			X	X									Vivarium-Multiple Species Non-human Laboratory
Osteology NASA-ARC,-JSC MMCX-0604	S6M	BG					S6A S6R	Med (Oppor-tunity)	Initial/ Evol. Afford-able	Research	360			X	X									HMF Vivarium-Rat & Small Primate Non-Human Lab
Musculoskeletal Physiology NASA-ARC,-JSC MMCX-0605	S6N	DN					S6A S6R	High (Oppor-tunity)	Initial/ Evol. Afford-able	Research	360			X	X									Vivarium-rat & small primate Animal Centrifuge Non-human Laboratory
Hematology/Immunology NASA-ARC,-JSC MMCX-0606	S6U S6AD S6AG S6AH	GS GT GU					S6A S6V S6W S6X S6P S6AJ	High (Oppor-tunity)	Initial/ Evol. Afford-able	Research	30-90			X	X									HMF Animal Centrifuge Bank blood samples Vivarium-mice Non-human Laboratory
Fluid/Electrolytes NASA-ARC MMCX-0607	S6Q	EB					S6A S6P S6U	High (Oppor-tunity)	Initial/ Evol. Afford-able	Research	360			X	X									Vivarium-Rat & small primate Non-human Laboratory Animal Centrifuge Metabolic cages
Metabolism (Endocrinology, Ca^{++}) NASA-ARC,-JSC MMCX-0608	S6R	EC					S6A S6M S6N	High (Oppor-tunity)	Initial Evol. Afford-able	Research	360			X	X									HMF Vivarium-Rat & small primate Animal Centrifuge Non-human Laboratory Metabolic cages

Table 8.2.2-1 Life/Biological/Medical Sciences - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Operational Medicine MMCX-0601												21±5								
Cardiovascular Physiology MMCX-0602												21±5								
Vestibular/Neurophysiology MMCX-0603												21±5								
Osteology MMCX-0604												21±5								
Musculoskeletal Physiology MMCX-0605												21±5								
Hematology/Immunology MMCX-0606												21±5								
Fluid/Electrolyte Imbalances MMCX-0607												21±5								
Metabolism (Endocrinology, Ca^{++}) MMCX-0608												21±2								

Table 8.2.2-1 Life/Biological/Medical Sciences - Space Station Mission Model

MISSION AGENCY OR SPONSOR LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE LAUNCH YRS DESIRED AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV. RETREV	SERV. REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Embryology/Devtl Physiology NASA-ARC MMCX-0610	S6F S6G S6H	EF EJ EK					S6L S6M S6N	Med (Opportunity)	Evol Affordable	Research	30-360			X	X									Vivarium-Mouse, rat, eggs Non-human Laboratory Animal Centrifuge
Psychology/Behavior NASA-ARC,-JSC MMCX-0611		CO						Low (Opportunity)	Evol Affordable	Research														HMF Vivarium- Non-human Laboratory Animal Centrifuge
Radiation Biology NASA-ARC MMCX-0612	S6L	GF GG	285-57 75-90	Below 57 Above 75			S6F S6G S6H	Low (Opportunity)	Evol Affordable	Research	180 and 730			X	X									Vivarium-Mice Animal Centrifuge 3 levels of shielding Most research can be ground-based
Basic Space Biology MMCX-0614		CP						Med (Opportunity)	Affordable															Vivarium Animal Centrifuge Non-human Laboratory
CELSS-Controlled Environmental Life Support System NASA-HQ,-ARC MMCX-0615	S6C S6D S6E	GH GI GJ					S6J S6K	Low (Opportunity)	Evol. Affordable	Concept Verif Tech. Demon. Research	30-120			X	X									Vivarium Plant Growth Facility CELSS workshop results Most research will be ground-based
Botany NASA-ARC MMCX-0616	S6J S6K	GD GE						Medium (Opportunity)	Evol Affordable	Research	28-90			X	X		X	X						Possible platform reqmt at high alt. Plant centrifuge needed Vivarium-plant Non-human Laboratory

Table 8.2.2-1 Life/Biological/Medical Sciences - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER W / DURATION HRS	POWER & DURATION: OPER POWER W / DURATION HRS	POWER & DURATION: STDBY POWER W / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Embryology/Devtl Physiology MMCX-0610												21±5								
Psychology/Behavior MMCX-0611												21±5								
Radiation Biology MMCX-0612												21±5								
Basic Space Biology MMCX-0614												21±5								
CELSS-Controlled Environmental Life Support System MMCX-0615	10^{-3}																			
Botany MMCX-0616	10^{-4}																			

Table 8.2.2-1 Life/Biological/Medical Sciences - Space Station Mission Model

MISSION AGENCY OR SPONSOR LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE LAUNCH YRS DESIRED AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV.: RETREV	SERV.: REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Health Maintenance Facility (HMF) MMCX-0617	New	New						High	Initial Affordable	Mission Support Facility	3650			X	X									This facility is required to support medical ops and human experiment requirements
Vivarium MMCX-0618	New	New						High	Evol Affordable	Mission Support Facility	3650			X	X									This facility is part of the Life Sciences Research Module and it is required to support all non-human experiments
Life Sciences Laboratory Facility MMCX-0619	New	New						High	Evol. Affordable	Mission Support Facility	3650			X	X									Facility is part of the Life Sciences Research Module and it is required to support non-human experiment operations

Table 8.2.2-1 Life/Biological/Medical Sciences - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER w / DURATION HRS	POWER & DURATION: OPER POWER w / DURATION HRS	POWER & DURATION: STDBY POWER w / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Health Maintenance Facility (HMF) MMCX-0617							TBD	1.5kw / 4 hrs 1 day /week	TBD / 24 hrs day			21 ± 5	NOTE	INCORPORATED WITHIN THE HABITABILITY MODULE				13		
Vivarium MMCX-0618								1.5kw / Cont.				21 ± 5	2.2	2.4	2.4	7000		13		Minimum size is 1/2 STS Spacelab
Life Sciences Laboratory Facility MMCX-0619							1.5kw / TBD	1.5kw / TBD Intermittent	TBD Intermittent			21 ± 5	2 2	2.4	2.4	7000		13		Minimum size is 1/2 STS Spacelab

8.3 USER MISSION DATA/CONCEPTS

8.3.1 Contacts

The Life/Biological/Medical Sciences discipline was divided into fourteen subdisciplines for greater ease in handling the data obtained from the potential SS user community. Experts were identified to represent each of the subdiscipline areas from the Spacelab Missions 1, 3, and 4 investigator pool and the American Physiological Society Gravitational Biology Symposia contributors and attendees. A great deal of enthusiasm for the SS was expressed by the investigators which became more evident by the continuing referrals and expansion of the potential contact list. The final contacts and their organizations are listed in Table 8.3.1-1. The contacts participated throughout the study effort and they expressed an interest in continuing their involvement. They represented three classes of investigators:

1) Those currently involved in the Life Sciences Flight Experiments Program,

2) Those interested in future involvement in the flight research program, and

3) Those currently advancing the state-of-the-art in relevant research technologies/techniques.

Table 8.3.1-1 Life Sciences Contact List

Individual	Organization	Individual	Organization
C. Arnaud	UCSF	M. Correia	UT, Galveston
B. Haverlin		G. Pascuzzo	USA-MRICD
C. Cann		J. French	Cornell Univ
G. Musgrave	VCU	J. Levinson	CU, Denver
J. Duke	UT, Houston	G. Harris	
C. Ward	Rice Univ	K. Baldwin	UC-Irvine
C. Dunn	Baylor Univ	J. Sevier	USRA
M. Reschke	NASA/JSC	C. Huber	BYU
C. Leach-Huntoon		E. Alberqueque	UM-Baltimore
J. Rummel		*W. Alexander	Brooks AFB (USRA)
*B. Williams	NASA/ARC	W. Harvey	
N. Daunton		M. Ross	UM-Ann Arbor
L. Kraft		D. White	Florida St. Univ
*R. Johnston	Texas Med. Ctr., Inc.	D. Daphne	UT-Dallas
D. Radmer	MML		

* Data Validation

8.3.2 Concepts Data Approach

A total of 68 potential experiments were obtained from source documents (listed in the Bibliography Appendix B) and from the contacts in the Life Sciences discipline. These experiment concepts were individually analyzed for equipment requirements, and inflight crew involvement. The experiment concepts were then categorized into the 14 subdisciplines mentioned previously with each subdiscipline designated as a "mission". Each of the subdiscipline "missions" was documented in the Mission Concept Reference Data (Appendix C). This appendix contains the detailed information concerning the research objectives, experiment concepts, equipment items, crewmember involvement and SS facility requirements to support the conceptual research activities. A unique source tracking system was employed for the Life Sciences discipline to directly trace the individual requirements since there is a relatively high level of redundancy between the subdiscipline equipment requirements lists.

8.3.3 Validation

The data obtained from the user community and derived from the experiment concepts were reviewed by Dr. B. A. Williams (NASA/ARC), the University Space Research Association (USRA) represented by Dr. J. Sevier and Dr. W. C. Alexander (Brooks AFB School of Aerospace Medicine), and R. S. Johnston (Texas Medical Center, Inc.). The issues addressed in the validation process included verification and prioritization of:

1) Research objectives for each subdiscipline,

2) Experiment concepts' approach and feasibility, and

3) The SS study methods for determining equipment requirements and implementation approaches.

8.4 RECOMMENDED COMPLEMENT

8.4.1 Prioritization

The subdiscipline missions were ranked and ordered as indicated below (Table 8.4.1-1) based upon external inputs during the validation process. Extensive discussion of the subdiscipline mission objectives and rationale for the relative ranking are presented under Science Objectives, Section 8.1, and Appendix C.

Table 8.4.1-1 Life Sciences Mission Prioritization

Rank/ Order	Langley Mission No.	Subdiscipline Mission Title
1	601	Operational Medicine
2	607	Fluid/Electrolyte Imbalances
3	605	Musculoskeletal Physiology
4	602	Cardiovascular/Cardiopulmonary
5	606	Hematology/Immunology
6	608	Metabolism/Nutrition
7	603	Vestibular/Neurophysiology
8	604	Osteology
9	610	Embryology/Developmental Physiology
10	614	Basic Space Biology
11	616	Botany
12	611	Psychology/Behavior
13	615	CELSS
14	612	Radiation Biology

The experiment concepts within each subdiscipline mission were then ordered with regard to the hypotheses, experiment complexity, feasibility of implementation and logical progression. The hypotheses ranged from very basic to highly specific. In terms of experiment complexity and feasibility, the simple, easily accommodated experiments could be implemented early as crew schedules and facility space become available. The overriding factor in the time-phasing of experiments within each subdiscipline was the logical progression. Experiments dependent upon data from another experiment were scheduled accordingly and experiments requiring long lead time technology were postponed to later phases in the SS evolution. Some experiment concepts obtained were identical as the user community saw the need for the same information, so these were combined as indicated in Figure 8.4.1-1 and simultaneously scheduled. Experiment concepts summaries are provided in Appendix C and they can be traced by the assigned experiment concept number. For example, 02/2/04 indicates that the concept is in the Cardiovascular subdiscipline mission (Langley Mission Number MMCX-0602), it has a non-human subject "2" (human subject is "1") and it is the fourth ("04") experiment concept listed in the mission description in Appendix C.

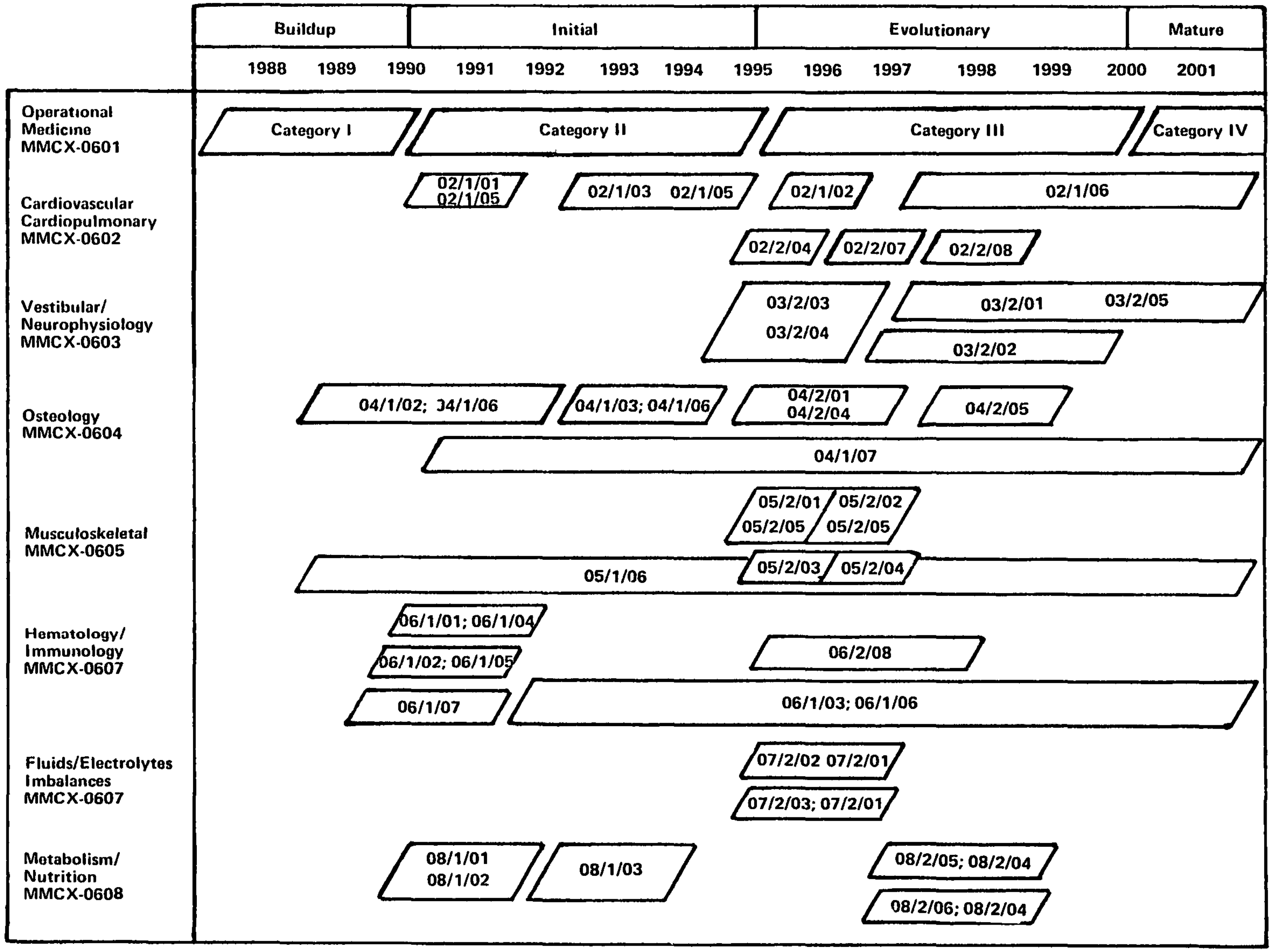
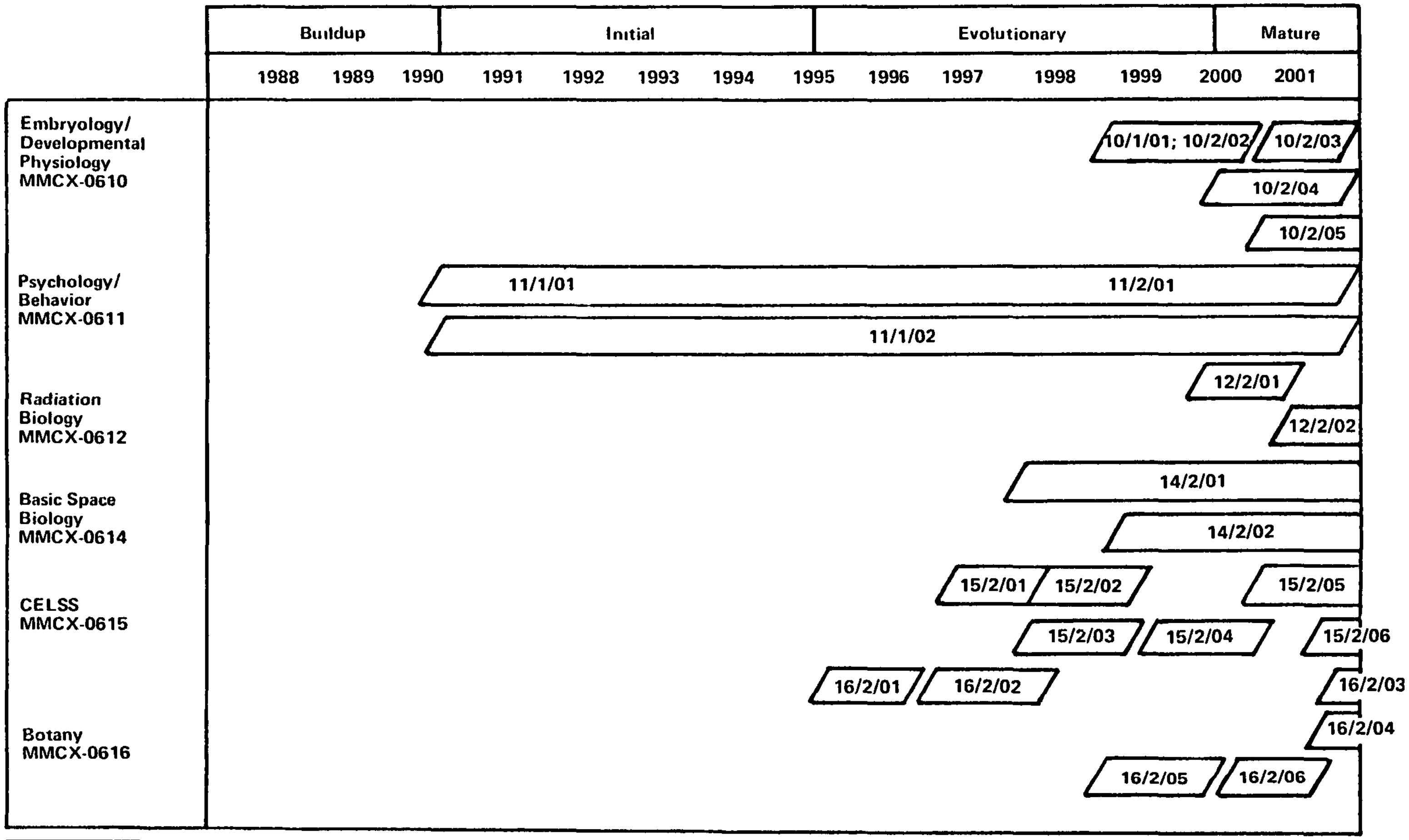


Figure 8.4.1-1 Life Sciences Experiment Concepts Time-Phasing



Experiment Concept Code: XX / X / XX
(1) (2) (3)

1. Subdiscipline Designated by Last Two Digits of Langley Mission Code e.g., MMCX-06<u>02</u>
2. Subject is either Human "1" or Non-Human "2"
3. Experiment Concept Number to Locate in Mission Concept Reference Data—Appendix C

Figure 8.4.1-1 (concl)

8.4.2 Affordability

All experiment concepts can be easily accommodated by the Life Sciences SS budget as represented in Figure 8.4.2-1. The Life Sciences budget projection analysis was based upon the NASA Life Sciences budget history which was then extrapolated into the future. ROM mission costs were estimated and budget allocations determined for each mission set in terms of relative priorities. The Life Sciences Research Module (LSRM) development costs were relegated to the SS budget. A number of the experiment equipment items, such as the Large Primate Facility and the Large General Purpose Centrifuge, are planned for the Shuttle Spacelab therefore, it was assumed that they will be accommodated by the STS Spacelab budget. An effort was made to utilize experiment equipment items developed for STS and Spacelab, where appropriate, to minimize new development costs. In Life Sciences a great deal of information can be derived from simple relatively inexpensive experiments which will then serve as the basis upon which more complex experiments can be designed. Most experiment concepts proposed by our contacts were of this basic type so they did not heavily impact the projected budget.

8.4.3 Evolutionary Approach

Health Maintenance Facility - The human experiment concepts in each subdiscipline mission should be implemented in the order dictated by their relative priorities in the designated Health Maintenance Facility (HMF) which is located in the Habitability Module. The Health Maintenance Facility will accommodate the SS medical operations as well as the biomedical research activities since there is a great deal of redundancy in the equipment item requirements as well as methods and techniques employed. The HMF will evolve as dictated by the SS requirements for increased capability in conjunction with the increasing diversity and complexity of the SS activities.

The HMF requirements presented herein were drawn primarily from two NASA documents: NASA/JSC TM58248 Medical Operations and Life Sciences Activities on Space Station 10/82, and NASA/HQ Operational Medicine Support to Long Duration Manned Missions in Low Earth Orbit and Beyond 2/82. An attempt was made to utilize the terminology initiated by NASA to provide consistency and minimize confusion. Categories I through IV discussed below represent the increasing levels of medical operations and research capabilities to be employed in the SS. Deviations from the concepts set forth in the NASA documents were based upon inputs from our contact pool and in-house analyses.

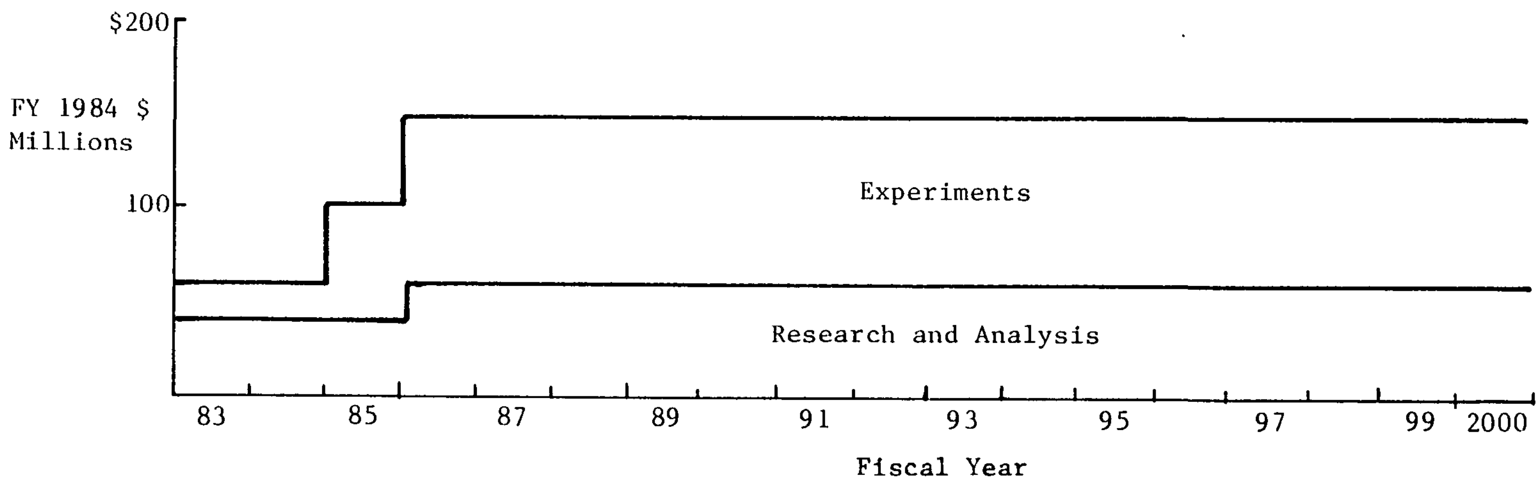


Figure 8.4.2-1 Life Sciences Budget Projection

The deviations from the NASA concepts represent a general belief that the initial SS buildup and construction activities will pose uniquely hazardous situations, particularly in the early phases with relatively inexperienced crewmembers. It would, therefore, be better to initiate an ambitious health care program capable of handling these unique contingencies earlier in the SS program than was initially conceptualized. With experience, the HMF capability can be expanded or descoped as considered appropriate, once sufficient realistic data has been obtained. Thus, requirements that were strongly recommended by the study contacts included:

1) Recompression capability as soon as SS buildup is initiated,

2) A dynamic imaging system as soon as the long term habitation missions are initiated,

3) A computerized early detection diagnostic capability (i.e., individual medical record keeping),

4) Close proximity to habitation compartments and easily accessible for emergencies,

5) Quarantine capability to isolate contagious crewmembers, and

6) Isolation from areas designated for animal research.

Category I

During SS buildup (1988-1990) the STS will provide the necessary medical support until the first Habitability Module is activated at which time the Category II HMF will be operational. The Category I medical equipment will resemble an expansion of the Shuttle Orbiter Medical System (SOMS). The medical operations will be assigned to a highly trained, flight experienced crewmember physician. All other crewmembers will have emergency trauma treatment training with one crewmember more extensively trained than the others to fill in for the physician if he is somehow incapacitated. Little biomedical experimentation was proposed for this phase by our user contingent since the missions would be of short duration and the crewmembers will most probably be heavily scheduled with construction activities. Due to the nature of the anticipated buildup operations, it was considered to be imperative that a means of recompression be available in this phase for contingency decompression sickness. This could conceivably be a collapsable device designed for rapid deployment available on the Shuttle. A type of repressurization system to be implemented in an airlock was also proposed.

Category II

The Category II (1990-1995) capability will be available as soon as the first Habitability Module is operational containing the HMF. At this time crews of up to four will be able to stay without STS support for up to 90 days. The HMF will primarily support routine and contingency medical operations and health maintenance (such as exercise). Some human experiments could easily be accommodated at this time in conjunction with routine medical evaluations as indicated in Figure 8.4.1-1, however research will have a lower priority than the basic medical support. The user community would like to see a computerized early detection diagnostic system implemented on SS as soon as possible since it would enable sufficient warning to schedule STS emergency crewmember(s) evacuation to ensure crew health and safety. This system would preferably be employed during Category II, but no later than the Category III phase. The HMF will be under the jurisdiction of an experienced physician crewmember as in Category I even though his time may not be totally committed to medical or research activities. Requirements for the training of the remaining crewmembers remain the same as in Category I.

Category III

The category III capability would be implemented in the 1995 to 2000 time frame to support a crew complement of 8 to 12 crewmembers. The medical support capabilities would be expanded in response to the requirements developed through SS onboard experience and previously accumulated STS and SS biomedical experiment data. It is anticipated that the HMF will be expanded to resemble a physician's office with minor surgery and trauma treatment capability. Some invasive experimental techniques can be readily accommodated and an expanded area provided for exercise and instrumentation for human research. A quarantine capability should be available no later than the Category III phase. State-of-the-art automated analyses and diagnostic instrumentation will be incorporated for both medical operations and human research. Some advanced form of computer-aided dynamic imaging system must be implemented. (Inflight imaging systems will have been utilized previously on the STS and SS as experiment specific items. However, it is strongly suggested by the user community that a multi-purpose system be made readily available on SS.) The facility should be manned by a trained and experienced physician assigned to the HMF as his primary duty. His duties will include research as well as medical support. The research activities could be additionally supported by qualified payload specialists.

Category IV

The Category IV (year 2000+) HMF will expand upon the Category III capabilities as required by changes in SS operations. It would be desired to increase the area devoted to human experimentation. Imaging devices that are currently experimental in nature, such as Positron

Emission Tomography (PET), Nuclear Magnetic Resonance (NMR), and the Multi-Wire Proportional Counter (MWPC) may be ready for implementation in medical/research applications. Enthusiastic researchers have also expressed a desire to integrate a cyclotron on SS to support the PET system. In addition to the physician, a clinical researcher may be assigned to support the research activities with additional help from qualified technical payload specialists as required.

The suggested equipment complement for the HMF is provided in Table 8.4.3-1. Examples of the types of pharmaceuticals to be provided are shown in Table 8.4.3-2. The medical support equipment lists were obtained from the NASA documents previously cited. The research items were drawn from the human experiment equipment lists for the subdiscipline missions. The time phasing was derived from the contacts' expressed desires.

Life Sciences Research Module - The Life Sciences Research Module (LSRM) concept will satisfy the requirements for the non-human life sciences experiment concepts. The pressurized module will be located onboard the SS and it will consist of a vivarium for support of non-human specimens and a laboratory area (Life Sciences Laboratory Facility) to support experiment operations. It is anticipated that the facility will be designed to utilize Spacelab equipment where appropriate with the flexibility to perform onboard changeout in order to evolve with the state-of-the-art technology and SS capabilities. It is highly desired by the contacted investigators to environmentally isolate the vivarium and laboratory areas to prevent cross contamination. In addition, this module must be environmentally isolated from the crew habitability areas and the Health Maintenance Facility.

The vivarium will provide support for multiple animal and plant holding facilities and associated support equipment items. The vivarium recommended equipment complement based upon the non-human experiment concepts is listed in Table 8.4.3-3. The animal holding facilities will be designed to support primarily common laboratory research species such as rodents (rats and mice) and small primates (squirrel monkeys). However, the facility will be designed to easily incorporate compatible cage modules for other species such as cats or birds. In addition, facilities for large primates must be provided (macaque and rhesus) for both restrained and non-restrained research requirements.

An animal centrifuge must be implemented with the capability of providing a variable-g environment. A zero to five g range of control settings would encompass all experiment concept requirements, however settings of 0.0 to 2.0 g with 0.25 increments would be the initial recommendation. The system should be modular to easily accommodate the

Table 8.4.3-1 Health Maintenance Facility Equipment Complement

	Category I (Buildup)	Category II (1990-1995)	Category III (1995-2000)	Category IV (2000+)
Medical Operations Support Items	- Exam Equipment - Stethoscope - Blood Pressure Measurement Device* - Otoscope - Ophthalmoscope - Reflex Hammer - Guaiac Cards - Thermometer - Physiological Status Monitoring (PSM)* - Bends Recompresssion Capability to 3 ATA - Medical Checklist - Procedures & Instruction Manual - Bandages, Tape, Burn Type - Respiratory Equipment - O_2, O_2 Masks - Oral Airway - Ambu-bag - Laryngoscope - Ventilator with Positive Pressure Capability - Chest Tube & Section - Hot Packs, Cold Packs - Pharmaceuticals (Table 8.4.3-2)	- Dynamic Imaging System* - Computerized Diagnostic Syst - EKG or Echocardiography* Monitoring with Downlink - Pulmonary Function Test Apparatus * - Tracheostomy Tray - Paracentesis, Thoracentesis - Peritoneal Lavage Tray - Lumbar Puncture Tray - Woods Light, Fluorescein - Medical Treatment Area & Equipment - Environmental Monitoring - Exercise Machinery & Facilities* - LBNPD* - Mass/Center of Gravity Measuring Device (LMMI)* - Anthropometry - Minor Surgery Tray & Instruments - IV Fluids - Tubing - Catheters - Pumps - CVP Lines - Pressure Transducers - Orthopedic Equipment - Splints - Cast Material - Wraps - Anaesthesia - Local - Laboratory Equipment* - Microscope, Centrifuge(s) Blood Drawing Supplies, Laminar Flow Workbench (GPWS) - Dental Care Equipment	- Medical Support & Equipment Expanded - Urinary Catheter - Wall Suction & Nasogastric - Surgical Equipment Expanded - Irrigation Fluids - Dentistry Instrument - Orthopedic Equip. Expanded - Pins - Closed Reduction Traction - Anaesthesia - Local & General - Chemistry - Serum Sodium, Potassium, Chloride, Carbon Dioxide, Glucose, Creatinine, (SGOT, SGPT, GGTP), Alkaline Phosphatase, Bilirubin, Amylase, Cholesterol, Triglyceride, & Cardiac Isoenzymes - Toxicology - Carbon Monoxide, & Other Atmospheric Trace Contaminant Gases - Microbiology - Culture & Antibiotic Sensitivity, Staining Characteristics - Expanded Medical Treatment, Exercise & Research Areas - Quarantine Capability - Hematology - CBC-Differential & Platelets, Reticulocytes, Coagulation, Erythrocyte Indices Set Rate, Prothrombin Time (PT)	

*Research support items as well

Table 8.4.3-1 Health Maintenance Facility Equipment Complement (concl)

	Category I (Buildup)	Category II (1990-1995)	Category III (1995-2000)	Category IV (2000+)
Additional Items to Support Human Research Activities		- Limb Plethysmograph - Refrigerated (+4°C) & Freezer Storage (-10° to -20°C) - Radiological Storage/Handling Capability	- Retinal Photography - Airblast Ocular Tonometry - Retinal Pressure - Saline Injection Kit - EMG - Bone Densitometry - Automated Blood Analysis System - Muscle Biopsy Kit	- PET, NMR or MWPC - Radiological Matls Generator (Cyclotron) - Acceleration Devices - Visual Motion System - Artificial g-inducing Sys

Table 8.4.3-2 Examples of Pharmaceuticals

Allergy relief

Anaesthetics--injectable
- Local

Analgesics/antipyretics

Antacids

Anti-inflammatories

Antiasthmatics and bronchial dilators

Antibacterials/antibiotics

Antibacterial
- Mydriatics and cycloplegics

Anticoagulants

Anticonvulsants

Antidiarrheals/Antiflatulents

Antihistamines

Antimotion sickness/antinauseants

Antiseptics, germicides

Antispasmodics

Bowel evacuants

Cardiovascular preparations
- Antiarrhythmics
- Antihypertensives
- Digoxin
- Vasodilators
- Vasopressors

Cough and cold preparations

Decongestants

Dermatologicals

Electrolytes

Hormones - glucocorticoids

Hemorrhoidial preparations

Hemostatics

Laxatives

Muscle relaxants

Nutritional aids
- Peripheral and central hyper-alimentation fluid

Ophthalmologicals
- Irrigants

Otic preparations

Psychotropic agents

Plasma expanders
- Plasma fractions

Radiopharmaceuticals
- X-ray contrast media

Sedatives

Throat lozenges

Table 8.4.3-3 Vivarium Equipment Item List

Equipment Item:	Number of Experiments
o Animal Holding Facility (w/ECS)	
- Mice	6
- Rats	17
- Primates (unrestrained)	7
- Multispecies	4
- Other-gerbil	1
- Unspecified	1
o Animal Centrifuge	
- Mice	6
- Rats	13
- Primates	8
- Large Primate	1
- Multispecies	1
- Other-gerbil	1
- Unspecified	1
o Plant Growth Facility	6
o Plant Centrifuge	3
o Metabolic Cages	
- Rodent	2
- Primate	2
o Maternal Cages	
- Mice	4
- Rats	1
- Primates	2
o Holding Cage Shielding	2
o Egg Facility	
- Fowl	1
- Amphibian	1
o Large Primate Facility (restrained)	3
o Biotelemetry System	5
o Videorecorder	8
o IR Video	1
o Video Timer, Shroud, Mirrors	1
o Gas Analysis	5
o Active Dosimeters	2
o Dynamic Environment Monitoring System (DEMS)	3

animal holding facility cage modules. NASA is currently supporting work in the area of centrifuge development through the Vestibular Research Facility (VRF) program at NASA/ARC and the Vestibular Function Research (VFR) program. It is assumed that the VRF will be flown on STS Spacelab and that modifications for SS application would be minimal.

The Life Sciences Laboratory Facility (LSLF) will be similar to the Spacelab design in order to utilize Spacelab equipment where appropriate. Access to the vivarium would be direct via an airlock. The laboratory would contain multiple generic equipment items such as General Purpose Work Stations (GPWS), dissecting kits, microscopes, freezers, refrigerators, and centrifuges, in order to support multiple simultaneous experiment operations. The design would be modular in order to provide easy experiment-specific equipment changeout onboard. This would allow the research capability to evolve with advances in the state-of-the-art technology and with the evolution of SS activities and capabilities. The equipment complement presented in Table 8.4.3-4 is based upon the proposed non-human experiment concepts. The additional items listed, while not in direct support of the proposed experiment concepts, were suggested by either the contact pool or SS related documentation.

8.5 COMPOSITE REQUIREMENT

8.5.1 Integration Concepts

As indicated in the previous Section 8.4, all Life/Biological/Medical Sciences research activities will be implemented onboard the SS. The Health Maintenance Facility will be part of the first Habitability Module to be integrated in 1990 and fully operational at IOC. The Health Maintenance Facility will first support medical operations and secondarily the human research activities. As the SS facility evolves from Category II (1990) to Category III (1995) and Category IV (2000), the research equipment items will be incorporated as indicated in Section 8.4.3 and more specifically in Table 8.4.3-1. The Life Sciences Research Module will contain the vivarium and the Life Sciences Laboratory Facility and be integrated with the SS in 1995 to support the non-human experiment requirements. Experiment-specific equipment items will be changed out as required.

Table 8.4.3-4 Life Sciences Laboratory Facility Equipment Complement

GENERIC ITEMS:

Equipment Item	Number of Experiments
o General Purpose Work Station (GPWS)	28
o Small Mass Measurement Instrument (SMMI)	20
o Sacrifice/Dissection Kit	
- Rodent	19
- Primate	11
o Tissue Preparation Kit (i.e., slides, solutions)	
- Animal	6
- Plant	5
o Tissue Storage	
- Refrigerator (+4°C)	2
- Freezer (-10° to -20°C)	4
- Cryogenic (-50° to -70°C)	5
- Unspecified	13
o Urine Storage	
- -10°C	15
- +21°C	1
- +4°C	3
o Feces Storage	
- +21°C	1
- +4°C	15
o Blood Storage	
- Plasma	8
- Hematocrit	8
- Unspecified	17
o Blood Collection Kit	11
o Blood Centrifuge (+4°C)	10
o Oscilloscope	8
o Strip Chart Recorder	2
o Dissecting Microscope	3
o Life Sciences Laboratory Equipment (LSLE) Microcomputer	3
o Tektronics Power Frame	3

Table 8.4.3-4 (Continued)

GENERIC ITEMS (CONT) Equipment Item	Number of Experiments
o Voice Recorder	3
o Culture Centrifuge	2
o Acceleration Devices	3
o Electrophysiology Kit	3
o Microelectrode Puller (Horizontal)	3
o Visual Motion System	2
o Experiment Control Unit	3
o Microdrive and Controller	3
o Specialized Animal Holder and Unit Tester (AHUT)	2
o Audiomonitor	3
o Headset	3
o Algal Culture System	2
o Chemical Analyses (Organic & Inorganic)	2
o Display Microprocessor	3
o Stereotaxic Device	2
EXPERIMENT-SPECIFIC ITEMS:	
o TEM Tissue Processing H/W	1
o Microscope	1
o Physiograph/Computer	1
o Electromyograph (EMG) Kit	1
o Tissue Culture Kit	1
o Hematocrit Centrifuge	1
o Incubator (cell culture)	1
o Plant Nutrient Sample Storage (-10°C to -20°C)	1

Table 8.4.3-4 (continued)

EXPERIMENT SPECIFIC ITEMS (CONT)

Equipment Item	Number of Experiments
o Pilot Waste Processing System	1
o Lower Body Negative Pressure Device LBNPD (Primate)	1
o Pharmaceutical Kit (Primate)	1
o Payload Specialist "Perch"	1

SUGGESTED ADDITIONAL ITEMS FOR SS EVOLUTION:

- o Radiological Storage Containers
- o Rodent Exercise System
- o Automated Blood Analysis System
- o Automated Urine Analysis System
- o Dynamic Imaging System
- o Bone Densitometer
- o Enlarged Plant Growth Systems ($6m^3$)
- o Autoclaves
- o Electrophoretic Equipment
- o Gas Chromotography
- o Lyophilizer
- o Electron Scanning Microscope
- o Microtome
- o pH Meter
- o Spectrophotometer
- o Scintillation/Gamma Counter
- o Tissue Homogenizer
- o Vacuum Chambers

8.5.2 Operational Support

The HMF should have a fully trained and flight experienced physician available to support contingency medical operations at all times from Category II initiation in 1990 to Category IV in the year 2000 and beyond. It is preferred by the contact pool, to have a physician with clinical research experience to support their human experiments. It is anticipated that the medical crewmember will not be totally dedicated to medical operations or research operations particularly in the early phases of the space station buildup activities. As the priorities for biomedical research increase, it would be beneficial to have a clinical researcher (PhD or MD) to serve in the capacity of a payload specialist with his/her primary assignment to research during the periods of high experiment work loads. This person could possibly have dual responsibilities for human and non-human research as experiment schedule requirements fluctuate.

The non-human research activities will typically be heavy on approximate mission days one through seven and again on days 30, 60, 90, 180, 270, and 360. It is anticipated that a non-technical, trained crewmember could perform the periodic (perhaps one day per week) specimen maintenance in the vivarium. It is preferred by the investigator pool to have an experienced animal researcher (PhD, MD, or DVM) assigned to their experiment operations and routine animal care. This is particularly important when utilizing primate subjects.

8.5.3 Maintenance Repair/Service

The HMF and the Life Sciences Research Facility (LSRF) will be routinely resupplied with consumables by the Shuttle probably at 90 day intervals. Routine maintenance is anticipated for both facilities. Experiment-specific equipment items will be changed out as required. Biological samples and data will be returned via the Shuttle at each routine visitation.

8.5.4 Subsystems Support

The space station will provide basic subsystems support to both the Health Maintenance Facility and to the Life Sciences Research Module to the levels indicated in Table 8.5.4-1.

8.6 BENEFITS ASSESSMENTS

8.6.1 Direct Mission Benefits

The most dominant SS benefit is the capability for long duration missions. All of the Life Sciences conceptual experiments will benefit by the opportunity to study greater numbers of subjects, both human and non-human, over a longer period of adaptation to the conditions of spaceflight. The SS will provide the opportunity to implement a zero-g

Table 8.5.4.1 Life Sciences Subsystem Support Requirements

LIFE SCIENCES FACILITIES \ SUBSYSTEM	PRESSURIZED	WEIGHT (KG)	POWER (KW)	INTERNAL TEMPERATURE	INTERNAL HUMIDITY	DATA HANDLING CONSIDERATIONS
Health Maintenance Facility	13 $\pm$ 2 psi	N/A*	1.5	$21^{o} \pm 3^{o}C$	40-60%	•Computer diagnostic system downlink •Two-way confidential voice link •Video downlink and data downlink during experiment activities
Vivarium	13 $\pm$ 2 psi	7000	1.5	Set Point $\pm 3^{o}C$	Set Point +10%	•Video, digital data of holding facility status, and bio-telemetry •Continuous recording periodic downlink
Life Sciences Laboratory Facility	13 $\pm$ 2 psi	7000	1.5	$21^{o} \pm 3^{o}C$	40-60%	•Video and digital data downlink only during experiment activities

*Part of the Habitability Module

laboratory containing all the instrumentation and operational advantages of an earth-based laboratory. Greater experimental controls can be exerted to eliminate confounding variables which have compromised the results of past flight experiments (e.g., the stresses of launch and reentry can mask or obscure the zero-g effects). The inflight flexibility offered by relaxed crew schedules can maximize the informational return by such things as allowing additional data collection in light of promising realtime results, and the opportunity to persevere in complex procedures when things go wrong rather than abandon the effort due to rigid time constraints.

By providing environmental isolation between crew habitability and research areas and the animal support and research areas, the possibility of cross contamination is minimized.

8.6.2 Alternate Mission Evaluation

Experiments requiring less than thirty days duration can easily be accommodated by the Shuttle Spacelab. However, as the STS program emphasis shifts from scientific to a "trucking" type service, there will probably be fewer shuttle flights dedicated to data collection. It is anticipated that the scientific activities, especially in the Life Sciences, will be best accommodated by a space station.

An alternative means of implementing non-human experiments could be established in an unmanned orbiting platform system. Conceivably, the environmental support, waste management and biotelemetry data could be totally automated requiring only periodic manned visitation for animal/plant specimen changeout and consumables resupply. However, what one gains in apparent simplicity, one pays for in real dollars for the development of the highly complex automated system while sacrificing a significant amount of experimentation capability due to the limited flexibility of an automated system.

The non-human researchers prefer a continuously manned facility in order to provide rapid response to a contingency situation which may result in the potential loss of a specimen. The availability of crewmember response to contingency situations threatening animal health and safety is even more critical when the use of primates is initiated. A manned station is inherently necessary for the implementation of the human experiments.

8.6.3 Derived Benefits

The primary benefits derived from life sciences research aboard SS are in the area of applied medicine on earth. For example, the data obtained on the neural mechanisms of cardiovascular function during Skylab contributed significantly to the Handbook of Circulation currently in use throughout the US medical community. The Life Science Flight Program has served to bring greater knowledge and awareness of normal earth physiology. The study of normal healthy living systems in space will provide valuable data in a number of unique areas. There is a gravity component in many processes such as plaque formation, aging, platelet stickiness, blood viscosity and flow. The study of the inflight musculoskeletal deconditioning will be applicable to such areas as osteoporosis in post-menopausal women, muscle disuse atrophy and musculodistrophy. Cardiovascular studies will provide data on healthy crewmembers with applicability to earth-based Barter's Syndrome and congestive heart failure. The study of inflight immunological suppression will contribute to the earth-based studies of leukemia. A system previously developed by NASA/JSC for Shuttle inflight blood analysis (Centrifugal Fast Analyzer) has found its way into clinical applications prior to its being assigned to a STS mission. The spacesuit technologies have also found earth-based applications in liquid-cooled garments for individuals afflicted with rare painfully debilitating diseases such as "burning limb syndrome," skin diseases and hypothalamic disorders resulting in lack of homeostatic thermal control. These examples barely touch upon the valuable contributions of the NASA Life Sciences Program. The spinoffs of the SS technology can only be conjectured at this time, however the potentials appear limitless particularly in the areas of medical knowledge and treatment capabilities.

9.0 MATERIALS PROCESSING IN SPACE

9.1 OBJECTIVES

Materials processing in Space (MPS) first displayed its potential to the American public during the skylab missions. It was a demonstration of the practicality of space research and the technological advancements that would provide new and better products for everyday life. Yet today this potential remains unfulfilled.

Only the Johnson and Johnson - McDonnell Douglas pharmaceutical electrophoresis venture appears to have any likelihood of success over the next decade as a commercial entity. Several other space processing technologies have shown enough success to warrant enthusiasm, but none have developed commitments for flight opportunities and financing. Meanwhile NASA research support continues at relatively low funding levels for instance, $21 million for fiscal 1984 compared to a total of $719 million for Astronomy and Planetary Sciences.

Two commercial ventures have been proposed by GTI Corporation and Microgravity Research Associates. These ventures propose to fly a furnace for melting alloys and a crystal growth facility for semiconductor crystals on the Space Shuttle. The GTI furnace is on the verge of being cancelled due to a lack of market support, while Microgravity is still awaiting NASA approval of a Joint Endeavor Agreement submitted in 1980. Clearly these examples have not encouraged commercial industry to invest heaviliy in MPS.

Materials Processing in Space is still a science very much in its infancy. The basic physical phenomena associated with a near zero-gravity environment are not well understood and no organized plan has been presented to develop this understanding. Experiments flown to date have been of a random exploratory nature to determine what types of processes might be improved or modified by the zero-gravity environment.

It would seem that the primary role in developing a nationally organized research program to implement the requirements of the science and industrial communities for MPS should fall upon NASA. It appears that the only impediment prohibiting NASA from fulfilling this responsibility is its lack of commitment, as demonstrated by the limited funding that the MPS program receives. The mechanisms necessary to accomplish this task already exist, although some modifications, like a simplified management structure are required.

The American Institute of Aeronautics and Astronautics (AIAA) Corporate Associates Program, the NASA Outreach Program, and articles in various national publications have alerted private industry to some of the potentials of MPS. Everyone seems interested in the program, some are excited, and a few have expended the effort to work with the NASA team at Marshall Space Flight Center to develop experiment programs for Drop Tube and Aircraft Flight investigations of zero-gravity processes. However, these programs present a severe constraint on the time available in the near zero-gravity environment, and no orbiting facility now exists that readily allows their research to progress. It is difficult for industry to maintain interest in a project that they know will dead end; or alternatively, require extensive investment in a three year program to obtain the results to a relatively simple experiment. There is no driving need for anyone to commit to such an investment, only a curiosity to investigate a potential opportunity.

Therefore, the primary objective for Materials Processing in Space must be to provide an orbiting materials processing laboratory capability. It must be emphasized that the primary objective of this laboratory will be research. If commercialization is shown to be feasible, it will naturally develop from the knowledge gained through research. The laboratory capability could develop in several forms, such as multiple STS-Spacelab flights, individual instruments with multiple STS flights, or an unmanned platform. But the most functionally effective approach is a manned laboratory as a part of the Space Station.

9.1.1 Science Objectives

The product areas that have been emphasized thus far in MPS are the following:

1) Biomedical Processing
2) Ceramics and Glasses Processing
3) Crystal Growth
4) Fluids and Chemical Processing
5) Metals and Alloy Solidification

The general objectives of materials processing in space are to take advantage of the natural phenomena associated with the near zero-gravity environment of low earth orbit in the following ways:

1) Develop processes for new or improved products that cannot be duplicated by production on earth;

2) Study the physical phenomena that are masked by gravity effects in earth processes so that improvements might be made in earth processing.

An example of the physical phenomena being investigated would be the elimination of thermally and compositionally induced convection, and its applications in allowing more consistent mixtures of alloys, more perfect crystal growth from liquids and gases, and more selective separations of biological materials in electrostatic fields. Other major phenomena are listed in Table 9.1.1-1.

The ultimate objective of expanding this MPS scientific data base is then to exploit space processing through commercialization. The

Table 9.1.1-1 Major MPS Physical Phenomena

	Acoustic Containerless	Electrostatic Containerless	Electromagnetic Containerless	Vapor Crystal Growth	Crystals From Solution	Floating Zone	Directional Solidification	Fluids/Chemical Process	Fluid Experiment System	Gradient Furnace	Isothermal Furnace	Electrophoresis Separation
Crystal Growth												
- Phase Boundary Models					X	X	X		X	X	X	
- Chemical Homogeneity	X	X	X	X	X	X	X		X	X	X	
- Electronic Properties				X	X	X	X			X	X	
- Morphology Control				X	X	X	X		X	X	X	
Fluids												
- Diffusion				X	X	X	X	X	X	X		X
- Vapor Transport				X								
- Solutal Convection					X	X	X	X	X	X		X
- Surface Segregation	X	X	X			X		X	X			
- Homogenization						X	X	X	X	X	X	
- Miscibility						X	X	X	X	X	X	
- Isoelectric Focusing												X
- Bubble Behavior	X	X	X					X	X			
- Marangoni Effects	X	X	X			X	X			X	X	
Glasses/Ceramics												
- Nucleation	X									X	X	
Metals												
- Thermophysical Properties	X		X									
Biological Materials								X	X			X

ultimate measure of success for the MPS program should be determined by the quantity of MPS-derived, or MPS-improved, products consumed by the American public.

9.1.2 Space Station's Role

As described earlier, the major shortcoming inhibiting the development of Materials Processing in Space is the lack of a readily accessible orbiting laboratory. A manned Space Station represents the most functionally effective method of fulfilling this need.

A Space Station (SS) MPS Laboratory containing a complement of versatile materials processing facilities, along with some basic sample analysis hardware, could perform specialized experiments developed by universities, NASA, private industry, or research groups on a continual basis. The experiment hardware should be modularized and small enough to be transported to and from space station with any orbiter visit. These individual experiments would be in the form of cartridges, ampoules, or module inserts and will be sized to fit the SS MPS laboratory facilities. The Space Station crew or an experiment technician would insert and remove the experiment samples from the furnaces, initiate experiment sequences, and readjust hardware settings before or during experiment sequences. A manned presence in the Laboratory is extremely important both as an observer and controller, and as a means of simplifying experiment interfaces to reduce the time period required between initial experiment conceptualization and actual data return. Increased automation for individual experiments inherently implies increased cost and time arising from hardware complexity, redundancy, and test requirements. It is conceivable that implementing a partial laboratory as an unmanned platform, or in any of several orbiter cargo bay configurations, with a less thorough approach could only partially meet the existing requirements and would impose severe constraints on overall flexibility and multi-user system utility.

The Space Station MPS Laboratory could also provide workspace and utilities for both commercial MPS development hardware and commercial MPS production hardware on a 'lease-as-available' basis. This is to imply that small MPS development units for commercial production could be installed in the Laboratory and then leased for short time periods, up to several months. This could be an extremely useful service as crewmembers could adjust and modify the hardware between production runs to properly balance the hardware parameters for larger scale production of processes shown to be successful in the laboratory. Small commercial MPS production hardware could also be leased along with space and utilities within the laboratory, but on a lower priority basis so as not to interfere with the primary objectives of research and development. An example of this type of hardware would be a Monodisperse Latex Reactor production facility.

During our conversations with potential users within the commercial industry, a number of potential users expressed apprehension with NASA's access to proprietary processes and data. We discussed with them the advantages of having a third party that is familiar with aerospace requirements, perform as an intermediary, or Laboratory Manager, and could guarantee commercial hardware certification to NASA.

We presume that the McDonnell Douglas Aerospace Company (MDAC) is fulfilling a comparable role in its Electrophoresis Operation in Space (EOS) relationship with Johnson and Johnson. Careful delineation of this management task would eliminate the industry's concerns for its proprietary processes becoming compromised and made accessible to both national and foreign competition.

Large commercial production hardware, such as the EOS units, can be attached to the Space Station externally, leasing power and servicing capabilities, on an 'as available' basis. These units would be serviced/resupplied with the Space Station based Teleoperator Maneuvering System (TMS). A major consideration in establishing these utility leasing arrangements is appreciating that each utility capability is limited. Only a finite quantity of commercial MPS production facilities can be accommodated by a Space Station before it expends its available power. Production facilities can then be accommodated with MPS Platforms that would be serviced and resupplied with the Space Station based TMS. Typically it would be preferable to locate production hardware on the Space Station, however there may be processes developed that cannot withstand the instantaneous 10^{-3} G level disturbances anticipated on the SS and would require a platform mounting location. The commercial industry would then be expected to pay for the platforms and lease the associated TMS/STS support.

9.2 MISSION MODEL

The Space Station MPS Mission Model presented herein is primarily directed toward defining the facilities required for the Research Laboratory. The investigations performed throughout this Study Contract indicate that basic research should remain the primary area of emphasis for the near term. The time period required to transition from this period of research is dependant upon the success of the research program itself. However research will be greatly accelerated with the availability of the SS Laboratory as compared to an STS based program.

It is anticipated that the basic defined Laboratory facility complement listed in Table 9.2-1 and detailed in Appendix C will accommodate 90% of the planned experiments. The Laboratory will be capable of handling Single Purpose Experiment hardware for short time periods, similar to its capability to accommodate Commercial Development hardware. It will also be possible to readily replace any of the basic facilities as its technology becomes outdated. Care must be taken to assure that research needs of private industry are satisfied by the Laboratory facilities; and that the hardware designs are not overly biased toward university research programs. It may be possible to combine facilities for some of the functions identified in the Mission Model, for example the Gradient and Directional Solification Furnaces, as their design requirements become better known.

Table 9.2-1 Materials Processing - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE (LAUNCH YRS DESIRED / AFFORDABLE)	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV. RETREV	SERV. REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
SS Materials Processing Lab NASA-JSC MMCX-0801	A1A	HH HX		Any		Any		Candi-date	Initial 1991 Afford-able	Science	7300 (20 yrs)	1		X	X									A1B Through A1S Are All Contained on A1A 8000 KG
Acoustic Containerless Furnace NASA-JPL MMCX-0802	A1B	HS		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									45 KG
Electrostatic Containerless Furnace NASA-JPL MMCX-0803	A1C	HT		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									45 KG
Electromagnetic Containerless Furnace NASA-MSFC MMCX-0804	A1D	JN		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									45 KG
Vapor Crystal Growth Facility NASA-MSFC MMCX-0805	A1E	HU		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									275 KG
Crystals From Solution Facility NASA-MSFC MMCX-0806	A1F	HU		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									34 KG
Floating Zone Furnace NASA-MSFC MMCX-0807	A1P	JT		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									70 KG
Directional Solidification Furnace NASA-MSFC MMCX-0808	A1H	HU		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									70 KG

Table 9.2-7 Materials Processing - Space Station Mission Model

MISSION / LaRC CODE	ACCEL SENSITIVITY, g: SUST	ACCEL SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER W / DURATION HRS	POWER & DURATION: OPER POWER W / DURATION HRS	POWER & DURATION: STDBY POWER W / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP DEG C	THERMAL: TOLER	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
SS Materials Processing Lab MMCX-0801							8000/0.3	6000/4	200/16					8 0	4 6	4.6	8000	1			
Acoustic Containerless Furnace MMCX-0802								5000/2						1.0	0.6	0.6	45				
Electrostatic Containerless Furnace MMCX-0803								3000/2						1.0	0.6	0.6	45				
Electromagnetic Containerless Furnace MMCX-0804								3000/2						0.7	0.7	0.7	45				
Vapor Crystal Growth Facility MMCX-0805								550/24 For 30 Days						2.0	1.0	2.0	275				
Crystals From Solution Facility MMCX-0806								75/24 For 30 Days						0.6	0.6	0.6	34				
Floating Zone Furnace MMCX-0807								1200/2						0.4	0.5	0.5	70				
Directional Solidification Furnace MMCX-0808								1250/24 For 5 Days						1.2	0.6	0.6	70				

Table 9.2-1 Materials Processing - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMMITMENTS / MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV. RETREV	SERV. REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Fluids/Chemical Process Facility NASA-MSFC MMCX-0809	A1J	JP		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									40 KG
Fluid Experiment System NASA-MSFC MMCX-0810	A1K	JQ		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									135 KG
Gradient Furnace NASA-MSFC MMCX-0811	A1L	JR		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									45 KG
Isothermal Furnace NASA-MSFC MMCX-0812	A1M	JS		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									45 KG
Electrophoresis Separation NASA-GSFC MMCX-0813	A1N	HY		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-	7300	1		X	X									450 KG
Combustion Research NASA-LeRC MMCX-0814	A1Q	JJ		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	7300	1		X	X									60 KG
Single Purpose Experiments NASA-LeRC MMCX-0815	A1S	HZ		Any		Any	A1A	Candi-date	Initial 1991 Afford-able	Applica-tion	60	10		X	X									135 KG

Table 9.2-1 Materials Processing - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS/DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Fluids/Chemical Process Facility MMCX-0809								50/24 For 2 Days					2.0	0.7	0.7	40				
Fluid Experiment System MMCX-0810								1000/2					1.0	0.7	2.0	135				
Gradient Furnace MMCX-0811								500/24					1.2	0.7	0.7	45				
Isothermal Furnace MMCX-0812								500/2					1.2	0.7	0.7	45				
Electrophoresis Separation MMCX-0813								1000/3					2.0	2.0	1.7	450				
Combustion Research MMCX-0814								200/1					1.0	0.5	0.5	60				
Single Purpose Experiments MMCX-0815								1000/1					1.0	0.7	0.5	135				

Table 9.2-1 Materials Processing - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	SS SUPPORT FUNCTIONS: ATTACHED	SS SUPPORT FUNCTIONS: PLATFORM	SS SUPPORT FUNCTIONS: FREE SAT	SS SUPPORT FUNCTIONS: SERV. RETREV	SS SUPPORT FUNCTIONS: SERV. REMOTE	SS SUPPORT FUNCTIONS: RESUPPLY	SS SUPPORT FUNCTIONS: LAUNCH	SS SUPPORT FUNCTIONS: ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
MDAC - Electrophoresis (EOS) MDAC, J&J MMCX-1801	C1A	HO HP HQ HR		Any		Any		High (Planned)	Initial 1988 Affordable	Commercial	1825 (5 Yrs)	19	X		X		X	X			X			4550 KG
Monodisperse Latex Reactor Lehigh University MMCX-1802	C1B	RK		Any		Any		Planned	Initial 1990 Affordable	Commercial	25	20		X	X						X			200 KG
MPS Commercial Development Units Commercial Sponsors MMCX-1803		JT		Any		Any		Opportunity	Evol 1994 Affordable	Commercial	60	15		X	X									2275 KG
MPS Commercial Production Units Commercial Sponsors MMCX-1804		JU		Any		Any		Opportunity	Evol 1995 Affordable	Commercial	1825 (5 Yrs)	20		X			X				X			9000 KG

Table 9.2-1 Materials Processing - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
MDAC - Electrophoresis (EOS) MMCX-1801							3500	3500 / Continuous	225			-20 to +30	2.5	4.3	4.3	4550		26		2275 KG Resupply
Monodisperse Latex Reactor MMCX-1802								300				70 Max	3.0	1.5	1.0	200	1	0.7		40 KG Resupply
MPS Commercial Development Units MMCX-1803								3000					3.0	1.0	1.0	2275	1			
MPS Commercial Production Units								30,000 / Continuous					6.0	4.3	4.3	9000		4		

Two commercial MPS production payloads are identified for the initial Space Station, the MDAC EOS and the Monodisperse Latex Reactor. Other commercial units may develop prior to the initial SS, and utilities will be available for them.

Commercial MPS development hardware and subsequent production hardware will evolve from successful experimentation in the SS Research Laboratory and from pre-Space Station STS flights. These missions are included in the evolutionary phase of the SS Mission Model. No attempt has been made to predict which processes will develop most quickly, although semiconductor crystal manufacturing offers the most potential at the present time.

The Space Station MPS Mission Model is shown as Table 9.2-1.

9.3 USER MISSION DATA/CONCEPTS

The MPS objectives, Mission Model, and Space Station requirements were compiled after teleconferences or consultations with the following individuals:

Marshall Space Flight Center (MSFC)

J. Williams, MPS Experiments Development Office
W.R. Adams, MPS Payload Development Office
H. Atkins, MPS Commercial Applications Office
J. Horton, Space Sciences Laboratory (SSL)-Space Processing Deputy Director
Dr. R. Snyder, SSL-Separation Processes
Dr. A. Lehocsky, SSL-Crystals, Directional Solidification
J. Zweiner, SSL-Vapor Crystal Growth
Dr. D. Frazier, SSL-Fluids/Chemical Processing
Dr. R. Kroes, SSL-Crystals Grown from Solutions
M. Robinson, SSL-Immiscible Alloys
Dr. P. Curreri, SSL-Electromagnetic Containerless Processing
Dr. E. Etheridge, SSL-Glass Processing

Jet Propulsion Laboratory (JPL)

Dr. T. Wang, Containerless Processing Program Manager
Dr. D. Elleman, Containerless Processing Program Scientist
D. Kerrisk, Containerless Processing Chief Engineer
Dr. M. Weinberg, Glass Processing Scientist

Langley Research Center

Dr. J. Singh, Instrument Research Div (IRD)-Electronic Materials Processing
Dr. R. Crouch, IRD-Electronic Materials Processing
Dr. A. Fripp, IRD-Electronic Materials Processing
Dr. L. Melfi, Space Systems Div. - Molecular Wake Shield

Lewis Research Center

D. Stalnaker, Electrochemistry Branch - Bromine Phase Separation
T. Labus, Space Experiments Branch - Combustion Research

Johnson Space Center (JSC)

K. Demel, Earth Resources Applications - Materials Processing Laboratory

Goddard Space Flight Center (GSFC)

D. Suddeth, Flight Projects Directorate-Electrophoresis Separation

Lehigh University

Dr. MacCaulley, Monodisperse Latex Reactor

University Space Research Association

Dr. G. Rindone, Pennsylvania State University
Dr. D. Uhlmann, Massachusetts Institute of Technology
Dr. D. Day, University of Missouri-Rolla
Dr. N. Kreidl, University of Missouri - Rolla, Emeritus

Martin Marietta Labs

J. Venables, Materials and Surface Science
J. Skalny, Advanced Ceramics
R. Rodmer, Biosciences
W. Chen, Semiconductor Physics

Ball Aerospace Systems Division

R. Greenwood, STS MPS Carrier Program

International Nickel Co., Inc. (INCO)

Dr. J. Benjamen, Research Manager Metals Division

Aluminum Company of America (ALCOA)

R. McNiel, Forging Accounts Manager

Deere and Company Technical Center

J. Graham, Materials Technology Manager

Owens-Corning Fiberglas

Dr. G. Mishioka, Glass Research and Development

Eaton Corporation

L. Eltinge, Director of Research

Battelle Columbus Laboratories

K. Hughes, Office for Biomedical Space Research

9.4 RECOMMENDED COMPLEMENT

The first priority for Space Station MPS missions is the Materials Processing Laboratory. At that point a track record of continued successful experimentation would be required to attain a sufficient knowledge and experience level before the commercial industry could realistically be expected to become heavily involved in space processing.

The secondary priority then becomes the support of commercial industry in pursuing its space processing objectives. This includes providing guidance and assistance for their ground test program, as well as working with them in an integration capacity to develop their flight hardware for both their Development and Production phases. Finally, it requires the development of a servicing organization, either independent or within NASA, whose prime objective is to provide the transportation and support needs of space industrialization.

It is anticipated that the Space Station MPS Laboratory will cost about $350 million when fully equipped in FY1984 dollars. This is a larger budget than MPS has been allocated in the past, but when spread over a four year period is certainly credible and feasible. This estimate is based upon the Laboratory envolving a Spacelab derivitive, but does not include savings that might result from commonality with others Space Station modules. This estimate also excludes any Single Purpose Experiments. All commercial experiments and hardware will be required to pay their own way, although some Joint Endeavor Agreement-type arrangements may initially be required. Early additional funding is also required to develop an adequate experiment base for performance within the Laboratory. Each flight experiment must be preceded by a comparable, exploratory earth experiment to provide a baseline reference, as well as experiment design data.

As a final comment of affordability, it must be mentioned that the Russians, Germans, French, and Japanese are all currently investing more heavily in MPS than the United States. A Space Station Laboratory presents an excellent opportunity for quickly recovering lost initiative and technological advance, as well as opening the door to the international sharing of technologies.

The suggested approach for accomplishing these objectives is presented in the following paragraphs.

The first and paramount step is to affirm a strong commitment toward the Space Station MPS Laboratory and make it well known among the industrial and university communities that these capabilities will be available during the 1990's.

It will then be necessary to continue, and reemphasize, the educational effort of informing industry of the history and potential of MPS. Throughout this study it was confirmed that the MPS and its applications are neither well understood nor even known, by a large percentage of the industrial community. After learning of its potential uses, and knowing that there will be a continuing program, industry will become interested and involved in ground testing in anticipation of the expected availability and applications of the SS Laboratory.

Six to seven years prior to the Laboratory launch a MPS Laboratory Working Group should be established to confirm the needs of the entire research community, industry, universities, and NASA; verify the initial Laboratory hardware complement; and begin establishing acceptable management procedures. This group should also be instrumental in establishing a coordinated research program to efficiently utilize all of the available experiment facilities. It is important that the entire MPS community present a consistent front with a well defined Long Range Plan and a well established list of priorities.

The furnace and facility complement of the Laboratory should also begin development concurrently with the hardware development of the Laboratory. It would be worthwhile to fly these facilities on an STS development mission prior to the launch of the Space Station.

The Laboratory will require a low level of continual STS launch and return support for experiment samples. These samples could be transported in a Mid-deck type facility and not require any cargo bay volume.

The Initial Phase Space Station should contain the Materials Processing Laboratory, along with the Monodisperse Latex Reactor Facility, and up to four units of the MDAC-Johnson and Johnson Electrophoresis Operations in Space (EOS).

The Mission Model assumes six EOS units to be in production as free-flyers prior to the Space Station activation. Four units will then be mounted on the SS, with the SS based TMS providing resupply capabilities to all ten units every six months. Only four EOS units can be accommodated by SS because of its power and architectural limitations. An additional six units may then be required on an EOS Platform, with the original six free-flyers phased out of production as their 5-year design lives expire.

It was assumed that twenty operational missions lasting 25 days each and requiring crew participation to resupply the hardware and initiate each production sequence would be required for the commercial Monodisperse Latex Reactor Facility.

The Mission Model for the Evolutionary Phase of the SS contains Single Purpose Research Experiments and MPS Commercial Development Units.

The Single Purpose Experiments include hardware to perform those experiments that cannot be accommodated by the basic complement of Laboratory facilities. The Model assumes there will be ten (10) such experiments, each operated for a 60-day period in the Laboratory and then returned to earth.

The Commercial Development Units are built as the intermediate step between a successful MPS experiment and a full-scale commercial/production facility. Their purpose is to verify product quality for large-scale production processes that have been derived from basic experiments. Crew members can adjust the hardware control parameters based upon production run results. The Mission Model assumes fifteen (15) of these units, each operated for a 60 day period in the Laboratory and then returned to earth.

The Mission Model for the Ultimate Phase Space Station include the MPS Commercial Production Units. These commercial units may be located on or within the Space Station if their utility requirements are not excessive. However, their power or process requirements will probably require them to be colocated on an MPS Platform that is operationally supported by the SS and its TMS. The Model assumes twenty (20) of these units prior to the year 2000, requiring servicing/resupply every 90 days, and designed for a 5 year life.

9.5 COMPOSITE REQUIREMENTS

The Research Laboratory would be a Spacelab-type module sized for a partial Orbiter cargo bay launch capability--eight meters in length and 4.6 meters in diameter, weighing 8,000 kilograms. Its docking port/entry way would attach to the SS Main Body Section. Its typical operating power requirement would be 6,000 watts, with 8,000 watts its peak demand.

The Laboratory crew requirements have been anticipated at one crewman for 50 percent of the work day to service and resupply the facilities, as well as to initiate, monitor, and adjust the hardware to accommodate the processing sequences.

The four EOS units all attach to a Multiple Docking Port on the SS. Each unit weighs 4,550 kilograms and is 2.5 meters in length by 4.3 meters in diameter. Each unit also requires 3,500 watts of electrical power. The only crew support required for those units is for TMS control during resupply and installation operations.

The EOS and MPS Platforms will require TMS servicing/resupply support from the Space Station.

The traffic model for all MPS operations is as shown in Figure 9.5-1.

9.6 BENEFITS ASSESSMENT

The foremost benefit of the Space Station for Materials Processing in Space will be the enormous advancement in scientific knowledge and experience resulting from the Research Laboratory. An indepth understanding of the physical phenomena affecting low gravity materials processing will allow more purposeful experimentation in defining space processing techniques that are economically advantageous.

The second benefit is in providing a permanent facility that allows the testing of commercial processes, both at the research and development levels.

The third benefit will be the provision for an operational capability to support commercial MPS production both onboard the Space Station and on the MPS Platforms.

The ultimate payoff will then become a reality when new consumer goods are available in the marketplace as a direct result of their manufacture in space, or the result of improved processes derived from MPS. Industry requires some assistance in reaching this ambition, and that provides the aerospace community with an excellent opportunity to demonstrate its value and capabilities to the nation. That important first step is a strong NASA commitment.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
MPS Research Laboratory		→									→	
Monodisperse Latex Reactor		→									→	
- Resupplies			2	3	3	2	2	2	2	2	2	20
MDAC/J&J EOS												
- Free Flyers*	5	1 →					→					6
- SS TMS Resupplies		6	12	11	8	4	1					42
- SS EOS			4 →								→	4
- TMS Resupplies			4	8	8	8	8	8	8	8	8	68
- Platform EOS				6 →							→	6
- TMS Resupplies				6	12	12	12	12	12	12	12	90
MPS Commercial Development Units				1	2	2	2	2	2	2	2	15
MPS Commercial Production Units						2	3	4	5	3	3	20
- TMS Resupplies						4	12	22	36	48	54	176

* Launches Began in 1988

Figure 9.5-1 Space Station MPS Traffic Model

10.0 COMMUNICATION

Objectives - In 1965 "Early Bird" became the first commercial communications satellite ever launched. It weighed all of 38 kilograms, generated 40 watts of power, and was designed to last 1.5 years. In March, 1983 the first TDRS (Tracking and Data Relay Satellite) will be launched at 2250 kilograms, producing over 1800 watts of power, and designed to operate in three different frequency bands for 10 years. The communications industry has come a long way and is an excellent example of successful commercial utilization of space technology.

The cumulative commercial investment in U.S. communication satellite systems, including their ground stations, has grown from $170 million in 1974 to approximately $1.6 billion in 1982. This success appears certain to continue for at least the next 20 years, with or without a Space Station. It is impossible to justify Space Station as necessary for the development or continuation of the communications industry. There are, however, economic and technology development opportunities that offer distinct advantages when Space Station becomes a reality.

Industry Objectives - The communications industry as it applies to Space Station is comprised of three general categories: the commercial communications satellite industry, the military communications satellite industry, and the manned spacecraft communications techniques for crew-to-crew contact and teleoperator control.

The manned spacecraft communications techniques represent a utility derived from Space Station, rather than a requirement for it. Certainly technology developments in this area will be tested and utilized on-board Space Station, but they do not require any unique accommodation capabilities.

The military communications satellite industry has essentially the same technical objectives as the commercial industry, with the addition of technologies like anti-jamming capability. However, these also do not require any unique Space Station capability. Therefore, the discussions in this section will be directed toward the commercial communications industry, yet will be considered to include all communications categories.

The objective of this section then is to understand and quantify the potentials of a SS to contribute to the continued technological development for communication satellite systems and to improve the economic effectiveness of the satellites as well as their space delivery system.

The primary objective of the satellite communications industry is to efficiently accommodate the continuously expanding national and international communications market. INTELSAT has experienced a growth rate of 25 percent each year throughout the past decade. That is probably an optimistic projection for total market growth through the year 2000, but it is feasible and represents an upper bound for study purposes. The restricting factors that may preclude this growth are the limited quantity of satellite positions within the usable geostationary arc and the limited usable frequency spectrum. For example, the usable geostationary arc for North American traffic is about 70°. Current FCC regulations require a minimum separation distance of 4° for C-Band satellites, and 3° for Ku-Band satellites. There are already 23 satellites utilizing this space, with eight additional scheduled for launch this year. The geostationary arc is indeed a limited resource and could be filled over North America by 1990 if satellite efficiencies do not improve. The allocated commuication satellite frequency bands are listed in Table 10.0-1.

The derived objective then is to increase the efficiency of communication satellites to better utilize the available space. The following technology areas are being pursued to meet that goal:

1) Improvement in antenna design to reduce intersatellite interference and allow a 2° spacing of satellites,

2) Utilization of new frequency bands, such as the 30/20 GHz technology being developed by the Advanced Communications Technology Satellite (ACTS) and already flown by the Japanese,

3) Increased utilization of frequency reuse techniques, such as orthogonal polarization, Time-Division Multiple Access (TDMA), and Frequency-Division Multiple Access (FDMA),

4) Increased utilization of multiple beam antennas and on-board switching,

5) Increased utilization of direct satellite-to-satellite relays, and

6) Increased size of satellites to carry more transponders and incorporate more frequency bands.

While improvement in all of these technologies will be accomplished prior to Space Station, there will continue to be an on-going effort to further enhance efficiencies, similar to increases in computer speed and capabilities over the years. An illustration of the improvement in satellite efficiencies over the past eighteen years is shown in Figure 10.0-1.

Another industry objective is to develop new markets to provide for consumer needs. Examples of these are the Direct Broadcast Satellites (DBS) as another form of pay-TV distribution, the Mobile Satellite Program for providing mobile telephone service to remote areas, and the Search and Rescue Payloads used for locating downed aircraft.

Table 10.0-1
Communication Satellite Frequency Bands

Band	U.S. Allocation	Satellites	Maturity
UHF (240-400 MHz)	Military	Fltsat, Leasat, Milstar	Mature
L (1.5 - 1.6 GHz)	Commercial	Marisat	Growing
C (6/4 GHz)	Commercial	Intelsat, Anik, Satcom	Mature
X (8/7 GHz)	Military	DSCS, NATO	Mature
Ku (14/11 GHz)	Commercial	Intelsat, SBS, TDRS	Growing
KA (30/20 GHz)	Comm & Mil	ACTS, Milstar	Development
Q (43-45 GHz)	Military	Tacsat	Research

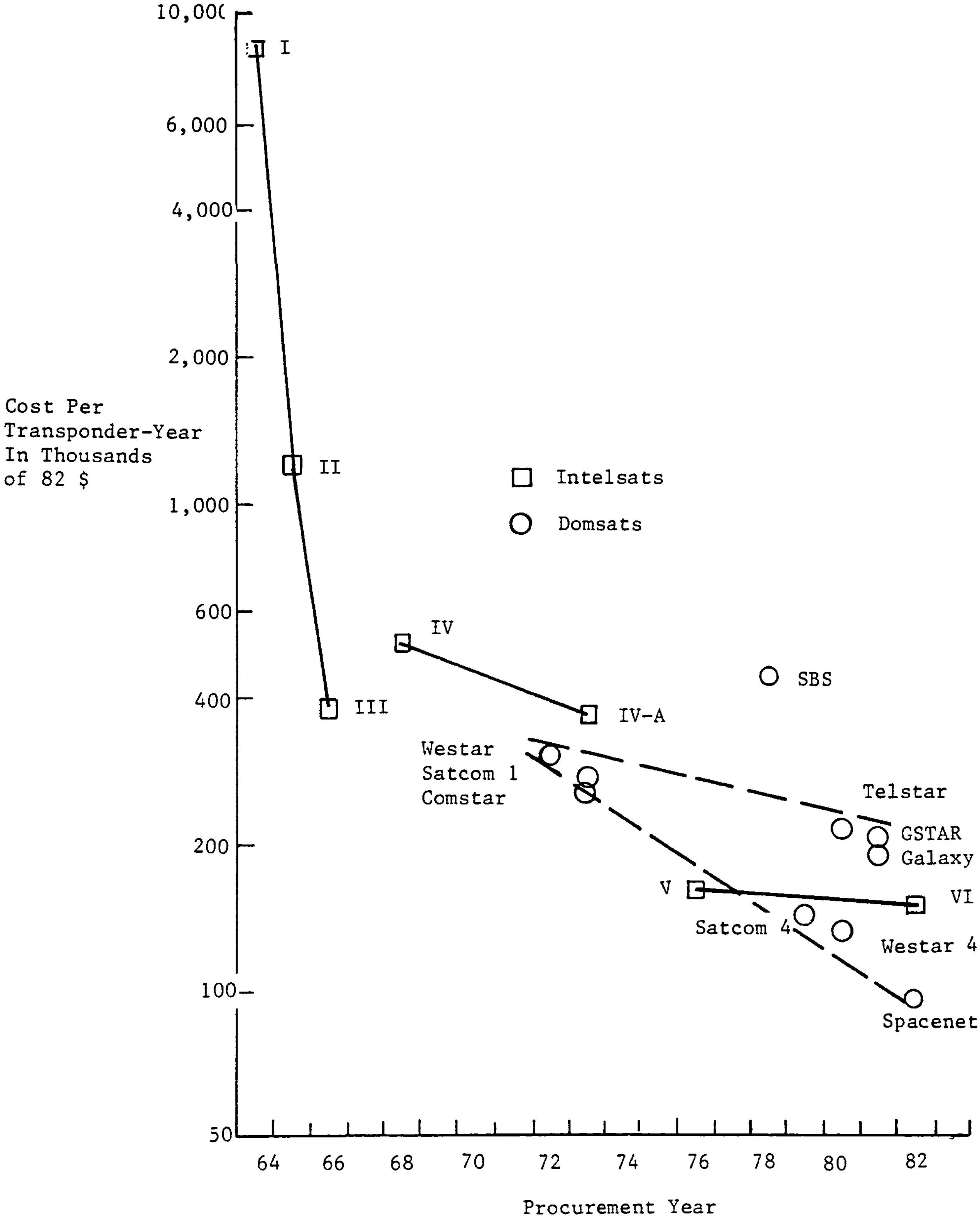


Figure 10.0-1 Satellite Investment Cost Per Equivalent Transponder (36 MHz Bandwidth)

10.1 SPACE STATION'S ROLE

There are several Space Station applications that would benefit the communications industry. The Space Station could be used as an orbital antenna range for testing new hardware designed to satisfy the first five objectives. New equipment, e.g., antennas, receivers, transponders, and switching circuits could be transferred to SS for test eliminating the need for dedicated satellites to demonstrate new technologies and capabilities.

The most significant role the Space Station could perform in advancing communication satellite systems is that of improving their launch services. The SS could become an operational base for reusable Orbital Transfer Vehicles (OTV) that could boost commercial satellites from low earth orbit, where they were delivered to the SS by shuttle, to their operational position in geosynchronous orbit. Typically communications satellites utilize a solid propellant, expendable upper stage with a maximum capability of boosting a 2,000 kilogram payload to GEO, and an expendable Apogee Kick Motor to circularize their orbit. As satellites continue to grow in size, larger upper stages are required, and it would soon become economically advantageous to develop a reusable upper stage that is not expended after a single launch. This is the same logic that led to the development of the Space Transportation System (STS). The following step is to maintain the reusable upper stage in low earth orbit and eliminate the need for its continual transfer between earth and low earth orbit. This concept develops into the Space Station based reusable OTV being the most economical means for launching satellites to geosynchronous orbit, as shown in Figure 10.1-1, and further detailed in Section 6.4 of Volume III. Given the reusable OTV capability, further scenarios develop to justify GEO refueling and servicing of communications satellites as a method for extending their performance lifetime. This becomes feasible since overall satellite weight becomes less critical and the additional hardware required for refueling can be accommodated with little penalty.

These scenarios raise the possibility of having the communications satellite industry provide, or at least contribute toward, a low earth orbit service station and reusable OTV. Our study efforts have not uncovered any communication industry organization willing to do so at this time. Existing communications carriers have their satellites in orbit and assume they will be able to replace them with next generation technology. They are profitably serving a developed market and see no advantage in disturbing the status quo, or risking significant capital investment at this time. The general attitude of the communications industry is one of "wait and see". If NASA demonstrates a new capability, the industry will then perform trades to compare its cost and risk benefits to consider utilizing the new capability. This attitude may gradually shift with the success of proposed cost sharing programs like ACTS (Advanced Communication Technology Satellite) and M-SAT (Mobile Satellite).

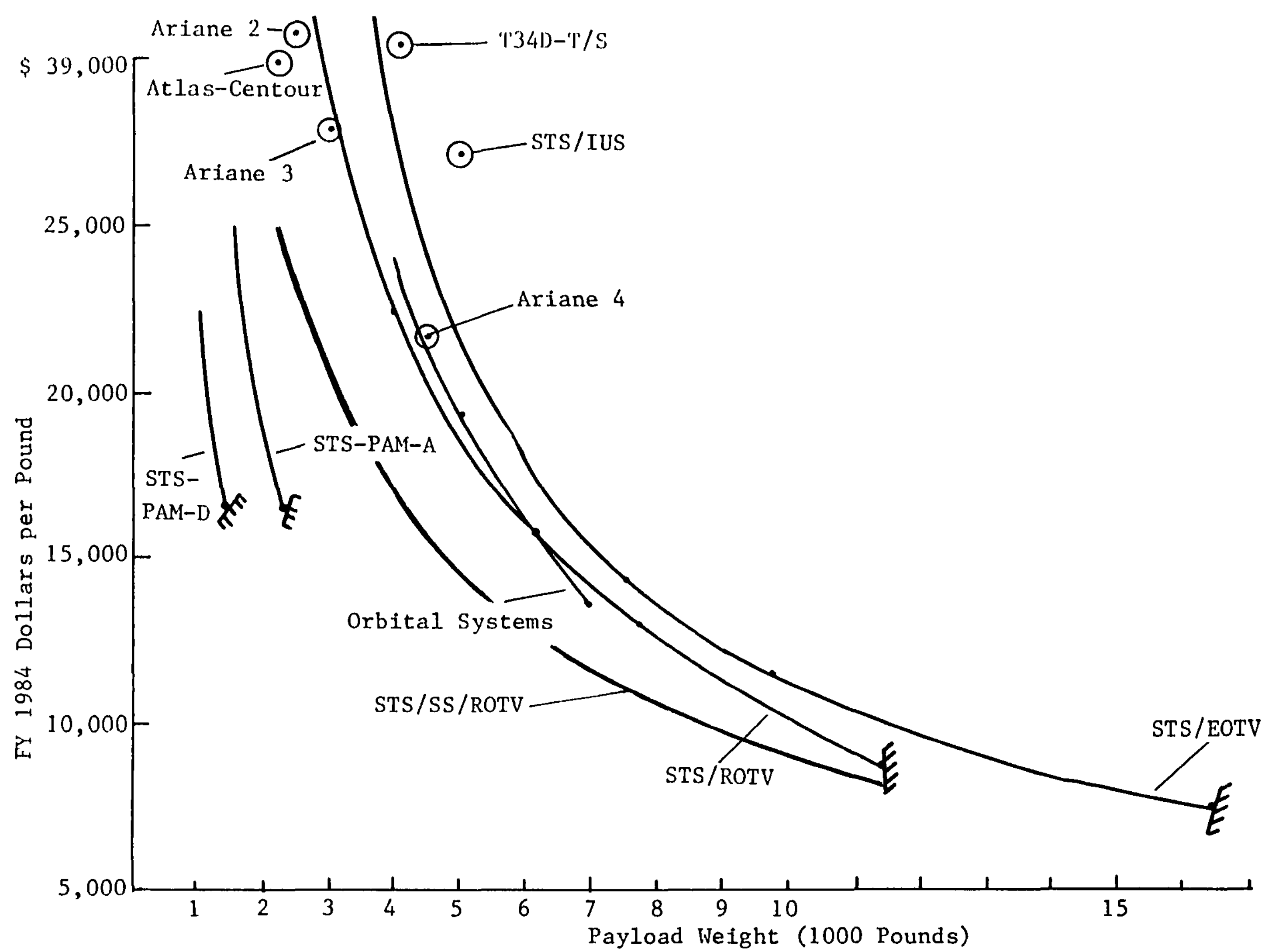


Figure 10.1-1 Comparative GEO Transportation Costs

A final, and controversial, objective is the development of large antenna platforms. These antenna platforms would combine the functions of many individual satellites into one orbital location and take advantage of a single attitude control and power subsystem for all payloads. The technologies necessary to assemble and control such platforms, and to limit antenna interference are not yet available. But the proposed Experimental Geostationary Platform (XGP) provides an important first step in developing these capabilities. Communications hardware improvements are delaying the necessity for these combined function platforms, but they appear to be an inevitable and desirable future development.

10.2 MISSION MODEL

The Space Station Communications Mission Model assumes the need for the development and economic advantage of a reusable OTV. Without an economical OTV there is no foreseeable need for Space Station to be involved in the launch/operation of communications satellites.

Following this premise the Model includes those new generation satellites that could be designed compatible for reusable OTV launch after 1990. The 1981 Battelle High Traffic Model was chosen as the basis for this listing. With the current trend, and presumed launch capability for larger, heavier communications satellites, each new generation was assigned a higher weight and increased payload capability. This trend is shown in Figure 10.2-1. It was also assumed that geosynchronous orbit refueling would become advantageous for extending satellite life, therefore, many of the post-1994 satellites include this capability.

The Communications Model though somewhat arbitrary, was prepared to be a representative estimate to use in sizing the accommodations necessary for effective SS utilization. No approved model exists that identifies the size of communication satellites when their design is not constricted by expendable launch vehicle fairings and existing upper stage capabilities.

No attempt has been made to update this model as individual program plans have changed since the initiation of this Study. Satellite Colombia is still contained here even though the program has been cancelled, while the new program of Ford Aerospace Services is omitted. The Model is intended only to provide size and quantity estimates for commercial communication satellites through the 1990s. It does not include military or maritime satellites. The Space Station Mission Model is shown in Table 10.2-1.

10.3 USER MISSION DATA/CONCEPTS

The Communications objectives, Mission Model, and Space Station requirements were compiled after teleconferences/consultations with the following individuals:

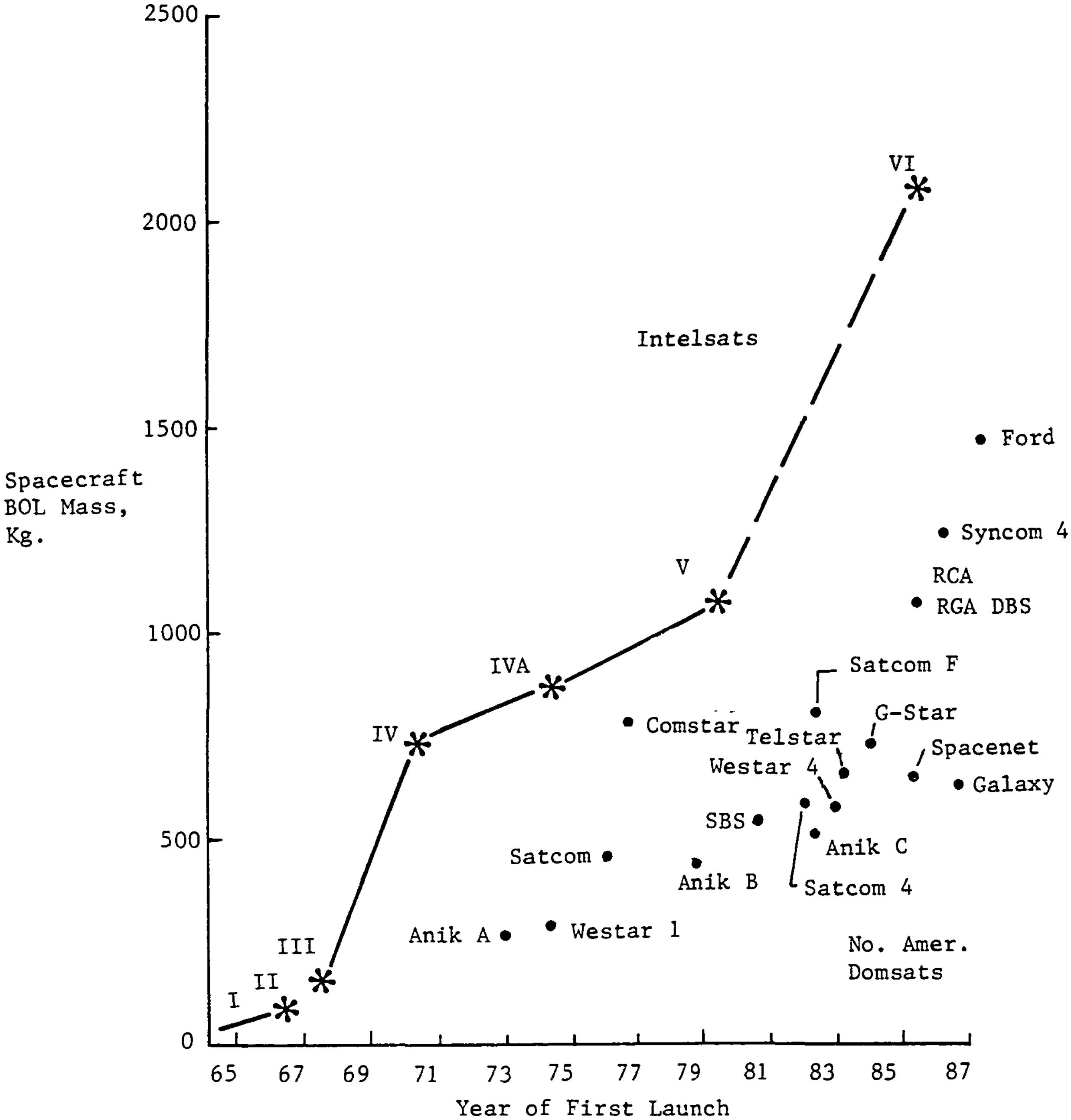


Figure 10.2-1 Trend in Communication Spacecraft Mass

Table 10.2-1 Commercial-Communications - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	ORBIT PARAMETERS: INCLINATION USEFUL	ORBIT PARAMETERS: ALTITUDE, km OPTIMUM	ORBIT PARAMETERS: ALTITUDE, km USEFUL	COMPLEMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	SS SUPPORT FUNCTIONS: ATTACHED	SS SUPPORT FUNCTIONS: PLATFORM	SS SUPPORT FUNCTIONS: FREE SAT	SS SUPPORT FUNCTIONS: SERV. RETREV	SS SUPPORT FUNCTIONS: SERV. REMOTE	SS SUPPORT FUNCTIONS: RESUPPLY	SS SUPPORT FUNCTIONS: LAUNCH	SS SUPPORT FUNCTIONS: ASSEMBLY	ALIGNMENT	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
XGP-Experimental Geostationary Platform NASA-MSFC MMCX-1001	C2AH	LV	0		GEO			High (Planned)	Evol. 1992 Affordable	Devel	5840 (16 Yrs)	1		X							X	X		X	5450 KG
SARSAT-Search and Rescue Mission NASA-HQ MMCX-1002	C2AJ	LY	90	Above 57	926	Any	NOAA COS-PAS	Operational	Initial 1990 Affordable	Application	7300 (20 Yrs)	1	X		X		X		X						45 KG
ODSRS-Orbiting Deep Space Relay Station NASA, JPL MMCX-1003	C2AK	MD	0		GEO		Deep Space Probes	Opportunity	Evol. 1998	Application	7300 (20 Yrs)	1		X						X	X	X	X	X	8500 KG
Commercial Communication Satellites MMCX-1004	C2A-C2Z C2AA-C2AG	Many NA-RJ	0		GEO			Operational	Initial 1990 Affordable	Commercial		145	X					X			X	X			900-4600 KG

Table 10.2-1 Commercial-Communications - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS PER DAY	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
XGP-Experimental Geostationary Platform MMCX-1001	0.1	0.1											9.0	4.0	4.0	5450	2	416	16	30 X 35 X 20 m Deployed
SARSAT-Search and Rescue Mission			Inertial					100/24					0.5	0.5	0.5	45				
ODSRS-Orbiting Deep Space Relay Station MMCX-1003													28	18	25	8500		260		Assembled Dimensions 3 STS Launches
Commercial Communication Satellites MMCX-1004																900-4600		208		

NASA Headquarters

T. McGunigal, Search and Rescue Program
G. Knouse, Mobile Satellite Program
H. Fosque, Orbiting Deep Space Relay Station
L. Holcomb, Laser Communications

Marshall Space Flight Center (MSFC)

T. Carey, Experimental Geostationary Platform
R. Durrett, Experimental Geostationary Platform

Goddard Space Flight Center (GSFC)

J. Schwartz, Tracking and Data Relay Satellite and Tracking and Data Acquisition System

Jet Propulsion Laboratory (JPL)

Dr. J. Layland, Orbiting Deep Space Relay Station
J. Randolph, Communications Technology Developments

Langley Research Center

W. Grantham, Large Antenna Development

RCA Astroelectronics

J. Blankenship, et.al., Advanced Programs Director

RCA American Communications

J. Schwarze, Space Systems Director
R. Setzer, Advanced Technology Engineering Manager

Hughes Aircraft Company, Space and Communications Group

Dr. H. Rosen, Engineering Vice President

General Electric - Valley Forge Space Division

M. VanHorn, Military Satellite Manager

Ford Aerospace

L. Cuccia, Space Advisory Committee

Communications Center of Clarksburg

W. Morgan, Consultant

COMSAT General Corporation

Dr. G. Gordon, Senior Staff Scientist

10.4 RECOMMENDED COMPLEMENT

The evolutionary approach for Space Station accommodation of Communications requirements begins with the launch of the Experimental Geostationary Platform (XGP)in 1992. XGP would provide the first operational demonstration using Space Station to assist in the deployment of its antenna booms and aligning the antennas prior to its boost to geostationary orbit.

This would soon be followed by implementation of the reusable OTV capability later is 1992. The XGP represents too heavy a payload (5450 kilograms) to use for the first OTV demonstration flight. However it seems preferable to use a NASA payload for this demonstration. Subsequent communications satellites could then plan on using the reusable OTV in multiples to utilize its maximum payload capacity. A reservicing demonstration of XGP could be scheduled for the 1994-95 timeframe. Commercial satellites could have previously implemented refueling design concepts and begin refueling operations in 1996.

The Search and Rescue payload would be incorporated into the polar orbiting Earth Observations Platform in 1996.

The Orbiting Deep Space Relay Station does not appear to be economically feasible at this time, but should that criterion change it could become the first large space structural assembly demonstration for SS in the late 1990s or early 2000.

The Communications Satellite Traffic Model is shown in Figure 10.4-1.

10.5 COMPOSITE REQUIREMENTS

The Space Station facility requirements for the communications industry primarily includes those operational capabilities associated with the reusable OTV launch and geosynchronous orbit refueling operations. Some limited command and telemetry capability will be necessary for spacecraft checkout after OTV mating, and a docking port with extra vehicular activity (EVA) accessibility will be necessary for deployment and alignment of antenna booms.

The only other facilities required would be an external mounting location with power services for on-orbit testing of new antennas/transponders. This location should be earth facing for life testing, even though most performance testing would interface with Teleoperator Maneuvering System (TMS) mounted hardware.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total
OTV Compatible Satellite Launches											
- 900 kg				1		1					2
- 1350 kg	2	7	11	17	16	13	12	8	2		88
- 2275 kg		1	2	2	3	2	1				11
- 2725 kg					2	2					4
- 4000 kg				4	7	8	8	7	3	1	38
- 5450 kg			1								1
Total	2	8	14	24	28	26	21	15	5	1	144
OTV Launches	0	0	4	12	12	12	12	8	3	1	64
Remaining* Satellites	2	8	6	0	4	2	0	0	0	0	22
GEO OTV Refueling Missions	0	0	0	1	0	0	1	1	1	1	5
No. of Satellites	0	0	0	1	0	0	2	8	11	10	32

*SS Operational Capability is Limited to One Communications OTV Launch per Month

Figure 10.4-1 Space Station Communications Traffic Model

10.6 BENEFITS ASSESSMENT

The key benefit that a Space Station contributes to communications is that of improving the economies of satellite delivery by introducing a SS based resusable Orbital Transfer Vehicle. Other benefits to communications provided by the Space Station are maintenance and servicing of GEO satellites using the OTV and technology development that will lead to a new plateau in communications systems; the large antennae platforms.

The communications industry has been unable to identify any firm requirements for Space Station, but it becomes a primary beneficiary of its capabilities after they are developed.

11.0 TECHNOLOGY DEVELOPMENT

11.1 TECHNOLOGY OBJECTIVES

The technology development missions identified in this study report are considered to be typical examples of how the space station capabilities can be utilized to support the development of a wide variety of space technology applications. It is anticipated that many more applications will develop as the space station is developed and technology development organizations become aware of the unique capabilities it can provide.

The primary mission selection criteria that has been applied is to address the advancement of a general area of space operating technology rather than the solution to a specific program design problem. While the technology developments may be beneficial to the evolution of the space station, such direct applicability has not been used as a reason for the selection of missions.

Missions have also been selected to cover a wide variety of space technology disciplines in order to illustrate the range of adaptability of the space station to these development endeavors. The selected missions are listed in Table 11.1-1 and are grouped by discipline area. The missions are identified by the Langley Data Base number, and the proposed year of activity initiation is also shown.

Table 11.1-1 Technology Development Missions Grouped By Discipline

Discipline Area	Title	Langley Data Base No.	Performance Year
Structures	- Large Structures Technology	MMCX-2022	92
	- Structural Strain Monitoring	MMCX-2018	91
	- Thermal Driven Shape Control	MMCX-2001	95
Power Systems	- Large Space Power System Technology Demo	MMCX-2012	94
	- Low Cost Solar Panel Technology	MMCX-2009	93
	- Solar Array Plasma Effects	MMCX-2013	93
Attitude Control	- Attitude Control System Development	MMCX-2015	92
	- Tether Dynamics Technology	MMCX-2023	95
Thermal Control	- Advanced Radiator Technology	MMCX-2014	95
Propulsion Systems	- Fluid Management Technology	MMCX-2010	91
	- Low Thrust Propulsion	MMCX-2011	94

Table 11.1-1 (Concluded)

Discipline Area	Title	Langley Data Base No.	Performance Year
Communications/ Tracking	- Laser Communications and Tracking	MMCX-2017	94
	- Antenna Range Facility	MMCX-2016	94
	- Large Antenna Development	MMCX-2002	93
Materials	- Spacecraft Materials Technology	MMCX-2020	92
Servicing Technology	- Satellite Servicing	MMCX-2021	92
	- OTV Servicing	MMCX-2008	92
Safety	- Fire Safety	MMCX-2019	90
Advanced Energetics	- Large Solar Concentrator	MMCX-2003	95
	- Solar Pumped Lasers	MMCX-2004	96
	- Laser-To-Electric Energy Conversion	MMCX-2005	96
	- Laser Propulsion Test	MMCX-2006	98
	- Solar Sustained Plasmas	MMCX-2007	96

11.2 TECHNOLOGY DEVELOPMENT MISSION MODEL

11.2.1 Technology Development/Rationale

The mission model designated for this study has been selected using the general criteria discussed in Section 11.1.

Also, those missions that were selected present a significant degree of integration challenge. The intent was to enlarge and develop the envelop of integration requirements for the station architecture analysis. Those missions which could be accommodated by easily integrated carry-on packages do not contribute significantly to this capability development and were, therefore, not included.

11.2.2 Technology Listings and Data

The selected mission model data sheets are shown in Table 11.2.2-1.

11.2.3 Analysis/Conclusions

The missions selected present a variety of integration challenges for the space station. The unique characteristics in each of the major discipline areas are as follows:

Structures - The capability to assembly large light weight structures in space is considered to be a fundamental technology requirement to achieve many of the proposed technology advancements. In addition the development of advanced stress strain monitoring and shape control capabilities is addressed.

Table 11.2.2-1 Technology Development - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE / LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV. RETREV	SERV. REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Thermal Shape Control Tech Dev NASA-LaRC MMCX-2001	011B	LB						Low (Opportunity)	Evol 1995 Affordable	Devel	30D	1		X		X	X							123 KG
Large Antenna Development NASA-LaRC MMCX-2002	08C	LC					08A 08D 08E	Low (Opportunity)	Evol 1993 Affordable	Devel	90D	3		X		X	X							Flt 1 = Short Baseline, 2 Antennas, 409 KG Flt 2 = TMS Deployed P/L, 227 KG Flt 3 = Addit 227 KG + Free Flyer Sat 8017 KG
Large Solar Concentrator NASA-LaRC MMCX-2003	09C	MA					06C 09D 09E 09F	High (Opportunity)	Evol 1995 Affordable	Devel		10		X		X	X							1500 KG
Solar Pumped Lasers NASA-LaRC MMCX-2004	09E	MB					06C 09C 09D 09F	High (Opportunity)	Evol 1996 Affordable	Devel	90D	3		X		X	X							1 Set Up Flt, 1996 = 600 KG Pointing System = 91 KG 2 Service Flts at 6 Mos = 68 KG ea 600 KG
Laser to Electric Energy Conversion NASA-LaRC MMCX-2005	09F	LS					06C 09C 09D 09E	High (Opportunity)	Evol 1996 Affordable	Devel	90D	4		X		X	X							Set Up Flt 1996 = 627 KG 3 Servicing Flts = 59 KG ea 627 KG
Laser Propulsion Test NASA-LaRC MMCX-2006	06B	LQ					06A 06B 09C 09D 09E 09F	High (Opportunity)	Evol 1998 Affordable	Devel	90D	1		X		X	X							273 KG
Solar Sustained Plasmas NASA-LaRC MMCX-2007	09D	LR					06C 09C 09E 09F	High (Opportunity)	1996 Affordable	Res	90D	1		X		X	X							250 KG
OTV Servicing Technology NASA-MSFC MMCX-2008	05A	LK					01A 03A 03B 03C	High (Candidate)	1992 Affordable	Devel	90D	6		X		X	X							Inherent in SS

Table 11.2.2-1 Technology Development - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS/DURATION MIN	THERMAL: TEMP DEG C	THERMAL: TOLER	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW	MAINT/REPAIR CREW REQMTS: SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Thermal Shape Control Tech Dev MMCX-2001																	123					
Large Antenna Development MMCX-2002			Inertial Earth					1/24									8017					
Large Solar Concentrator MMCX-2003			Solar														1500					
Solar Pumped Lasers MMCX-2004			Solar														600					
Laser to Electric Energy Conversion MMCX-2005			Solar														627					
Laser Propulsion lest MMCX-2006																	273					
Solar Sustained Plasmas MMCX-2007																	250					
OTV Servicing Technology MMCX-2008																	Inherent in SS					

Table 11.2.2-1 Technology Development - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMPMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE LAUNCH YRS DESIRED AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV.: RETREV	SERV.: REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Solar Panel Technology NASA-GSFC MMCX-2009	09A	LT	Any				09B	Med (Opportunity)	Initial 1993 Affordable	Devel	90	4		X		X								4 Solar Module Replacements 9 KG ea every 3 months 109 KG
Fluid Management Technology NASA-LeRC MMCX-2010	03B	KI	Any				01A 03A 03C 05A	High (Candidate)	Initial 1991 Affordable	Devel	730	5		X		X	X							4 Servicing Flights, 341 KG ea every 6 months 3955 KG
Low Thrust Propulsion Technology NASA-LeRC MMCX-2011	06A	KK	Any		Any	TBD Drag Below $10^{-3}g$	06B 06C	High (Opportunity)	Evol 1994 Affordable	Devel	90D	3		X		X	X	X						2 Flights for Support, 41 KG ea every 6 months 75 KG
Large Space Power System NASA-LeRC MMCX-2012	09B	KL	Any		300-400	Any	09A	High (Opportunity)	Evol 1994 Affordable	Devel	730D	1		X		X	X						X	6 Month Minimum Stay 200 KG and Weight of Array
Solar Array Plasma Effects NASA-LeRC MMCX-2013	09G	KM	Any				06A 06C	High (Opportunity)	Evol 1993 Affordable	Devel	180	2		X		X	X							Set Up Flt Racks = 400 KG, Array = 341 KG, Thruster = 45 KG } 786 KG Servicing flights at 6 months 52 KG
Advanced Radiator Technology NASA-LeRC MMCX-2014	011A	KN	Any		Any			High (Opportunity)	Evol 1995 Affordable	Devel	90D	2		X		X	X							2 Flights with Total Replacement 52 KG ea, 90 days ea 52 KG
Attitude Control System Development JPL MMCX-2015	07A 07B 07C	KP KQ KR	Any				02A 07A 07B 07C 07D 07E	High (Opportunity)	Initial 1992 Affordable	Devel	90	3+		X		X	X							3 Extra Flights, 182 KG Up and Down (Total Replacement) 182 KG
Antenna Range Facility NASA, JPL MMCX-2016	08A	KS	Any		Any		08C 08D 08E	High (Opportunity)	Evol 1994 Affordable	Devel	90D	3		X		X	X							Antenna Onboard SS/Transmitter on TMS 2 Setup Flights 22727 KG ea. 3 Service Flights 455 KG ea over 2 years 22727 KG

Table 11.2.3-1 Technology Development - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER ω / DURATION HRS	POWER & DURATION: OPER POWER ω / DURATION HRS	POWER & DURATION: STDBY POWER ω / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP DEG C	THERMAL: TOLER	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Solar Panel Technology MMCX-2009			Solar														109				
Fluid Management Technology MMCX-2010			N/A	N/A	N/A	N/A											3955				
Low Thrust Propulsion Technology MMCX-2011																	75				
Large Space Power System MMCX-2012			Solar														200				
Solar Array Plasma Effects MMCX-2013			Solar														786				
Advanced Radiator Technology MMCX-2014																	52				
Attitude Control System Development MMCX-2015																	182				
Antenna Range Facility MMCX-2016																	22727				

Table 11.2.2-1 Technology Development - Space Station Mission Model

MISSION / AGENCY OR SPONSOR / LaRC CODE	SSMM REF	COMM REF	ORBIT PARAMETERS: INCLINATION OPTIMUM	INCLINATION USEFUL	ALTITUDE, km OPTIMUM	ALTITUDE, km USEFUL	COMPLIMENT MISSIONS	PRIORITY	SS PHASE: LAUNCH YRS DESIRED / AFFORDABLE	MISSION TYPE	MISSION DURATION (DAYS)	FREQUENCY	STATUS: EXIST	STATUS: NEW	SS SUPPORT FUNCTIONS: ON BOARD	ATTACHED	PLATFORM	FREE SAT	SERV. RETREV	SERV. REMOTE	RESUPPLY	LAUNCH	ASSEMBLY	CRITICAL INTEGRATION PARAMETERS AND OTHER CONSIDERATIONS
Laser Comm, Track and Ranging NASA, JPL MMCX-2017	08B	KT	Any		Any			High (Opportunity)	Evol 1994 Affordable	Devel	90	3		X		X								2 Service Flights 45 KG ea 90 Day Interval 532 KG
Structural Strain Monitors NASA-LaRC MMCX-2018	02A	KX	Any				07A 07C	High (Opportunity)	Initial 1991 Affordable	Devel	·365	3		X		X	X							Transducers Delivered with Initial SS 45 KG
Fire Safety Technology NASA-LeRC MMCX-2019	010B	KJ	Any					High (Opportunity)	Initial 1990 Affordable	Devel	90	3		X	X		X							Initial Flight Setup 545 KG 2 Servicing Flights (Exp Revisions) 364 KG ea 1955 KG
Spacecraft Materials Technology NASA-LaRC MMCX-2020	012A	KY	Any				012B 012C	High (Opportunity)	Initial 1992 Affordable	Devel	Cont			X		X	X							Long Duration Exposure 284 KG Includes Materials and Mounting Facility 284 KG
Satellite Servicing Technology NASA-MSFC MMCX-2021	01A	LJ	Any				03A 03B 03C 05A	High (Opportunity)	Initial 1992 Affordable	Devel	90	6		X		X				X	X			Inherent in SS
Large Structure Technology NASA, JPL MMCX-2022	02B	KO	Any				02A, C,D, E 07A-E	High (Opportunity)	Evol 1992 Affordable	Res	90	4		X		X	X							Set Up Flight 1992 = 27273 KG 2 Servicing Flights 1996 = 455 KG ea 27273 KG
Tether Dynamics Technology NASA-JSC MMCX-2023	04A	LM	Any					High (Opportunity)	Evol 1995 Affordable	Devel	30	4	X		X			X						1st Flight 250 KG Tether 205 KG P/L 455 KG 3 Flights at 6 Mos, 205 KG P/L ea 455 KG

Table 11.2.2-1 Technology Development - Space Station Mission Model

MISSION / LaRC CODE	ACCEL. SENSITIVITY, g: SUST	ACCEL. SENSITIVITY, g: TRANS	POINTING: VIEW DIRC	POINTING: FOV DEG	POINTING: ACCUR ARC-SEC	POINTING: STABL ARC-SEC/SEC	POWER & DURATION: PEAK POWER w / DURATION HRS	POWER & DURATION: OPER POWER w / DURATION HRS	POWER & DURATION: STDBY POWER w / DURATION HRS	DATA/COMM: COMMAND RATE KBPS UPLINK/DNLINK	DATA/COMM: RECORDING RATE KBPS / DURATION MIN	THERMAL: TEMP TOLER DEG C	PHYSICAL CHARACTERISTICS: LENGTH M	PHYSICAL CHARACTERISTICS: WIDTH M	PHYSICAL CHARACTERISTICS: HEIGHT M	PHYSICAL CHARACTERISTICS: MASS KG	MAINT/REPAIR CREW REQMTS: CREW	MAINT/REPAIR CREW REQMTS: SIZE	MAINT/REPAIR CREW REQMTS: SERV FREQ WKS	MAINT/REPAIR CREW REQMTS: MAN HRS PER SERVICE	SPECIAL CONSIDERATIONS
Laser Comm, Track and Ranging MMCX-2017																532					
Structural Strain Monitors MMCX-2018																45					
Fire Safety Technology MMCX-2019																1955					
Spacecraft Materials Technology MMCX-2020																284					
Satellite Servicing Technology MMCX-2021																Inherent in SS					
Large Structure Technology MMCX-2022																27273					
Tether Dynamics Technology MMCX-2023								1								455					

Power Systems - The emphasis in this area is on the development of large area high voltage solar array technology. Additional areas to be developed are the construction of lower cost solar arrays and the interaction of plasma generating devices (such as ion thrusters) on solar arrays. The interactive nature of these development missions has been a consideration in their selection.

Attitude Control - The unique characteristics of the space station (assembled modules) will be used to explore and develop new concepts for sensing and control of such assemblies. In addition the guidance and control technology to adapt the tethered platform concept to space station applications will be explored. The operational integration of these tethered platforms will also be a subject of vital importance to station technology.

Thermal Control - The interest here is in the development of advanced radiator technology with significantly increased reliability and durability. The selected example is to explore the applicability of liquid droplet radiators. The inherent advantages of such a concept are the constant renewal of the radiating surface and the insensitivity to puncture by micrometeorites.

Propulsion - The two major areas of emphasis selected are the development of fluid management technology and the development of low-level thrusters. The fluid management capability is a prerequisite to proceeding with the on-orbit maintenance and servicing of a wide variety of operational programs.

The development of the low-level thruster technology is motivated by the need for a class of thrusters requiring the minimum amount of fuel expulsion when activated and the additional requirement to exactly compensate for drag forces on a real time matching basis. This capability will be of value for station keeping platforms and for those missions where extremely low levels of acceleration are required.

Communications/Tracking - The first area selected is the development of a laser communication and tracking system which would be of significant value in controlling and assisting the operation of free flying spacecraft in the vicinity of the station.

The construction of large lightweight antennas can be considered as a special application of the large structures technology discussed earlier. An additional objective addressed is the testing and characterization of antenna systems designed to operate in space. With many of these systems and particularly on the state of the art advances, ground based test ranges are too constraining and therefore not adequate to perform these tests.

Materials - The capability to perform long term exposure tests on a variety of materials and to monitor this degradation is the most direct application of the space station facility.

Servicing Technology - Of all the newly emerging and prerequisite technologies, on-orbit servicing represents one of the key driving and most compelling technology; i.e., undoubtedly new concepts will emerge and modifications will continue as the technology evolves and matures. The space station represents an ideal location for such a developmental test bed to support these efforts.

Safety - With the expanding range, complexity and scale of manned space operations there is a need for establishing a test bed facility to investigate flammability characteristics of materials and the methods of detecting, controlling and extinguishing fires.

Advanced Energetics - This group of missions was selected to illustrate the interactive aspects of a group of investigations, all of which require the presence of a large aperture solar concentrator.

11.3 TECHNOLOGY DEVELOPMENT MISSION DATA/CONCEPTS

The selected mission model was primarily based on the set of Candidate Technology Development Missions compiled by S.V. Manson of the NASA Headquarters staff. The candidate list was prepared at the NASA Field Centers and coordinated by the Technology Development Working Group.

We have assigned each of the candidate missions to an engineer analyst with an appropriate technical background. These analysts have contacted the mission originator for clarification and discussion as required to ensure an adequate understanding of the objective. In most instances these contacts have been made by phone, limiting personal visits to a few select cases.

Based on these contacts the list of candidate missions was consolidated and reduced to the list shown in Table 11.1-1. Due to the generic nature of these mission concepts little detailed information is available on the integration requirements at this time. A judicious amount of projected scoping and derivation of engineering estimates was performed to identify mass and volume envelopes. These estimates were used primarily to size the amount of STS traffic required. Where the information was not specifically required to support the architecture definition phase the data forms were left blank.

To the extent that the information on the objective was available the user data forms were completed and are presented in Appendix C.

11.4 TECHNOLOGY DEVELOPMENT RECOMMENDED COMPLEMENT

The recommended complement of technology development missions to be used as a basis for the space station architecture definition is listed in Table 11.1-1 and the recommended prioritization/scheduling is identified in the mission model data sheets, Table 11.2.2-1.

11.5 TECHNOLOGY DEVELOPMENT COMPOSITE REQUIREMENTS

Due to the defined objective of selecting a group of missions which cover a wide range of technologies, there is a corresponding broad range of integration requirements. There are areas of commonality in the need for support capabilities from the station as illustrated by the following examples:

Example 1 - The missions for Large Structures Technology, Large Space Power System Technology, Large Antenna Development and Solar Concentrator will all require an analogus capability to transport, assemble, mount and control large, light weight structures.

Example 2 - Fluid Management Technology, Satellite Servicing, OTV Servicing will all involve the technology of fluid management under low gravity conditions.

Example 3 - Tether Dynamics, Satellite Servicing and Laser Communications will all involve the capability to conduct operations with vehicles in the near vicinity of the station.

11.6 TECHNOLOGY DEVELOPMENT BENEFITS ASSESSMENT

The generalized benefits to technology development are derived from the availability of a test bed approach which permits alternate design approaches to be evaluated, optimized and proven before commitment of a program.

Most of the technology missions selected can only be demonstrated and studied in the environment and with the operational capabilities provided by the space station.

Some of the unique capabilities afforded by the space station to the implementation of the test bed concept are as follows:

1) Zero gravity environment,

2) Human operator participation in prototype operations prior to automation,

3) Capabilities for extended duration operations,

4) Space exposure environment (i.e., vacuum, solar illumination, radiation, atomic oxygen, thermal cycles), and

5) Capability to assemble and accommodate large unwieldy objects

These unique capabilities and aspects will support the development of a wide variety of space technology disciplines with the potential for significantly reducing development schedules and costs over alternative approaches.

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APPENDIX A ACRONYMS AND ABREVIATIONS

A	Angstrom
AC&S	Attitude Control and Stabilization
ACC	Aft Cargo Carrier
ACS	Attitude Control Subsystem
ACTS	Advanced Communications Satellite Corporation
AFB	Air Force Base
AHUT	Animal Holder and Unit Tester
AIAA	American Institute of Aeronautics and Astronautics
AIE	Advanced Interplanetary Explorer
AL	Airlock
ALCOA	Aluminum Company of America
AMIMS	Advanced Meteorological Infrared & Microwave Soander
AMPTE	Active Magnetosphere Particle Tracer Experiment
AO	Announcement Opportunity
AP	Action Potential
ARC	Arnold Research Center
ASE	Airborne Support Equipment
ASO	Advanced Solar Observatory
ASTO	Advanced Solar Terrestrial Observatory
ATP	Authority to Proceed
AXAF	Advanced X-Ray Astrophysics Facility
B	Billion
BASD	Ball Aerospace Division
BCK	Blood Collection Kit
BIT	Built-In Test

APPENDIX A ACRONYMS AND ABREVIATIONS

BITE	Built-In-Test-Equipment
BIU	Bus Interface Unit
BOL	Beginning of Life
BTS	Biotelemetry System
BYU	Brigham Young University
C	Core
c	Centigrade
Ca	Calcium
CB	Cargo Bay
C&DH	Command and Data Handling Subsystem
CDP	Coronal Diagnostic Package
CDR	Critical Design Review
CELSS	Controlled Environment Life Support System
CER	*Cost Estimating Relationship*
CF	Construction Facility
CG	Center of Gravity
CIT	California Institute of Technology
Cl	Chloride
CLIR	Cryogenics Limb Scanning Interferometer & Radiometer
CM	Command Module
CMD	Command
CMG	Control Moment Gryo
CMM	Composite Mission Model
CO_2	Carbon Dioxide
COBE	Cosmic Background Explorer

APPENDIX A ACRONYMS AND ABREVIATIONS

COMPMM	Composite Mission Model
COMSAT	Communications Satellite Corporation
COSMIC	Coherent Optical System Modular Imaging Collector
CR	Comet Rendezvous
CRM	Chemical Release Module
CRMF	Chemical Release Module Facility
CRO	Cosmic Ray Observatory
CRT	Cathode-Ray Tube
CSR	Comet Sample Return
CU	Colorado University
CZCS	Coastal Zone Color Scanner
DBS	Direct Broadcast Satellite
DBV	Derived Boost Vehicle
DDT&E	Design Development, Test and Evaluation
DEMS	Dynamic Environment Monitoring System
DMPS	Data Management and Processing System
DOD	Department of Defense
DRM	Design Reference Mission
DSN	Deep Space Network
DVM	Doctor of Veterinarian Medicine
EAAR	Earth Approaching Asteroid Rendezvous
ECG	Electrocardiograph
ECLS	Environmental Control Pipe Support
ECLSS	Environmental Control/Life Support Systems

APPENDIX A ACRONYMS AND ABREVIATIONS

ECS	Environmental Control System
EEG	Electroencephalogram
e.g.	Example
EKG	Electromyogram
ELS	Eastern Launch Site
EMC	Electromagnetic Compatibility
EMG	Electromyogram
EMI	Electromagnetic Interference
EMU	Extravehicular Mobility Unit
ENG	Electonystagnogram
EOL	End of Life
EOS	Electrophoresis Operations In Space
EOTV	Expendable Orbital Transfer Vehicle
EPS	Electrical Power
EPDS	Electrical Power and Distribution System
ERB	Earth Radiation Budget
ET	External Tank
ETCLS	Environmental and Thermal Control and Life Support
EUVE	Extreme Ultraviolet Explorer
EVA	Extra-Vehicular Activity
Exper	Experimeter
Expmt	Experimeter
fps	Feet per Second
FCC	Federal Communications Commission
FDMA	Frequency-Division Multiple Access

APPENDIX A ACRONYMS AND ABREVIATIONS

FF	Free Flyer
FILE	Feature Identification and Location Experiment
FLOPS	Floating Point Operations Per Second
FOC	Full Operating Capability
FOCC	Flight Operations Control Center
FOT	Faint Object Telescope
FSF	First Static Firing
FUSE	Far Ultraviolet Spectroscopy Explorer
FY	Fiscal Year
g	Gravity
GG	Gravity Gradient
G_Z	Vertical Gravity Acceleration Component
GaAs	Galium Arsemide
GEO	Geosynchronous Earth Orbit
GEOSTO	Geosynchronous Solar Terrestrial Observatory
GFP	Government-Furnished Property
GG	Gravity Gradiometer
GHZ	Gigadertz
GND	Ground
GPS	Global Positioning System
GPWS	General Purpose Work Station
GRIST	Grazing Incidence Solar Telescope
GRO	Gamma Ray Observatory
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center

APPENDIX A ACRONYMS AND ABREVIATIONS

GSS	Ground Support System
GSSI	Geosynchronous Satellite Sensor Intercalibration
GTE	Gamma Ray Timing Explorer
H	Hangar
H_2O	Water
H/W	Hardware
HM	Habitation Module
HMF	Health Maintenance Facility
HNE	Heavy Nuclei Explorer
HOL	Higher Order Language
I&C	Installation and Checkout
I/F	Interface
ID	Identification
INCO	International Nickel Company
INTELSAT	International Telecommunications Satellite Organization
IOC	Initial Operating Capability
IPS	Instrument Pointing System
IR	Infrared
IRAS	Infrared Astronomy Satellite
IRD	Instrument Research Division
IS	Imaging Spectrometer
ISP	Initial Specific Impulse
ISPM	International Solar Polar Mission
ISTO	Initial Solar Terrestrial Observatory
IUE	International Ultra Violet Explorer
IVA	Intravehicular Activity

APPENDIX A ACRONYMS AND ABREVIATIONS

J&J	Johnson and Johnson
JEA	Joint Endeavor Agreement
JHU	John Hopkins University
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
K	Potassium
Kbps	Kilobits Per Second
KG, kg	Kilogram
KSC	Kennedy Space Center
KW, kw	Kilowatt
lbm	Pounds
LAMAR	Large Area Modular Array Reflectors
LAMMR	Large Antenna Multifrequency Microwave Radiometer
LaRC	Langley Research Center
LBNP	Lower Body Negative Pressure
LBNPD	Lower Body Negative Pressure Device
LDR	Large Deployable Reflector
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LIDAR	Light Detection and Ranging
LiOH	Lithium Hydroxide
LM	Logistics Module
LMMI	Large Mass Measurement Instrument
LSEPS	Large Spacecraft Effects on Proximate Space

APPENDIX A ACRONYMS AND ABREVIATIONS

LSLE	Life Sciences Laboratory Equipment
LSLF	Life Sciences Laboratory Facility
LSM	Life Support Module
LSRF	Life Sciences Research Facility
LSRM	Life Sciences Research Module
LSS	Life Support Systems
LRU	Line Replaceable Unit
LWA	Long Wavelength Antenna
mV	Millivolt
M	Million
MAM	Main Belt Asteroid Multirendezvous
Mbps	Megabits Per Second
MD	Medical Doctor
MDAC	McDonnell Douglas Astronautics Company
MeV	Million Electron Volts
MGCM	Mars Geochemistry/Climatology Mapper
MIT	Massachusetts Institute of Technology
MMC	Martin Marietta Corporation
MML	Martin Marietta Laboratories
MMS	Multimission Modular Spacecraft
MMU	Manned Maneuvering Unit
MOHM	Megaohms
MOTV	Manned Orbital Transfer Vehicle
MP	Materials Processing
MPN	Mars Probe Network

APPENDIX A ACRONYMS AND ABREVIATIONS

MPS	Materials Processing in Space
MR	Microwave Radiometer
MRICD	Medical Research Institute for Chemical Defense
MRWS	Mobile Remote Work Station
M-SAT	Mobile Satellite
MSFC	Marshall Space Flight Center
MWPC	Multi-Wire Proportional Counter
MWS	Microwave Sounder
N/A	Not Applicable
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NiH_2	Nichel Hydrogen
NM	Nautical Miles
NMR	Nuclear Magnetic Resonance
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
ODSRS	Orbiting Deep Space Relay Station
OIST	Orbiting Infrared Submillimeter Telescope
OMP	Ocean Microwave Package
OMS	Orbital Maneuvering Systems
O_2	Oxygen
O_2/N_2	Oxygen/Nitrogen
OPEN	Origin of Plasma in the Earth Neighborhood
OSA	Optical Society of America
OTV	Orbital Transfer Vehicle
OVLBI	Orbital Very Long Baseline Interferometer

APPENDIX A ACRONYMS AND ABREVIATIONS

P	Phosphorous
PDR	Preliminary Design Review
PET	Position Emission Tomography
PhD	Doctorate of Philosophy
PH	Level of Acidity
PI	Principal Investigator
PIDA	Payload Installation and Deployment Aid
P/L	Payload
PLSS	Portable Life Support Systems/Personal Life Support System
PMD	Propellant Management Device
PMS	Physiological Monitoring System
P/OF	Pinhole/Occulter Facility
PS	Payload Specialist
psi	Pounds per Square Inch
psia	Pounds per Square Inch Absolute
PTE	Plasma Turbulence Explorer
QD	Quick Disconnect
R&D	Research and Development
R&T	Research and Technology
RAHF	Research Animal Holding Facility
RBC	Red Blood Cell
RCA	Radio Corporation of America
RCS	Reaction Control System
REM	Roentgen Equivalent, Mass

APPENDIX A ACRONYMS AND ABREVIATIONS

RF	Radio Frequency
RFP	Request for Proposal
RMS	Remote Manipulator System
ROM	Rough Order of Magnitude
ROSS	Remote Orbital Servicing System
ROTV	Reusable Orbital Transfer Vehicle
SAO	Smithsonian Astronomical Observeratory
SAR	Synthetic Aperture Radar
SARSAT	Search and Rescue Satellite - Aided Tracking
SAT	Satellite
S/C	Spacecraft
SCADM	Solar Cycle and Dynamics Mission
SCDM	Solar Coronal Diagnostic Mission
SCE	Solar Corona Explorer
SDCV	Shuttle Derived Cargo Vehicle
SDV	Shuttle Derived Vehicle
SERV	Servicing
SEXTF	Solar EUV/XUV Telescope Facility
SHEF	Solar High Energy Facility
SIDM	Solar Interior Dynamics Mission
SIDF	Solar Interior Dynamics Facility
SIRTF	Shuttle Infrared Telescope Facility
SIS	Solar Interplanetary Satellite
SL	Spacelab
SLFRF	Solar Low Frequency Radio Facility

APPENDIX A ACRONYMS AND ABREVIATIONS

SMMI	Small Mass Measurement Instrument
SOMS	Shuttle Orbiter Medical Systems
SO/P	Saturn Orbiter/Probe
SOT	Solar Optical Telescope
SP	Scientific Payload
SPELS	Space Plasma Effects on Large Spacecraft
SPIE	Society Photo-Optics Instrument Engineers
SRB	Solid Rocket Booster
SRR	Systems Requirements Review
SS	Space Station
SSCAG	Space System Cost Analysis Group
SSEC	Solar Systems Exploration Committee
SSF	Solar Shuttle Facility
SSL	Space Sciences Laboratory
SSMM	Space Station Mission Model
SSR	Solar Spectrometer/Radiometer
SSRMS	Space Station Remote Manipulator System
SSXTF	Solar Soft X-Ray Telescope Facility
ST	Space Telescope
STDN	Space Tracking and Data Network
STO	Solar Terrestrial Observatory
STS	Space Transportation System
SVI	Stereo Visual Image
TAT	Thinned Aperture Telescope
TBD	To Be Determined
TBR	To Be Required

APPENDIX A ACRONYMS AND ABREVIATIONS

TBS	To Be Supplied
TCS	Thermal Control Subsystem
TDAS	Tracking and Data Acquisition System
TDM	Technology Development Mission
TDMA	Time-Division Multiple Access
TDRS	Tracking and Data Relay Satellite
TDRSS	TDRS System
TEM	Transmission Electron Microscopy
THM	Tethered Magnetometer
TIMI	Thermal Infrared Multispectral Imager
TM	Technical Memorandum
TMS	Teleoperator Maneuvering System
TOPEX	Ocean Topography Experiment
TP	Thermal Panels
TPS	Thermal Protection System
TSS	Time Sharing System
TV	Television
um	Micrometer = micron
usec	Microsecond
uvolt	Microvolt
UARS	Upper Atmosphere Research Satellite
UC	University of California
UCSF	University of California, San Francisco
UHF	Ultra High Frequency

APPENDIX A ACRONYMS AND ABREVIATIONS

Ult.	Ultimate
UM	University of Maryland
UM	University of Michigan
UMS	Urine Monitoring System
U.S./USA	United States/United States of America
US	Upper Stage
USRA	University Space Research Association
UT	University of Texas
UV	Ultraviolet
V	Velocity
VAP	Venus Atmospheric Probe
VAFB	Vandenberg Air Force Base
VCU	Virginia Commonwealth University
Vdc	Volts Direct Current
VFR	Vestibular Function Research
VHEO	Very High Earth Orbit
VHSIC	Very High Speed Integrated Circuit
VLR	Very Large Radar
VLST	Very Large Space Telescope
VRF	Vestibular Research Facility
VRM	Venus Radar Mapper
WARC	World Administration Radio Conference
WBS	Work Breakdown Structure
WLS	Western Launch Site
WRU	Work Restraint Unit

APPENDIX A ACRONYMS AND ABREVIATIONS

XGP	Experimental Geostationary Platform
XRO	X-Ray Observatory
XTE	X-Ray Timing Explorer
Zero g	Zero Gravity
β angle	Angle Between Orbit Plane and Solar Vector
α_s	Coating Solar Absorptance
ε	Coating Emmitance
ω	Watts

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