UAH/NASA WORKSHOP ON

SPACE SCIENCE PLATFORM

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The University
Of Alabama
In Huntsville

THE SUMMARY OF THE PANEL REPORTS FROM THE UNIVERSITY OF ALABAMA IN HUNTSVILLE/ NASA WORKSHOP CONDUCTED AUGUST 21-25, 1978, AT JOE WHEELER STATE PARK RESORT, ALABAMA.

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REVISED DECEMBER 1978

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PREFACE

The Space Transportation System (STS) and Spacelab represent important new capabilities for space science. These new systems, which will become operational in the early 1980's, will facilitate the launch, retrieval, refurbishment and reflight of scientific payloads. These payloads will be in the form of traditional free-flying spacecraft and as Spacelab (STS-attached) payloads. This new retrieval capability, coupled with the large weight-carrying and power capabilities of the STS, makes possible the evolutionary development of large and complex instruments and facilities. The assembly of complementary groups of instruments that may be reconfigured from flight to flight to address different scientific problems will also be possible.

The STS and Spacelab are limited in one important commodity- time in orbit. Currently planned Spacelab missions range in duration from 7 days to a possible 20-30 days. However, many of the major space science instruments and facilities, once developed, will derive considerable scientific benefit from extended observing periods in space. At this time such periods can only be achieved through multiple Spacelab missions or by reconfiguring the instruments to be compatible with traditional free-flying spacecraft.

An alternative approach has recently been proposed which may prove to be a simpler and more cost-effective solution to the problem of long term flight. This approach involves the use of some form of orbiting space platform onto which Spacelab instruments can be offloaded. Power, telemetry and stabilization and other support services, otherwise provided by Spacelab, would be duplicated by the platform. This would provide the instruments with a common spacecraft interface. Once offloaded, the instruments or groups of instruments, would remain in space for as long as required to achieve their scientific objectives. They would be serviced or even manually operated during occasional visits of the STS to the platform. Upon completion of their programs, the instruments would be returned to earth by STS for possible refurbishment, reconfiguration and reuse.

It is not apparent at this time what form such a platform should take; how many platforms are required to satisfy the needs of the user communities; or whether such systems are, in fact, cost-effective alternatives to multiple Spacelab missions or to a series of traditional free-flying spacecraft. Thus, there is clearly a need to identify and quantify the scientific requirements for such platforms so that these questions may be addressed.

The purpose of this Workshop is to define the scientific user requirements for a Space Science Platform. Subsequent definition activities will involve a number of other offices within NASA. These include the Office of Aeronautics and Space Technology (OAST), the Office of Space Transportation Systems (OSTS), and the Office of Space and Terrestrial Applications (OSTA). The European Space Agency (ESA) is also interested in possible collaborations in this area. It is our intent that by the spring of 1979 the potential user benefits, technological implications, and cost of space platforms will be identified and the cost-effectiveness of such capabilities determined. This will then enable the Agency to decide whether this potentially attractive addition to the STS system will, in fact, play a role in the follow-on Spacelab program.

A. Timothy
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PURPOSE AND OBJECTIVES

The availability of the Space Shuttle Transportation System (STS) in the 1980's will greatly enhance the capability of the scientist to do Space Research. With STS the placing of large masses and volume in orbit as well as the ability to revisit for purposes of refurbishment and retrieval is possible. Studies are also being conducted on the construction of large structures in space. The Marshall Space Flight Center (MSFC) and the Office of Space Science (OSS) have been exploring various preliminary concepts of an orbiting Space Science Platform (SSP) to accommodate experiment programs.

In order to ensure proper direction, OSS felt that the participation of the scientific community at a very early stage of the planning process was essential. To accomplish this, OSS requested that MSFC determine the scientific benefits and requirements of an SSP. The University of Alabama in Huntsville (UAH), with the cooperationof MSFC, undertook to obtain this information by organizing a Workshop. To this end, UAH invited interested scientists from universities, private industry and government agencies to a five-day Workshop at Joe Wheeler State Park Resort, Alabama, for the purpose of becoming acquainted with the concept of a Space Science Platform and to discuss the scientific justification and requirements for potential scientific experiments that might benefit from the SSP.

Based on the activities of OSS, the discussions were centered in the following panels:

High Energy Astrophysics
Astronomy
Lunar and Planetary Sciences
Solar Physics
Space Plasma Physics
Atmospheric Sciences
Life Sciences.

A detailed account of the panel reports is included in the following chapters. In particular, we wish to draw the reader's attention to the summary discussions in Chapter I, which will give a general view of those participating in the Workshop.

As the coordinators of this Workshop, we would like to acknowledge those scientists whose cooperations made this activity so useful and successful. In particular, we would like to thank the co-chairpersons, Dr. A. Timothy of OSS, and Dr. R. O'Dell of MSFC, and the panel chairmen for preparing accurate panel reports for publication. Also, the encouragements of Dr. J. Dowdle, Vice President for Administration and Dean J. Hoomani of The University of Alabama in Huntsville are greatly appreciated, as is the support of Ms. Virginia Tomme for facility arrangements. Finally,

but certainly not least, we would like to give our great appreciation to Ms. Carol Holladay who served distinguishably as secretary and typist throughout this activity.

S. T. Wu
The University of Alabama in Huntsville

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CHAPTER I

SUMMARY

by

Charles R. O'Dell
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SUMMARY

The scientists participating in the SSP Workshop were able to identify many applications of a space platform to their disciplines and several examples of where their science could be done uniquely well.

Very clearly, experiments done while attached to the Space Shuttle will have important limitations due to the relatively short flight duration, low duty cycle, and power, mass and volume constraints. These limitations would prevent realizing many of the scientific goals set by these scientists even though the state of technology of detectors, stabilization and cryogenics would allow the necessary measurements to be made, given the appropriate vehicle. The workshop participants did not attempt to evaluate other alternatives to Shuttle attached operation, such as standardized spacecraft, or to evaluate the cost of various recommendations but were directed to assume the position of characrerizing the utility of Space Science Platforms and of separating out only a relatively few experiments that clearly and naturally fell into the major facilities category. Space Science Platforms have enormous potential during the 1980's and beyond; however, NASA may wish to assess other ways of achieving some of the experiments projected here.

There was a spectrum of enthusiasm for the SSP that ranged from the position that platforms would be useful to identification of platforms as the logical and most desirable way of carrying out the scientific goals of their disciplines. The overwhelming assessment of the Workshop participants was that the Space Science Platform concept should be studied further.

The Workshop participants assumed that their task was to generate requirements for Space Science Platforms rather than defining experiments compatible with the engineering concepts shown at the beginning of the meeting. This was both an advantage and a disadvantage. It allowed relatively unconstrained consideration of what the scientific disciplines really needed but also meant that the practical boundaries had to be presumed and the audacity of each discipline panel certainly varied.

It is now NASA's responsibility to tie the requirements generated into a practical Space Science Platform concept and the potential user community of scientists should be apprised of the results. This is a complex task, for many different requirements were identified, some apparently mutually exclusive. Clearly, a variety of Space Science Platforms would be required for all of the experiments and programs identified.

There are eight areas that characterize the Space Science Platforms envisioned. In some cases there are mutally exclusive requirements, in other there is a continuum of possibilities. The requirements in these various areas need to be met in some combination for all of the experiments and programs identified here. These areas are: Experiment Interface, Orientation, Orbit, Power, Service Dependence, Stabilization, Duration Man Dependence.

Experiment Interface means what interface requirements are placed on the experiments. This could mean Space Science Platforms which simulate the interface conditions of the Space Shuttle Orbiter bay and Spacelab, thereby allowing the low cost use of Shuttle experiments after they have initially been used for short duration missions or checkouts. It could also mean standardized interfaces for the SSP that differ from Shuttle but offer greater economy or the potential for different experiments. Finally, it could mean one of a kind interfaces for highly specialized experiments.

Orientation means the primary frame of reference for alignment of the SSP's. There seem to be two basic needs: the Celestial, where the sun or some other celestial object is the primary target and it is necessary to keep the SSP fixed in an inertial reference frame and the Terrestrial, where the earth and its immediate environment is the subject, in which case one wishes to maintain a fixed orientation with respect to a vector from the earth's center.

Orbit is characterized by Altitude and Inclination. Some experiments wish to have low altitudes and inclinations, thus minimizing the effects of the radiation belts, while other experiments wish high altitudes and even eccentric orbits to cover a variety of altitudes, latitudes and local times. Some disciplines require high inclinations in order to cover the earth while solar experiments want polar orbits to allow more continuous viewing.

Power requirements will vary enormously. Some experiments will require a few hundreds of watts, others would require the full capability of Shuttle (a few kilowatts) and some will exceed the Shuttle capability by an order of magnitude.

Service Dependence will vary enormously. Some experiments foresee use of expendables such as cryogenics or film, which has a limited lifetime in orbit due to particle fogging. These experiments may require Shuttle visits monthly or every few months. Other experiments will be free of these constraints and need the Shuttle only at the start and completion of a mission.

Stabilization means the short timescale variations in the orientation. It was assumed that where extremely precise stabilization is required, it would be provided by the instruments themselves; however, there would be distinct advantages in providing platform stabilities in three levels: a few arc seconds, a few arc minutes and a few degrees of arc. Some experiments are very sensitive to forces and a microgravity must be provided.

Duration requirements can vary enormously between experiments. Some must have flights of many months in order to gather enough photons, to map a sufficient area or even to cover the natural timescale of the astronomical, terrestrial or biological phenomenon being investigated. Others can be done in shorter periods, but generally longer than Shuttle missions.

Man Dependence ranges from the dependent, through the indifferent to the undesirable. Clearly many life sciences studies require man's presence as either a manipulator or subject, and his presence can simplify the design of many other experiments. Some experiments can tolerate the presence of man and could be performed independent of him. The presence of man would be undesirable for other families of experiments due to the stabilization and contamination problems that usually accompany him.

DISCIPLINE	INTERFACE			ORIENTATION		ORBIT				POWER		
	EXTENSION	STANDARDIZED	ONE OF A KIND	CELESTIAL	TERRESTRIAL	INCLINATION LOW	INCLINATION HIGH	ALTITUDE LOW	ALTITUDE HIGH	LOW	SHUTTLE	HIGH
High Energy	X			X		X		X		X		
Astronomy	X		(X)	X		X		X	X		X	
Lunar & Planetary		X		X		X		X			X	
Solar		X		X			X		X		X	
Space Plasmas			X		X		X	X	X			X
Atmospheric	X	X			X		X					X
Life	X											X

DISCIPLINE	SERVICE DEPENDENCE		STABILIZATION			MAN DEPENDENCE			DURATION (MONTHS)	
	LOW	HIGH	SECONDS	MINUTES	DEGREES	NECESSARY	INDIFFERENT	UNDESIRABLE	FEW	MANY
High Energy	X		X	X	X			X		X
Astronomy	X	(X)	X				X			X
Lunar & Planetary		X	X		X		X			X
Solar		X	X			X				X
Space Plasmas	X				X		X			X
Atmospheric		X	X	X			X			
Life	X					X			X	X

CHAPTER II

HIGH ENERGY ASTROPHYSICS PANEL

Panel Chairman: Arthur B. C. Walker, Jr., Stanford University

Panel Members: Gerald Fishman, MSFC
Paul Gorenstein, SAO
Allan Jacobsen, JPL
Louis Kaluzienski, NASA Headquarters
Dietrich Mueller, University of Chicago
Robert Novick, Columbia University

Panel Liasion (MSFC): Martin Weisskopf

1. SUMMARY

An effective program in High Energy Astrophysics requires both observatory class facilities and individual principal investigator class experiments. Within the content of these two approaches we have considered the potential role of space platforms, and have attempted to identify those investigations for which a platform would be suitable or desirable, and those investigations for which a dedicated free-flyer would be preferable. In particular, we have considered four distinct classes of automated (i.e., unmanned) free flying spacecraft:

Dedicated free flying observatories (e.g., GRO, AXAF,...)
Small single discipline platforms (3-4 shuttle pallets)
Large multiple discipline platforms (4-20 shuttle pallets)
Large platforms assembled in space (up to 100 m).

We consider the term "space platform" to include the last three classes above.

We believe the space platform concept is compatible with the requirements of a significant number of high energy astrophysics experiments which require extended observing time. Since the duration of a single shuttle flight is restricted to a maximum of fourteen to twenty days, shuttle attached high energy astrophysics experiments cannot achieve either the sensitivity or the comprehensive observational programs required to fully meet the scientific objectives of the discipline. A shuttle class instrument which is flown on a long duration space platform would not suffer from these limitations. The shuttle attached mode should be regarded as a proving ground to verify the scientific value and performance of various experiments before extended operation on a platform. It is important that the platform interface and the Spacelab interface be compatible, so that Spacelab hardware can be directly utilized for extended life missions on the platform without significant additional integration costs.

In each of the sub-disciplines, X-ray and EUV astronomy, gamma ray astronomy, and cosmic ray astronomy, we have identified investigations whose requirements for weight and volume are so large that they can only be accommodated on a large space platform; we have identified other investigations for which the space platform is an alternate but not necessarily the preferred mode of flight, and finally we have identified certain investigations for which the space platform would offer no advantages and would be less desirable than a single dedicated spacecraft. In Table 1.1, we have compiled a reasonably comprehensive review of the high energy astrophysics missions envisioned in the discipline Five Year Plan; we have attempted to match these missions to the four classes of free flyers we have established. Note that several of these instruments listed in Table 1.1 are modular (LAMAR, XRSE, XRTE), and can be expanded, or enhanced over a period of time by Shuttle revisits to a free flying platform.

EXPERIMENT TITLE	PRINCIPAL SCIENTIFIC OBJECTIVES	DURATION	WEIGHT SIZE POWER	POINTING ACC STABILITY	CLASS OF PLATFORM				COMMENTS
					I	II	III	IV	
AXAF 1.2 METER DIAMETER GRAZING INCIDENCE X-RAY TELESCOPE WITH HIGH RESOLUTION IMAGING DEVICES, SPECTROMETERS, AND A POLARIMETER IS THE FOCAL PLANE	THE STUDY OF FAINT X-RAY OBJECTS EXPECIALLY QUASARS, BI/LAC OBJECTS, SEYFERT GALAXIES, CLUSTERS, RADIO GALAXIES, AND INDIVIDUAL X-RAY OBJECTS IN EXTERNAL GALAXIES. SPECTROSCOPY OF THE PRESENTLY KNOWN GALACTIC SOURCES.	>10 YEARS	10,000 kg 6m X 6m X 16m 2 kw	30'' ONE ARC SEC PER SEC	R	I	I	I	SHUTTLE LAUNCHED FREE FLYER THAT IS SERVICED EVERY THREE YEARS AND RETURNED TO EARTH AT FIVE YEAR INTERVALS.
LAMAR: THIS IS A LARGE AREA MODULAR ARRAY X-RAY COLLECTOR CONSISTING OF GRAZING INCIDENCE X-RAY LENSES WITH INDIVIDUAL IMAGING PROPORTIONAL COUNTERS.	THE STUDY OF VERY WEAK X-RAY OBJECTS OF LARGE RED SHIFTS, THE STUDY OF DIFFUSE FEATURES, THE STUDY OF TIME VARIABILITY OF WEAK SOURCES, AND THE STUDY OF THE HOT INTERSTELLAR GAS IN OUR GALAXY AND EXTERNAL GALAXIES.	> 10 YEARS	2,000 kg 3m X 3m X 3m 025 kw (EACH MODULE	6' 10'' PER SEC	R	C	I	?	SHUTTLE LAUNCHEC MODULAR FREE FLYER THAN CAN BE ENLARGED THROUGH LATER LAUNCHES, ON-ORBIT SERVICING OF THE DETECTORS MAY BE REQUIRED. ONE MODULE IS DESCRIBED CAN GROW TO TEN
XRAO: THIS X-RAY AND EUV FACILITY WILL PRIMARILY BE DOVOTED TO SPECTROSCOPIC AND POLARIMETER STUDIES OF THE STRONGER X-RAY AND EUV SOURCES.	DETERMINATION OF THE IONIZATION STATE, TEMPERATURE, VELOCITY, AND DENSITY OF THE EMITTING PLASMA IN X-RAY SOURCES. DETERMINIATION OF ELEMENTAL ABUNDANCES, DETERMINATION OF THE GEOMETRY OF ACCRETION DISKS. POSSIBLE STUDY OF RELATIVISTIC EFFECTS AND BLACK HOLES.	10 YEARS	7,000 kg 6m X 6m X 6m 3 kw	1' PER SECOND 10''	P	I	I	P	SHUTTLE LAUNCHED FREE FLYER THAT IS SERVICED EVERY 2–3 YEARS
2-METER HIGH RESOLUTION X-RAY TELESCOPE. THIS EMPLOYS A HIGH RESOLUTION GRAZING X-RAY TELESCOPE, HIGH RESOLUTION IMAGING DEVICES, SPECTROMETERS AND POLARIMETER	DETAILED STUDIES OF WEAK SOURCE EXPECIALLY VERY DISTANT QUASARS, ACTIVE GALAXIES, BI/LAC OBJECTS, CLUSTERS, AND SEYFERT GALAXIES.	>10 YEARS	30,000 kg 6m X 6m X 30m PR SEC	6'' 0.1 ARC SEC	R	I	I	?	THIS INSTRUMENT WILL REQUIRE MULTIPLE SHUTTLE LAUNCHES AND IN ORBIT ASSEMBLY. ORBITAL SERVICING WILL BE REQUIRED EVERY THREE YEARS
LARGE AREA X-RAY COLLECTOR (LAXC)	DETAILED STUDIES OF WEAK X-RAY SOURCES WITH VARIOUS TYPES OF INSTRUMENTS AT THE FOCUS OF A LARGE AREA COLLECTOR	10 YEARS	60,000 kg 6m X 6m X 30m 2 kw	10'	I	I	I	C	
EXTREME ULTRAVIOLET EXPLORER (EUVE)	FIRST ALL SKY SURVERY IN THE EXTREME ULTRAVIOLET, TO LOCATE AND CATALOG DISCRETE SOURCES	1–2 YEARS	600 kg	N/A	P	C	I	I	THIS EARLY MISSION SHOULD BE CARRIED OUT BEFORE PLATFORMS
HIGH RESOLUTION X-RAY SPECTROSCOPY FACILITY (XRSE)	DEVELOPMENT OF DETAILED PHYSICAL MODELS OF MAJOR CLASSES OF X-RAY SOURCES, STUDY OF ABUNDANCES, RED SHIFTS;	2–6 YEARS	2,600 kg 3m X 3m X 1m	6' 10'' PER SEC	P	C	C	C	THE LONG LIFETIME OF THIS INSTRUMENT CAN BE ACHIEVED ONLY ON A PLATFORM OR OTHER FREE FLYER COULD BE BUILT UP OVER A PERIOD OF TIME FROM DOULAR COMPONENTS IF FLOWN ON A SUITALLE PLATFORM THE FIRST MODULE WOULD ADDRESS SPECTROSOPHY BETWEEN 6 AND 8 keV

NOTE:

R- REQUIRED C- COMPATIBLE

P- PREFERRED I- INCOMPATIBLE

TABLE 1.1 X-RAY AND EUV ASTRONOMY EXPERIMENTS

EXPERIMENT TITLE	PRINCIPAL SCIENTIFIC OBJECTIVES	DURATION	WEIGHT SIZE POWER	POINTING ACC STABILITY	CLASS OF PLATFORM				COMMENTS
					I	II	III	IV	
HIGH SENSITIVITY X-RAY SPECTROSCOPY FACILITY (XRSS)	OBSERVATION OF PHYSICAL PROCESSES IN COMPACT GALACTIC AND EXTRAGALACTIC SOURCES, OBSERVATION OF RED SHIFTS AND ABUNDANCES IN FAINT EXTRAGALACTIC SOURCES.	1–2 YEARS	1,000 kg 1.8m X 1.8m X 3m .15 Kw	6' 10'' PER SEC	P	C	C	C	THIS INSTRUMENT COULD BE OBTAINED WITH THE HIGH RESOLUTION SPECTROMETER IN A MODULAR CONFIGURATION OR SUITABLE PLATFORM
X-RAY POLARIMETRY FACILITY	DEVELOPMENT OF DETAILED MODELS OF ACCRETION DISKS IN COMPACT GALACTIC AND EXTRAGALACTIC SOURCES, STUDY OF SYNCHROTRON EMISSION IN SUPERNOVA REMNANTS	1–2 YEARS	1,000 Kg 1m X 1m X 3m 0.1 Kw	6' 10'' PER SEC	P	C	C	Q	THE LONG LIFETIME OF THIS INSTRUMENT CAN BE ACHIEVED ONLY ON A PLATFORM OR OTHER FREE FLYER
SOFT X-RAY/EUV SURVEY EXPLORER (SXSE)	EXTEND THE HEAO-1 SOFT X-RAY SURVEY TO 10^{-14} DAYS/ CM^2 SEC AND AT HIGH ANGULAR RESOLUTION (5''–10'') EXTEND THE EUV SURVEY TO 10^{-13} ERGS/CM^2 SEC	2 YEARS	0.2 kw 1,000 kg 1m X 1m X 3m	6' 10'' PER SEC	P	C	?	?	THE OPERATION OF THIS EXPERIMENT IN A SURVEY MADE BE INCOMPATIBLE WITH OTHER EXPERIMENTS ON THE SAME PLATFORM
LARGE AREA TIMING FACILITY (XRTE)	TO PERFORM DETAILED TIME VARIABILITY STUDIES WITH HIGH RESOLUTION OF THE COMPACT X-RAY SOURCES BOTH IN OUR OWN AND NEARBY GALAXIES. CAN ALSO PERFORM RADIUM RESOLUTION SPECTROSCOPY AT ENERGIES UP TO 60 keV.	1–2 YEARS	200 Kg 1.3m X 1.3m X 1.5m 0.1 w	1'' ONE ARC SEC PER SECOND	C	C	C	C	A SINGLE MODULE IS DESCRIBED ADDITIONAL MODULES WOULD BE ADDED OVER A PERIOD OF TIME TO ACHIEVE LARGER AREA
HARD X-RAY IMAGING FACILITY	TO PERFORM X-RAY SOURCE LOCATIONS WITH SPATIAL RESOLUTIONS OF ARCMINUTES TO MILLIARC SECONDS (ZONE PLATE) AT ENERGIES ABOVE A FEW KILOVOLTS	1–2 YEARS	1000 kg 3m X 3m X 100m 2 kw	1'' ONE ARC SEC PER SECOND	I	C	C	C	THIS CAN BE ACHIEVED BY A CODED APERTURE OR THE ZONE PLATE OR NARROW FIELD, LONG FOCAL LENGTH GRAZING INCIDENCE X-RAY TELESCOPES
HIGH ANGULAR RESOLUTION FACILITY	HIGH ANGULAR RESOLUTION (0.01'') IS NECESSARY TO UNDERSTAND THE MECHANISM OF ENERGY PRODUCTION IN ACTIVE GALAXIES, AND QUASARS, AND THE STRUCTURE OF DISTANT CLUSTERS OF GALAXIES.	1–2 YEARS	2000 kg 3M X 3m X 100m 2 kw	1'' 0.1 ARC SEC PER SEC	I	C	C	C	THIS CAN BE ACHIEVED BY THE USE OF CODED APERTURE OR A ZONE PLATE TECHNIQUES. ASSEMBLY IN SPACE ON A SUITABLE OPTICAL BENCH AND ACTIVE ALIGNMENT IS REQUIRED

NOTE

R– REQUIRED C– COMPATIBLE

P– PREFERRED I– INCOMPATIBLE

TABLE 1.1 X-RAY AND EUV ASTRONOMY EXPERIMENTS (CON'T)

TABLE 1.1

GAMMA-RAY ASTRONOMY EXPERIMENTS
(con't)

Experiment Title	Principal Scientific Objective	Duration	Weight Size Power	Pointing Acc.	Class of Platform				Comments
					I	II	III	IV	
Low Energy Gamma-Ray Spectrometer	Spectroscopic observations of nuclear gamma-rays lines and continuum from discrete and diffuse regions of the Galaxy and from extragalactic objects in the energy region 0.1-10 MeV	2-10 years	10,000 kg 5m dia x 10m 150 w	0.1-1°	C	C	C	C	May require cryogenics; isolated from other massive objects
High Energy Gamma-Ray Telescope	Gamma-ray imaging and low resolution spectroscopy of objects and retions from 20 MeV to 10 GeV	2-10 years	10,000 kg 3m dia x 5 m 100 w	0.1-1°	C	C	C	C	
Compton Telescope/ Polarimeter	Intermediate spectral and imaging observations, 2 MeV - 30 MeV	2-10 years	5m dia x 20m 250 w	0.1-1°	C	C	C	C	
Gas Ĉerenkov Telescope	Very high energy imaging and spectral measurements, 1 GeV	2-10 years	3,000 kg 5m dia x 15m	0.1-1°	C	C	C	C	
Gamma-Ray Burst Detector	All sky monitoring, spectral and temporal measurements of gamma-ray bursts and strong sources in the energy range 20-150 keV	2-10 years	1,000 kg 2m x 2m x 1m	N/A	C	C	C	C	Minimum of 2 modules with unrestricted fields of view

Notes: I - Incompatible
C - Compatible
R - Required
P - Preferred

TABLE 1.1

Cosmic Ray Astronomy
(con't)

Experiment Title	Principal Scientific Objectives	Duration	Weight Size Power	Mode I	Mode II	Mode III	Mode IV	Comments
Proton and Alpha spectrum up to 10^{16} eV; Medium Z nuclei (Li, Be, B) up to 10^{12} eV/nucleon. (Calorimeter)	Complete information on the most abundant cosmic ray species, overlap with air shower data, reference for calculations of secondary production, high energy interaction studies. Energy dependence of propagation path length.	1 year	5000 kg 2m x 2m x 3m 0.2 kw	P	P	C	C	Weight may exceed single pallet capacity
Elemental composition lithium-iron from 50 GeV/nucleon to several 10^4 GeV/nucleon. (transition radiation detector)	Source spectra of primary constituents, characteristics of sources and acceleration mechanisms, energy dependence and path length distribution of interstellar matter traversal.	1 year	3000 kg 3m x 3m x 3m 0.2 kw	P	P	C	C	
Elemental composition of ultraheavy cosmic rays ($26 \leq Z \leq 100$) (large active or passive detector arrays)	Detailed study of r and s process nucleo synthesis, cosmic ray dating in 10^7-10^9 year range. Search for transuranium nuclei.	2 years	1000 kg 3m x 3m x 3m 0.2 kw	P	P	C	C	Large size may exceed pallet capacity
Isotopic composition ($2 \leq Z \leq 28$) (super conducting magnet may be required)	Nucleo synthesis history of cosmic ray material, time scale of acceleration mechanism, age of cosmic rays.	1 year	3000 kg 3m x 3m x 4m 0.5 kw	P	P	C	C	Constraints on orbital inclination
Electron spectrum up to at least 1000 GeV (shower counter/ transition radiation detector)	Exact shape of electron spectrum: electromagnetic interactions in interstellar space, age of cosmic rays	6 months	2000 kg 2m x 2m x 3m 0.2 kw	P	P	C	C	
Position spectrum up to at least several 100 GeV (superconducting magnet with transition radiation detector and shower counter)	Determination of the source spectrum of electrons, electromagnetic interactions in interstellar space, age of cosmic rays, energy dependence of proton path-length in interstellar space.	1 year	4000 kg 3m x 3m x 4m 0.5 kw	P	P	C	C	Magnetic fringe fields may require shielding or separation of adjacent payloads. Size may exceed single pallet capacity. Required cryogenic services.

NOTES:

R - required
P - preferred
C - compatible
I - incompatible

NOTE: These experiments do not require precise pointing but should be oriented toward the zenith.

We do, however, have some concerns about the space platform concept as presented to the study panel in the briefing documents. Since X-ray and EUV experiments require high accuracy pointing; we are concerned that if flown on a space platform containing a manned habitat the continual motion of the man would prevent the attainment of the required experiment performance. On the other hand, a number of high energy astrophysics experiments (notably cosmic ray and gamma ray experiments) require minimal or no pointing capabilities and do not utilize the large range of resources and consumables that will probably be available on a large space platform. The cost-effectiveness of using the platform must be carefully considered in these cases.

We are also concerned that any attempt to combine manned life science experiments with high energy astrophysics experiments on a single platform would lead to the imposition of severe man rated safety requirements on the design and integration of the experimental hardware. We strongly recommend that high energy astrophysics experiments be accommodated on space platforms reserved for non-manned experiments.

We conclude that the space platform concept offers important, and in some instances, unique advantages to certain experiments in high energy astrophysics, we must however, emphasize that certain key investigations in a particular discipline may be best performed by conventional free flying satellite observatories.

2. INTRODUCTION

High energy astrophysics is the study of radiations of energy greater than ~ 0.04 keV from cosmic objects. The radiations are in general of relatively low intensity and highly penetrating, but not sufficiently so to penetrate the earth's atmosphere. For these reasons, the history of the research is intimately connected with the development of the space program and the instruments are of necessity large and massive. Research in the high energy region encompasses a wide variety of instrumental techniques and for this reason divides naturally into the subdisciplines of X-ray and EUV, gamma-ray and cosmic ray astronomy. Within the discipline, spanning and unifying the subdisciplines are some of the most important current astrophysical problems, including stellar structure and evolution into such intriguing objects as novae, super novae, neutron stars and black holes; the synthesis and distribution of the elements; the acceleration and distribution of the cosmic rays; the nature of bursting, flaring, pulsating and transient objects; the structure and evolution of galaxies; and, cosmology.

The progress of the various sub-disciplines is determined by the flux intensities and the ease of detection techniques. These are not uniform across the discipline and consequently progress has not been uniform across the discipline. The progress that has been made, however, is uniformly important and exciting.

2.1 X-Ray and EUV Astronomy

The rapid development of X-ray astronomy during the past 15 years, and the recent discovery of sources which radiate strongly in the extreme ultraviolet has major implications for a wide range of fundamental problems in astrophysics.

X-ray astronomy is on the threshold of a new phase in its development, which will exploit the early development of the discipline by: (1) the use of X-ray optics, which will extend sensitivity and angular resolution achieved by two orders of magnitude, (2) the use of spectroscopic and polarimetric observations, which will provide critical tests of detailed physical models, and (3) deep sky surveys which will allow the structure of the galaxy, and of the universe to be studied by determining the distribution of faint sources and hot diffuse matter. A planned extreme ultraviolet survey should firmly establish observations in that part of the spectrum as an integral part of the discipline.

Major astrophysical questions which will be addressed in the next decade include:

- The structure of compact stars and other highly evolved stars
- Searches for black hole candidates
- The evolution of stars in close binary systems
- The structure of the coronae of main sequence and dwarf stars
- The chemical evolution of the galaxy. The structure of the interstellar medium
- The evolution of supernovae remnants
- The detection of supernova explosions
- The nature of the emission process in active galaxies
- The origin and evolution of the hot gas in clusters of galaxies
- A search for evidence indicating the presence of a hot intercluster medium
- The nature and evolution of objects at large distance in the universe.

In order to fully exploit the opportunities which X-ray and EUV astronomy present for the study of major astrophysical problems, a program utilizing major free-flying X-ray observatories, Explorer-class free flyers, major Shuttle-attached facilities and PI class experiments, and rocket and balloon-born experiments has evolved, and is detailed in the High Energy Astrophysics Five Year Plan.

Three major free-flying observatories have been identified. The first, the Advanced X-Ray Astronomy Facility (AXAF) should provide a 5-fold increase in resolution and a 30-fold increase in sensitivity over the first major X-ray observatory, HEAO-B, which will be launched in late 1978. The other major observatories which have been identified will compliment and extend the observational capabilities of AXAF by providing enhanced sensitivity (by an order of magnitude) for the study of diffuse features and faint sources (the large area modular array reflector facility or LAMAR) and enhanced sensitivity and resolution for spectroscopy, polarimetry and selective deep-sky surveys (the X-Ray Astrophysics Observatory or XRAO). These major dedicated observatories are expected to have useful lifetimes measured in decades. It is difficult to foresee how their missions could be accomplished on multipurpose space platforms.

Four Explorer-class free-flyers have been identified by the X-ray astronomy community:

(1) A first EUV survey intended to greatly expand the catalogue of extreme ultraviolet sources (EUVE).
(2) An X-ray timing mission intended for the study of compact galactic sources (XRTE).
(3) A spectroscopy mission intended to study the emission lines and absorption structure in galactic and extra galactic sources due to atomic processes in highly ionized iron (XRSE).
(4) A survey at soft X-ray and EUV wavelength intended to extend our knowledge of the luminosity functions of all major classes of X-ray sources (SXSE).

These missions have complex observing programs and antitipated lifetimes from 2-5 years, and would appear best suited to dedicated free flyers.

The major Shuttle attached facilities identified include an early version of the LAMAR telescope, major spectroscopic and polarimetric facilities, and a high resolution moderate area X-ray telescope for specialized studies of extended objects and the development and testing of new focal plane instruments. All of these facilities (with the exception of the high resolution telescope) are prime candidates for the extended observational programs which the space platform concept makes possible. Additional facilities, which are not easily accommodated on the Shuttle due to limitations of observing time or of physical size would also appear to be well matched to the capabilities of the space platform. A prime candidate is a 2 to 4 meter diameter X-ray telescope of long focal length. Such a device, containing focal plane instrumentation for high resolution imaging and spectroscopy and polarimetry is the natural follow on to AXAF. Other facilities include an all sky X-ray monitor, which is especially important to the study of compact sources and transient sources within the galaxy, and instruments intended to allow imaging of extended hard X-ray sources and to achieve very high (0.01") angular resolution. In addition, all PI class X-ray Shuttle instruments would be greatly increased in effectiveness by the longer and more efficiently used observing time which the space platform concept makes possible.

2.2 Gamma-Ray Astronomy

Gamma-ray astronomy presents the opportunity to observe directly the radiations resulting from nuclear interactions, and high energy and explosive processes in near-by, as well as remote parts of our galaxy and the Universe. These processes are connected to some of the most important problems in astrophysics and the potential rewards of gamma-ray astronomy are beginning to be realized as it moves from the discovery phase to the exploratory phase. The problems addressed include the nature of compact objects such as neutron stars and black holes; the structure of supernovae and the sites and modes of nucleosynthesis; the origin and distribution of cosmic rays and their present effects on galactic structures; the nature of interstellar gases and dust, and perhaps cosmology.

The low energy gamma-ray region is unique in that it contains the line emissions that are the signature of specific nuclear processes taking place in an astrophysical setting. Mechanisms for production of discrete lines include production of radioactive nuclides, direct excitation of nuclear energy levels, neutron scattering and absorption, positron-electron annihilation, and cyclotron emission from electron transitions in strong magnetic fields.

It is also of great current interest to study in more depth the recently discovered low energy (~ 100 keV) gamma ray bursts, whose origin remains a mystery. The next step in this research should be to obtain good position information combined with detailed time profiles and energy spectra.

Gamma rays resulting from π^0 decays following cosmic ray interactions allow study of the far side of the galaxy and of dense spiral arm segments which are difficult to see at other wavelengths. With improved sensitivity, gamma ray astronomy also has the capability of studying the cosmic ray matter distribution in other galaxies.

Gamma ray astronomy can provide direct answers to questions relating to the origin of cosmic rays by identifying the locations of discrete sources and studying these sources in detail. Gamma rays have already been observed to be coming from pulsars that are supernova remnants, thereby indicating the presence of relativistic particles in association with these objects.

Exciting results in gamma-ray astronomy have already been obtained with satellite experiments on board OSO-3, OSO-7, Vela, SAS-2, and COS-B. These have clearly established:

- A general emission of high energy gamma rays from the galaxy, which is correlated with galactic structure but shows greater center-to-anticenter contrast than the matter distribution.
- Emissions from specific points or localized sources such as radio pulsars, Cygnus X-3, and other regions yet to be identified at other wavelengths.
- A diffuse high galactic latitude radiation which consists of two components, one a relatively local galactic component and another with a markedly steeper spectrum.
- That gamma ray lines are produced in solar flares by solar cosmic rays.
- That unidentified astrophysical source(s) produce strong bursts of gamma rays (~ 100 keV) that are observable several times per year.

In addition, balloon experiments using high resolution spectrometers have recently provided strong evidence that:

- A strong emission line precisely at 0.511 MeV is emanating from the galactic center region and,
- A twenty-minute long transient burst of gamma rays occurred which yielded primarily gamma-ray lines at several discrete energies.

New results in the low energy gamma-ray region are expected from the scintillation detector presently in orbit on HEAO-1 and from the high resolution solid state spectrometer to be flown on HEAO-C in 1979. The primary thrust beyond these missions is the Gamma-Ray Observatory (GRO). A comprehensive payload was selected and announced in August 1978. The large instruments selected fit naturally together on a large spacecraft because there is the desire to point all of them at the same regions of the sky, and there is a strong scientific advantage to having data collected from the same objects over the entire gamma-ray energy spectrum at the same time. The scientific return from the GRO mission is expected to be bountiful both intrinsically and in terms of its benefits to other fields of astrophysics.

Since the recently selected experiments for GRO represent the state-of-the-art, the next generation of gamma ray experiments can best be characterized as scaled up versions of the GRO instruments.

- They require low altitude, low inclination orbits.
- They are large, massive instruments.
- They have modest pointing and stability requirements (~ 0.1 degree).
- They are highly automated and require no real-time manned operation.
- They are not susceptible to gas and particulate contamination.
- They have modest thermal, vibration and acoustic requirements.
- Some will certainly require cryogenic support.

2.3 Cosmic Ray Physics

The cosmic particle radiation encompasses the nuclei of all known elements, from protons to the actinides, as well as electrons and positrons, and covers energies from the MeV region up to the highest energies encountered in nature, around 10^{20} eV. Studies of the flux intensities, energy spectra, composition (both elemental and isotropic), and arrival directions of cosmic ray particles give information on a wide range of astrophysical phenomena.

The origin and acceleration of cosmic rays is intimately connected to nucleosynthesis processes in stars and to violent phenomena such as supernova explosions. The propagation of cosmic rays through interstellar space and their containment in the galactic magnetic fields. are governed by the properties of the interstellar medium. The cosmic ray gas, with an energy density of about 1 eV/cm^3, strongly contributes to the dynamics of the galaxy. Cosmic rays also serve as probes for the properties of the heliosphere and of interplanetary space, and of the Earth's magnetosphere. Locally, the acceleration of cosmic ray particles can be observed in solar flares and in the magnetosphere of Jupiter and, perhaps, other planets. Finally, we should mention the traditional importance of cosmic ray observations for high energy physics phenomena at energies that are not accessible with accelerators on earth.

Shuttle-launched experiments which are inside the magnetosphere and below the radiation belt lend themselves toward studies of the galactic cosmic radiation at relatively high energies; i.e., in the GeV-region and above. Studies of solar and interplanetary effects can only be performed outside of the magnetosphere. Only if the Shuttle is used as a launch platform for high orbit free flying satellites, will we be able to utilize the Shuttle system for cosmic ray research at lower energies. We shall not discuss here the many exciting observations to be made in this region.

For the galactic cosmic radiation, the following goals appear to be presently at the center of interest:

(1) The elemental composition and energy spectra of the individual cosmic ray species, from hydrogen to iron, at very high energies.

(2) Abundance distribution of the ultraheavy cosmic rays, from iron to uranium, and including a search for transuranium elements.

(3) Isotopic composition of various elemental species of the cosmic radiation.

(4) Flux and energy spectra of electrons and positrons at very high energies.

Details of the scientific significance of these observations and techniques to implement successful measurements will be discussed in Section 4.3 of this report.

At the present time, most of these areas are in an active exploratory phase using high altitude balloons. Also, a few experiments are under development for exposure onboard HEAO-C, LDEF and the Space Shuttle. However, the next and more ambitious generation of experiments should lead to definitive and more accurate results than presently feasible. The experimental technology for such future endeavors is already well developed in many cases. Instruments of very large area (up to 20 m^2 SR), with weights of several tons, for long periods of time ($\geq$ 1 year) are required. A Cosmic Ray Observatory (CRO), is now in an early state of definition. Besides weight, size, and exposure time, the requirements of most cosmic ray experiments are modest: no precise pointing (but the instruments must face away from earth), no man-activities, power $\leq$ 500 W, telemetry ~ 10-100 Kb/sec.

3.0 The Role of Shuttle-Attached Payloads and Space Platforms

The requirement of all high energy astrophysics instruments for long observing times makes free flying satellites or platforms our preferred mode. The major facilities required for the discipline are, we believe, best implemented as dedicated free flying observatories. A number of missions with specific observational objectives, also appear to be most compatible with dedicated free flyers.

We view the role of Shuttle-attached payloads as primarily a mechanism for the development and testing (with specific observational programs) of instruments which will be placed on platforms or dedicated free flyers with projected operational lifetimes of at least one year.

It is difficult to discuss the role of space platforms in high energy astrophysics without some refinement of the general concept of platforms. For the present discussion, we will assume that NASA is considering four distinct types of free-flyers or platforms to carry out scientific investigations. These classes of free flyers, with examples of each, are summarized in Table 2.1. We can identify a role for space platforms in two situations.

(1) Providing extended observing time for facilities and P.I. instruments which have been successfully operated on the Shuttle for specific observational programs (observation of a single source, etc.).

(2) Accommodating facilities and instruments which are too large or too massive for Shuttle attached operation, or dedicated free flyers.

Table 2.1

Class	Examples	Type	Typical No. of Experiments	Typical Experiment Size
I. Dedicated Free-Flyers (Observatories, Explorers)	GRO, AXAF, CRO	Subdiscipline	1-5	1m - 10m
II. Small Space Platforms	3-4 pallets	Discipline or Related Discipline	5-10	1m - 3m
III. Large Space Platforms	10-17 pallets	Multi-Discipline	10-20	1m - 10m
IV. Space Fabricated Platforms	Large Space Truss	Multi-Discipline	> 20	1m - 100m

In order to accomplish the first role, it is imperative that the interface and environment for Shuttle attached payloads and for space platform payloads be as nearly identical as possible. All of the foreseeable high energy astrophysics instruments, both facilities and PI developed, are at least of order one half pallet in size, and can accomplish a wide range of observational objectives. The extended observational time which can be provided by a platform (or free-flyer) is scientifically important, and cost effective.

In order to accomplish the second role, the capability to assemble large structures in space is necessary. For these structures, the platform environment could be significantly different from that of a Shuttle pallet. For example, facilities to temporarily accommodate astronauts may be required. In some cases, a capability to monitor, and re-establish alignments automatically, or by remote control, may be required.

In Table 1.1 (continued in the Summary), are tabulated the major observational programs which we have been able to identify. We have attempted to match experimental requirements to the space platform concept, based on a small number of basic assumptions. Before we can fully assess the feasibility and desirability of performing high energy astrophysics experiments on a Shuttle supported space platform, a number of important questions must be answered. These include:

- Will there be more than one platform to accommodate differing orbital requirements?
- To what extent will pointing and stability be affected by movements and thermal distortions in other points of the platform?
- Will a large multi-disciplinary platform require a lengthy and costly integration effort due, for example, to mutual interference and contamination?
- How many independent pointing platforms can be reasonably accommodated on a large platform?
- How long can individual experiments remain in orbit (5-10 years desired for some experiments)?
- Will the presence of a manned capsule require costly and elaborate man rating of experiment components?
- To what extent will the costs of a large platform utilize funds which would otherwise be available for experiments or dedicated observations?
- Is it feasible to consider the assembly of large modular arrays such as LAMAR over a period of time by revisits to a dedicated High Energy Astrophysics Platform? (We assume that modular arrays would have relatively modest requirements on co-alignment ~ arc minutes).
- Is the resupply of counter flow gas and other consumables by the exchange of storage tanks of experiments on a platform thought to be a feasible and cost effective operation?
- What are the trade-offs between sizing of consumable storage facilities and built-in redundancy (multiple detectors, etc.) and resupply and replacement?

It is reasonable to expect space assembled structures to be used as "optical benches" for very long ($\gtrsim$ 100 m) focal length telescopes, if mirror arrays or coded apertures carried aboard the Shuttle for installation in space? (We assume the inclusion of an active alignment monitoring and correction capability which is automated or can be operated by remote control.)

4. INSTRUMENTATION FOR SPACE PLATFORMS

We have identified two mamor categories of instruments which are suited for a space platform, although the platforms required are vastly different in conception. The first category involves extending the lifetime of Shuttle attached experiments by means of a platform capable of accepting spacelab pallets. We briefly describe these experiments in this section. These instruments have been described in detail in the High Energy Astrophysics Five Year Plan and in Shuttle-Spacelab documentation.

The second class of platform experiments are those that involve structures too large in either weight, or volume to be accommodated in a Shuttle launched free flyer: i.e., these experiments must be assembled in space. In this section we have also provided brief descriptions of such experiments and of their scientific rationale; we have also specified their engineering requirements in Table 4.1.

4.1 X-Ray and EUV Astronomy

4.1.1 LAMAR. The Large Area Modular Array of Reflectors (LAMAR) will be developed as a Spacelab facility in X-ray astronomy. Its objectives encompass a wide variety of studies in high energy astrophysics with particular emphasis on: (a) the deep all sky survey, (b) the detection and imaging of diffuse emission, (c) time variations in faint sources, and (d) non-dispersive spectroscopy combined with imaging. The major features of the LAMAR are large collecting area, good angular resolution to avoid source confusion, and a modular concept. The effect of modularity is to reduce technical complexity, facilitate testing and integration, and allow an evolutionary development with substantial growth potential. It is clear that a single seven day Shuttle mission or a series of short duration missions will provide sufficient time for only a small fraction of the possible studies that researchers will wish to carry out with the LAMAR. A very large LAMAR can be built up over a period of many years by adding additional modules of 10^4 cm^2 aperture through a series of Shuttle launches. Since this is a modular instrument, observations can be carried out through this entire period.

The LAMAR itself consists of banks of grazing incidence X-Ray telescopes either of the Bacz-Kirkpatrick or Wolter Type I design. The focal length of each telescopes are relatively short, i.e., of the order of 3 meters so each module easily fits into the Shuttle bay. The detectors can be either imaging proportional counters or solid state devices. The individual telescopes do not have to be precisely co-aligned within a module. The detailed instrument requirements are given in Table 4.1.

4.1.2 Spectroscopy. Spectroscopic observations are critical to the development of detailed physical models of several major classes of X-Ray emitting objects, as well as to detailed studies of such parameters as abundance, velocity, optical depth and density. Objects with narrow emission lines include supernovae remnants, stellar cornae, the hot interstellar gas, and clusters of galaxies. The study of these objects will require dispersive spectrometers with high resolving power. Lines in compact sources will be broadened so non-dispersive instruments with moderate energy resolution, but with high time resolution are more appropriate for the study of these objectives. Little is currently known about the details of the acretion disc dynamics and stability in these objects. Spectroscopic observations are also required to provide data on ionization states and velocity patterns in accretion discs.

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EXPERIMENT	LAMAR*	HIGH RESOLUTION SPECTROSCOPY (XRSE)	MODERATE (FE LINE) SPECTROSCOPY	POLARIMETRY	2.4 METER TELESCOPE	LARGE AREA TIMING FACILITY	ALL SKY MONITOR	LARGE AREA COLLECTOR	HIGH ENERGY X-RAY IMAGING
MEASUREMENT RANGE	0.1 - 6 KEV	0.5 - 8.0 KEV	6 - 8 KEV	2.6 - 7.8 KEV	0.1 - 10 KEV	2 - 30 KEV	0.1 - 30 KEV 2 - 30 KEV	0.1 - 10 KEV	6 KEV
FIELD OF VIEW	1.2° X 1.2°	1°	1°	1°	0.5°	1°	ALL SKY	1°	1°
EXPOSURE TIME PER SOURCE	10^2 – 10^5 SEC	1-3 DAYS	1-3 DAYS	1 - 14 DAYS	10^3 - 10^4 SEC	VARIABLE	2 YEARS REQUIRED	10^3 - 10^5 SEC	1 - 14
ANGULAR RESOL.	1 ARC MINUTE	1 ARC MINUTE	30 ARC MINUTES	N.A.	0.1 ARC SEC	N.A.	N.A.	1 ARC MIN	0.5" TO 3"
DURATION	10 YEARS	2-5 YEARS	2 YEARS	1 YEARS	10 - 20 YEARS	2 - 5 YEARS	2 YEARS	10 YEARS	1 YEAR
POINTING	6 ARC MIN	6 ARC MIN	6 ARC MIN	6 ARC MIN	1 ARC MIN	1°	NONE	10 ARC MIN	1 ARC SECOND
STABILITY	0.2° (INERTIAL)	10 SEC/SEC	N.A.	1 ARC MIN/SEC	0.1 ARC SEC/SEC	1 ARC MIN/SEC	30 SEC/SEC	1 ARC SEC/SEC	1 ARC SEC/SEC
MASS	2,000 KG/MODULE	2,000 KG	100 KG	500 KG	30,000 KG	250 KG	200 KG	6,000 KG	1000 KG
DIMENSIONS	3MX3MX3M/MODULE	3MX1MX3M	1.6MX1.6MX3M	1.2MX1.2MX1.2M	5M DIA. X 3MX30M	1.3M X 1.3M FRONTAL AREA 1.5m DEEP/MINIMUM	8 UNITS EACH 1.2M CUBE	8M X 4.8M X 100M	3M X 3M X 100M
POWER	300 W	200 W	150 W	100 W	6 KW	100W	120	2 KW	2 KW
THERMAL CONTROL	22° ± 5°C	22° ± 5°C	22° ± 5°C	22° ± 5°	20° ± 1°C	20° ± 10°C	16° ± 10°C	20° ± 5°C	20° ± 1°
NO. OF OBSERVATIONAL PARAMETERS	20 BITS/COUNT	32 BITS/EVENT	512 CHANNELS	20 BITS/EVENT	40 BITS/EVENT	(20 BITS/EVENT)	4 X 10^4 BINS OF ACCUMULATION	20 BITS/EVENT	32 BITS/EVENT
DATA/RECORDING RATE	>50 KB/SEC	30 KB/SEC	10 KB/SEC	2 KB/SEC	10^6 BITS/SEC	250 KBS (MAX)	UP TO 4 KB/SEC	10^6 BITS/SEC	100 KB/SEC
DATA HANDLING CAPACITY REQUIRED (BITE/DAY)	5 X 10^9	10^9	10^9	10^8	10^{11}	10^8 TO 10^9	UP TO 4 X 10^8	10^{11}	100
NO. OF DAY COMMANDS	40	100	40	50	100	60 - 70	50	60	50
EXP. DEV. TIME	2 - 3 YRS.	2 - 3 YRS.	2 - 3 YRS.	2 - 3 YRS	5 - 7 YEARS	0.5 - 2.0	3 YRS.	3 YEARS	
SERVICES REQUIRED	INFLIGHT RESUPPLY OF GAS (2 YRS) ADDITION OF MODULES	INFLIGHT RESUPPLY OF GAS (2 YRS), CRYOGENIC SERVICES		—	ASSEMBLY IN ORBIT RESUPPLY GAS (8 YRS) EXCH. FOCAL PLAN INST. (3-4 YRS)	RESUPPLY OF GAS	—	ASSEMBLY IN ORBIT RESUPPLY OF GAS (2 YRS) EXCHANGE OF FOCAL PLANE INSTRUMENTS	ASSEMBLY IN ORBIT

* LAMAR MAY BE EXPANDED TO ENCOMPASS 10 OR MORE MODULES
THE ORBIT REQUIRED FOR ALL INSTRUMENTS IS < 28°, LOW ALTITUDE

TABLE 4.1 X-RAY INSTRUMENTS

Table 4.1

GAMMA RAY INSTRUMENTS
(con't)

	Low Energy -Ray Spectrometer	High Energy γ-Ray Telescope	Compton Telescope/ Polarimeter	Gas Cherenkov X-Ray Telescope	All Sky γ-Ray Burst Detector
Measurement Range	0.1-10 MeV	20 MeV-10 GeV	2 MeV-30 MeV	0.1 GeV-100 GeV	20-150 keV
Field of View	10^{o}	40^{o}	15^{o}	10^{o}	All Sky
Exposure Time (days/source)	5-100 days	5-100 days	5-100 days	20-100 days	Duration of Burst
Angular Resol.	0.3^{o}	2 min.	0.3^{o}	0.2^{o}	1 $\widehat{\text{min}}$.
Duration	2-10 years	2-10 years	2-10 years	2-10 years	2-10 years
Pointing	1^{o}	1^{o}	1^{o}	1 $\widehat{\text{min}}$.	None
Aspect	0.1^{o}	0.2 $\widehat{\text{min}}$.	0.1^{o}	0.2^{o}	0.1 $\widehat{\text{min}}$.
Mass	10,000 kg	10,000 kg	3,500 kg	3,000 kg	1,000 kg
Dimensions	5m dia. x 10m	3m dia. x 5m	2 discs, 5m dia. x 1m, 20 m sep.	5m dia. x 15m	4 units, each 2m x 2m x 1m
Power	150 w	100 w	250 w	150 w	120 w
Orbit	28.5^{o}	28.5^{o}	28.5^{o}	28.5^{o}	28.5^{o}
Thermal	Possible cryogenics regd. $100^{o}K$	$0^{o}-30^{o}C$	$0^{o}-30^{o}C$	$0^{o}-30^{o}C$	$5^{o}-35^{o}C$
Bits per event	16	16	32	32	32
Data/Recording Rate	10^{4}	3×10^{3}	10^{4}	3×10^{3}	Up to 10 kb/sec
Bits/Day	10^{9}	10^{9}	3×10^{9}	10^{8}	10^{9}
No. of Commands/ Day	100	50	50	50	50
Exp. Dev. Time Years	3 years	3 years	4 years	4 years	3 years

Table 4.1

COSMIC RAY INSTRUMENTS
(con't)

	Protons, Alpha Spectrum, Low Z Nuclei	Elemental Composition 3 Z 26	Ultraheavy Cosmic Rays	Isotopic Composition	Electron Spectrum	Position Spectrum
Measurement Range	Up to 10^{16} eV	50 GeV/n to 4 x 10^4/n	$26 \leq Z \leq 100$	$2 \leq Z \leq 26$	10-1000 GeV	10-3000 GeV
Field of View	± 30°	± 60°	± 60°	± 40°	± 40°	± 40°
Exposure Time	1 year	1-2 years	2 years	1 year	6 months	1 year
Duration	1 year	1-2 years	2 years	1 year	6 months	1 year
Pointing	N/A	N/A	N/A	N/A	N/A	N/A
Mass	5000 kg	3000 kg	3000 kg	2000 to 5000 kg	2000 kg	4000 kg
Dimensions	2 x 2 x 3m	3 x 3 x 4m	20 m^2 sr	3 x 3 x 4m	2 x 2 x 3m	3 x 3 x 4m
Power	200 W	200 W	200 W	200 to 500 W	200 W	500 W
Orbit	Not critical		Moderately high inclination	Moderately high inclination	Not critical	
Thermal	0-30°C	0-30°C	0-30°C	0-30°C Perhaps cryogenics	0-30°C	0-30°C cryogenics
Data Recording Rate	20 k bit/sec	100 k bit/sec	10 k bit/sec	100 k bit/sec	20 k bit/sec	50 k bit/sec
Bits/day	2 x 10^9	10^{10}	10^9	10^{10}	2 x 10^9	5 x 10^9
Commands/day	50	50	50	50	50	50
Exp. Dev. Time	2 years	5 years	2 years	2-3 years	2 years	2-3 years

Since the spectra of supernovae remnants in the adiabatic phase are expected to be dominated by narrow emission lines, analysis of line intensities can provide information on thermal structure and composition within the remnant. Since supernovau remnants are significantly extended, their surface brightness is low and the study of structure in these objects makes substantial demands on instrument sensitivity as well as resolution.

The spectra of several classes of stellar galactic sources, coronae of normal stars (Capella, Alpha Centauri), flare stars (UV Ceti, Ross 882), hot white dwarfs (HZ43) and the central stars of planetary nebulae, and extended enhanced regions in the interstellar medium, should contain narrow lines. In the case of stellar atmospheres, temperature, composition and density can be inferred from relative line intensities and models of stellar corona and transition regions can be tested.

Spectroscopy of active galaxies, e.g., Seyfert galaxies, radio galaxies and quasars is an exciting area of investigation. The low intensity of these sources will demand instruments of very high sensitivity. A search for the presence of cool material in the vicinity of 3C273, for example, could provide a significant test of some quasar models.

The discovery of iron line radiation in clusters has profound implications for theories of the origin and heating of the hot inter-cluster gas responsible for the X-ray emission of the clusters. Lines in cluster sources may be narrow and the line intensity may show significant structure within these extended sources.

There are requirements for both moderate resolution ($\Delta E \sim 150$ eV) and high resolution ($\Delta E < 25$eV) spectrometers for X-ray astronomy. The moderate resolution instruments can make use of collectors and non-dispersive spectrometers (i.e., cooled, solid state detectors) and can, consequently, achieve a much higher sensitivity per unit area of aperture than can higher resolution instruments. Sources which are known to have narrow lines (such as supernovae remnants and cluster sources) will require the high resolution inherent in crystal and grating spectrometers; the diffuse nature of such sources will make extreme demands on instrument sensitivity. The observing times required for even a single observation with instruments of large aperture strongly argue for the need for a long duration capability. High resolution spectrometers will make use of focusing crystal configurations or of post crystal concentrators, and will require accurate pointing. Detailed specifications for both types of spectrometer are given in Table 4.1. Spectroscopic instruments can be modularized, since observations in different parts of the X-ray and EUV spectrum will require different instrumental approaches. A comprehensive X-ray and EUV facility could be built up over a period of time by the addition of such modules.

4.1.3 Polarimetry. At the present, polarization has been observed in two cosmic X-ray sources, the Crab Nebula and the compact source Cyg X-2. The Crab polarization results are now well established and are not unexpected. The Cyg X-2 result is less well established and will require a substnatial improvement in instrument sensitivity if it is to be positively confirmed and refined.

Polarization is potentially important in two types of sources: objects with strong magnetic fields (pulsars) and those in which asymmetric scattering in a thick plasma is important. Accretion discs in binary systems fall into the latter category. The level of polarization expected for binary systems is small, between 0.5 and 3.2 percent for one model of Cyg X-1, but can provide a unique mechanism to test detailed models of accretion disc structure. Models of emission mechanisms in pulsars predict levels of polarization of a few percent in the pulsed component of the radiation. Polarization measurements in the repetitive burst sources, such as MXB 1730-335 may prove crucial to the testing of X-ray emission models for these objects. The energy dependence of the polarization will provide a unique observational test for the presence of a rotating black hole.

If we require that 1 percent polarization must be detected in one day for sources of strength 1000 Uhuru counts*, an instrument of 10^4 cm^2 aperture is required, assuming a focusing collector is used as the polarization sensitive element.

Alternatively, polarization studies can be accomplished with a large collecting area of Bragg reflecting cyrstals which functions as both the polarizer and the focusing device.

4.1.4 Large High Resolution Observatory (2.4 meter or larger telescope).

High resolution observations are an important component of the program in X-ray astronomy. The first of these observatories, HEAO-B, which contains a telescope of 0.6 m diameter and a focal length of 3.5 m is scheduled for launch in the fall of 1978. The next generation observatory is the Advanced X-Ray Astronomy Facility (AXAF) which will have a 1.2 m diameter and a 10 m focal length. AXAF will be launched as a free flying observatory in the mid 1980's. Although results are not yet available from HEAO-B, it is evident that a high resolution X-ray observatory will be needed beyond AXAF. At this time it is not clear what form this observatory should take, that is whether it should have a single telescope of 2.4 m dia or larger with a 20 m or longer focal length or consist of an array of smaller telescopes.

This observatory must have sub-arc-second resolution and will have a variety of complex focal plane instruments. The observatory will have special requirements for mechanical and thermal stability and the requirements for cleanliness will exceed those of other high energy astrophysics payloads. The size requirements of a large high resolution observatory are beyond the capability of a single Shuttle launch, a system of multiple Shuttle launches with on-orbit assembly of the observatory is needed.

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*1 Uhuru count/sec = 1.7×10^{-11} ergs/cm^2 sec, 2-6 keV.

4.1.5 Large Area Timing Experiments. One of the major developments in the field of X-ray astronomy has been the discovery that the X-ray sky is highly time variable. The observed variability spans a vast range of scales and categories from the 33 m sec periodic pulsations of the pulsar in the Crab Nebula to the months long decay time of some of the X-ray transients. The discovery of the X-ray bursters has added another category of time variability to this list. It is important that detailed studies of the time variability of both the galactic and extra-galactic sources be extended both in sensitivity, time resolution, and energy. An important objective of this type of observation will be the study of compact stars in close binary systems, and the search for very rapid time structures which is thought to be characteristic of black holes.

X-ray timing experiments covering the energy range from 0.1 keV to several tens of kilovolts can be accomplished by a variety of instrumental techniques; the majority of which are well within the current state-of-the-art. Examples are modular arrays of grazing incidence telescopes with imaging detectors (LAMAR) or a single large area grazing incidence telescope (LAXC) with long focal length and moderate spatial resolution and, for the higher energies, a modular array of gas (or possibly gas scintillation) proportional counters. One common feature that all the experiments must share is large effective areas in order to extend the sensitivity substantially. In Table 4.1, we have described the characteristics of a large area gas counter and scintillation (XRTS), which the X-ray community regards as the highest of high priority missions. An experiment of this type lends itself well to a modular approach, and could be enlarged by additions of other modules after initial development.

4.1.6 All Sky Monitor. Time variations are characteristic of essentially all galactic X-ray sources. They occur on virtually all time scales; it is not feasible to study the full range of time variations with a single instrument. One of the principle objectives of this field involves monitoring the long term intensity changes of sources on time scales of minutes to years. Such monitoring must track all the brightest sources simultaneously and be capable of detecting the appearance of the transient X-ray sources. These studies may be accomplished with an all sky monitor that has the following characteristics:

(1) distinct resolution cells of a square degree over the entire sky to avoid source confusion

(2) effective area of about 4 cm^2 for each cell as part of a 120 cm x 120 cm position sensitive detector

(3) energy range 0.1 to 30 keV (or 2 to 30 keV with less technical difficulty using sealed counters)

(4) observing times of several years

(5) need for inertial stability of 0.2° min

These observations can be accomplished, for example, with a set of simple pinhole cameras that each cover one steradian of sky. A resolution cell size is $1^{o} \times 1^{o}$ and has a dimension of 2 cm x 2 cm. Background in each cell is very small. A set of these pin hole cameras could be mounted on a space platform for years of uninterruped observing. The instrument described above should be considered representative of a class of instruments which are capable of achieving tha scientific objections. There are also other categories of all sky monitors such as those designed to study the nature of - and locate the origin of - X-ray bursts.

4.1.7 Large Area X-Ray Collector (LAXC). A large area X-ray collector (LAXC) is well suited for flight on the large space assembled platform. Such an instrument would consist of a grazing incidence lens and a complement of selectable focal plane instruments. The primary focal plane instruments will be imaging proportional counters, non-dispersive spectrometers, and polarimeters. Such an instrument can be used for deep sky surveys, for the determination of the time structure of weak sources, and for the determination of the spectra of both discrete and extended weak sources. A particularly interesting problem would be the study of the structure of the hot interstellar gas. The size of the lens would be limited by the size of the Shuttle bay. If the lens is launched as a single entity, then the aperture could be 4.5m x 4.5m. With a 75m foot length, and a spatial resolution of 1 arc minute, one would achieve a sensitivity of 10^{-14} ergs/cm -sec (10^{-5} photons/cm -sec at 1 keV) with an observing time of 1,000 sec.

The advantage of this device is that it could be used with diverse focal plane instruments that do not require high angular resolution but do require a large collecting area. Such an instrument would require assembly and alignment in space after launch. The sensitivity could be improved by the addition of more collector modules after initial deployment.

4.1.8 High Angular Resolution and Hard X-Ray Imaging Experiments. There are a variety of classes of X-ray sources which show finite angular extent at X-ray energies (0.1 to 50 keV). To date these include supernova remnants, active galaxies in clusters, clusters of galaxies, and possibly superclusters of galaxies. The angular scale of these objects ranges from several arc seconds to order a degree or more. Resolution from 10 milliarcseconds to a few arc seconds will be required to resolve the fine structure anticipated from these sources. The region of the spectrum above ~6 keV is especially important due to the discovery of iron line emission in a wide variety of objects both galactic and extragalactic, and more recently the discovery of cyclotron emission and/or absorption features which have been detected in at least two of the galactic X-ray binaries at energies of order 10's of kilovolts. X-ray imaging at these energies is ideally suited for a space platform experiment as the entire class of experiments require larger volumes and structures than can be accommodated by the space shuttle.

Imaging at high X-ray energies can be accomplished by a wide variety of techniques which range from those which are well within the current state of the art to those which require long development times. All of these techniques will require long focal lengths with a device such as a mask, coded aperture array, grazing incidence X-ray telescope, or Fresnel zone plate at large distances (from 100 to 1000 meters) from an imaging detector assembly.

The long focal length will require assembly in space of the mask, and detector, separated by a suitable "optical bench" structure.

4.2 Gamma Ray Astronomy.

4.2.1 Low-Energy Spectrometer, 0.1 - 10 MeV. The primary objective of this experiment is to detect and measure nuclear X-ray lines from discrete objects and diffuse regions of the Galaxy and from high-energy extragalactic objects such as quasars, Seyfert galaxies and radio galaxies. The instrument should be sufficiently sensitive so that discoveries made by the Gamma-Ray Observatory (GRO) in the mid-1980's can be investigated in more detail and fainter objects and regions may be detected in the nuclear gamma-ray region.

The detector would likely be a large modular array of actively-shielded germanium and/or scintillation detectors or perhaps a newly developed detector material. The type of detector and its configuration would follow from results obtained by the GRO, early Shuttle flights and from new laboratory developments over the next 5 -7 years. Modulation and collimation techniques would provide an angular resolution of ~0.3 degrees. The instrument should not be located near other massive experiments or structures; a guideline that is less than 10% of the total surrounding solid angle of the instrument should consist of materials that are greater than $100 gm/cm^2$ thick. Similarly, the artificial radiation field in the energy range of the detector should be less than 10% of the expected ambient background. Candidate detectors would require cryogenic cooling. A typical requirement for germanium detectors is 20 watts of cooling at $100^{o}K$.

4.2.2. High-Energy Telescope, 20 MeV-10 GeV. Various astrophysical processes such as pion decay and strong nuclear interactions can only be studied by high-energy gamma ray observations. This experiment would study spectral characteristics and spatial extent of high-energy gamma radiation from galactic and extragalactic objects and regions with a sensitivity and angular resolution up to a factor of 10 greater than that obtained on GRO. In addition, the high-energy limit would be increased to 10 GeV. The high angular resolution, ~2 arc min, would only be obtainable at the higher energies.

The telescope would operate by detecting the trajectory of an electron-position pair through a multi-layered detector, a technique successfully used on the SAS-2 and COS-B spacecraft and approved for the GRO. The detector would be a multiwire spark chamber, drift chamber or proportional counter. It may be feasible to include recoverable particle-track detectors for high spatial resolution of the pairs. The frequency of recovery would be 1 to 6 months, depending on the detector type and the radiation background.

4.2.3. Compton Telescope and Polarmeter, 2 - 30 MeV. A Compton telescope appears to be best suited for studying astrophysical sources in this energy range. The Compton telescope provides spectral and imaging capabilities and has excellent background rejection outside of the field-of-view. In addition, the Compton scattering allows polarization studies in the gamma-ray region.

A Compton telescope for a space platform would likely have a larger array size than that on the GRO and smaller cell dimensions in order to improve the angular resolution. Assuming an increase in sensitivity and angular resolution 5 times that of GRO, the overall envelope of the Compton telescope would be 5 m diameter and 20 m long.

4.2.4. Gas Cerenkov Telescope, 1GeV. At the highest observable gamma-ray energies, the photon fluxes from space are extremely low, requiring large sensitive areas and long integration times. Conventional detectors may not afford the required area. At very high gamma-ray energies, a balloon-borne gas Cerenkov telescope has been used to detect pulsed radiation from the Crab Nebula. The telescope operates by imaging the Cerenkov light rings produced by an electron-position pair. The size and location of the rings focused on an array of photomultiplier tubes gives the energy and direction of the incoming gamma ray. Anticoincidence and time-of-flight requirements provide excellent background elimination. The dimensions of the gas Cerenkov telescope would be 5 m diameter by 15 m long. The front of the telescope contains thin scintillators and a metal mirror with an optical accuracy of 1 min. The focal region contains an array of ~100 photomultiplier tubes.

4.2.5 Burst Detector. Gamma-ray bursts are enigmatic phenomena which have eluded a satisfactory explanation due to their brief and transient nature. A sensitive, all sky camera in the energy region 20 keV to 150 keV is required to identify and study these sources. A burst monitor which relies on interplanetary timing for precise locations is part of the GRO. A single spacecraft instrument sensitive to weaker bursts may be required following the GRO.

The instrument should have sufficient angular resolution to unambigously identify an event with an optical or X-ray counterpart. One possible approach is an all-sky camera system utilizing a randonly coded, one dimensional mask in the form of a half cylinder which surrounds a position sensitive xenon proportional counter. Two identical modules would be required to monitor the entire celestial sphere. A very large radius for the cylindrical mask is required in order to obtain very precise burst locations.

4.3 Cosmic Ray Physics. Cosmic Ray Observations require instruments that are, in general, tailored towards a particular aspect of the cosmic ray phenomenon. While many commonalities exist in the instrumentation (for instance, scintillators, Cerenkov counters, and proportional - or drift chambers will be used in almost all instruments), the character of the investigations will, for the foreseeable future, remain in the P. I. class. One exception would perhaps be a large superconducting magnet spectrometer which could be constructed as a general facility and could serve for a variety of experiments.

The investigations described in the following illustrate the type and significance of research that will be performed in the 1980's.

Needless to say, this list cannot be complete. For instance, we have omitted those experiments that use the cosmic radiation as a tool of high energy physics research. We also have not included investigations that are exclusively devoted to searches for exotic particles.

4.3.1 Elemental Composition. The elemental composition of cosmic rays reflects the processes that are involved in the nucleosynthesis history, the acceleration mechanisms, and the interstellar propogation of these particles. Perhaps one of the most challenging discoveries has been the recent observation of a very peculiar energy dependence of the elemental composition: "Secondary" cosmic ray (those which are generated in interstellar space as spallation products of the "primary" or source particles) have been found to become less abundant as the particle energy increases. This effect could imply an energy dependent galactic confinement time of cosmic rays, or it could point towards a structure of the interstellar medium such that high energy particles are excluded from penetrating high matter density regions, or it could indicate the presence of sources of high energy particles close to the solar system. The answer to this question requires more accurate composition measurements at very high energies. Such measurements might also reveal changes in the composition of the primary cosmic rays that may be characteristic for particular classes of cosmic ray sources. It is now feasible to reach, in direct measurements, energies in excess of 10,000 GeV/ nucleon, thereby overlapping with the energy region of ground-based air shower experiments. This cross-check will greatly help to understand air-shower measurements, the only measurements which are available to cover the cosmic ray phenomenon up to the highest energies, beyond 10 GeV. Experimentally, the best approach to this measurement are electonic counter telescopes incorporating scintillators for charge determination, and providing energy measurements with Gas Cerenkov counters (50 - 200 GeV/nucleon), calorimeters (up to 1000 GeV/nucleon), and transition radiation detectors (500 GeV/ nucleon to $\sim$20 TeV/nucleon). In order to obtain statistically accurate results, the instrumentation must be of rather large size (several meter ster), and of fairly large mass (2-5 tons), and must be exposed for long duration $\gtrsim$1 year.

4.3.2 Cosmic Protons and Alpha Particles. Protons and alpha particles account for about 98% of all cosmic ray particles. An accurate knowledge of their flux and energy spectrum is not only indispensable for a satisfactory understanding of the cosmic ray phenonmenon, but also for an understanding of the production of secondary particles in interstellar space (gamma rays, positrons, antiprotons, etc.) and in the terrestrial environment (air showers). However, the present uncertainty is of the order of 50% around 50 GeV, and grows at higher energies. In fact, a claim published in 1971 by Soviet scientists, that the flux of protons decreases drastically around 10 TeV, has never been checked in an independent measurement, and a similar inference from air shower data at still higher energies awaits clarification. For a measurement of protons and particles, an electronic counter telescope with plastic scintillators should be used for charge determination, and a deep calorimeter must provides energy measurements (0.1 to 10 TeV). Transition radiation detectors are useful over a limited energy range. A sufficient geometric factor (1 m^2 sr) requires large weight ($\geq$ 5 tons). The exposure time should be of the order of 1 year.

4.3.3 Composition of Ultraheavy Cosmic Rays. The flux of cosmic ray particles heavier than iron is exceedingly small, and a measurement of the elemental composition in this region requires not only excellent charge resolution but also, and most importantly, exposure of very large area detectors for long periods of time. Nevertheless, such investigations are of eminent astrophysical value. The elemental composition of ultraheavy nuclei carries the signature of nucleosynthesis processes in the sources. For instance, rapid neutron capture processes (r-processes) lead to an abundance maximum near Platinum ($Z=78$) and a substantial flux of actinides ($Z\sim90$), while slow neutron capture (s-processes) would generate just a maximum near lead ($Z=82$). Also, several unstable species provide cosmic ray dating in the 10 to 10 year range. In addition, such experiments would also be sensitive to such fundamentally interesting particles as transuranic nuclei, in particular, the hypothetical stable nuclei around $Z\simeq120$. To detect ultraheavy cosmic rays, both active and passive instruments can be used. Active detectors would consist of large area arrays of plastic scintillators, Cerenkov counters, and ionization chambers. A charge resolution $\Delta Z\sim0.2$ is feasible. The total data sample should exceed that expected from an instrument under construction for HEAO-C by about a factor of 10. This leads to a geometric factor of about 20 m^2 sr if an exposure time of 2-3 years can be achieved. Passive detectors will probably use plastic track detectors similar to Lexan but with improved charge resolution. Again, very large area (possibly deployed at altitude) and long exposure times are needed, and recovery of the detectors is mandatory. These experiments would benefit from high inclination orbits.

4.3.4 Isotopic Composition. While important information can be obtained from measurements of the elemental composition, further advances are possible through determination of the "fine structure" of the abundance distribution, the isotopic abundances. Both, the generation of cosmic rays by nucleosynthesis, and the spallation processes during the propagation of cosmic rays in interstellar space involve nuclear rather than atomic processes affecting the isotopic compostion of the individual elements. Isotopic abundance studies will, for example, yield the most intimate information about a fundamental question of cosmic ray research: are cosmic rays generated in supernova explosions, or are they basically interstellar material that has been accelerated by some other mechanism? The answer may come from measurements of the neutron excess of several elements, and, particular, from measurements of the isotopic composition of Iron nuclei. Other aspects of isotopic composition studies involve the search for unstable isotopes which provide natural clocks for astrophysical processes. Several isotopes that decay by K-electron can be used to obtain a measure of the time span between nucleosynthesis and acceleration (when they are stripped of their K-electrons and can no longer decay). Other unstable isotopes, most notably the interstellar spallation product Be (T=1.6 x 10 y), have lifetimes that are comparable with the expected galactic containment time of cosmic rays and can therefore be used as a measure of the cosmic ray containment.

The instrumentation required for isotopic composition measurements will consist of electronic detectors that measure the charge Z of the particle with scintillators or plastic Cerenkov counters, and those that determine two additional parameters from which the mass of the particle can be determined. A most promising technique in the energy region around 1 GeV/nucleon is a measurement of magnetic rigidity and particle velocity. Such measurements require a magnetic field. This can either be the earth's magnetic field, or large magnet (superconducting). Velocity measurements are performed with Cerenkov counters of appropriate index of refraction. The particular combination chosen puts constraints on the geomagnetic cut-off region in which the experiment can be performed, i.e. the orbital inclination is critical. Long duration flights (~ 1 year) are important for good statistical accuracy. An on-board magnet will make the detector quite massive (several tons) and may require protection of adjacent instrumentation from stray fields.

4.3.5 Electrons and Positrons. Negative electrons are accelerated in cosmic ray sources at an abundance of approximately 1% of the nuclear cosmic radiation. The characteristics of the acceleration process that are responsible for this particular abundance ratio are not understood at present. The shape of the electron energy spectrum measured near earth is influenced by radiative interactions between electrons and interstellar fields and may be quite different from the spectrum at the source. In fact, these radiative processes (which are absent for the nuclear cosmic radiation) are the reason for the great interest in studies of electrons as probes for the electromagnetic component of the interstellar medium. The shape of the electron spectrum is intimately related to the containment time of cosmic rays in the galaxy. Recent measurements give strong evidence for a rather steep spectrum and a long containment, ~10 years. However, the measurement must be made more accurate, and must be extended to higher energies, and, further, the injection spectrum of electrons is still unknown. The latter information can only indirectly be derived from a determination of the spectrum of positrons: Positrons are generated as secondary products of interstellar p-p collisions. Their injection spectrum is therefore essentialy known. They undergo radiative interactions in the same way as electrons, and the deformation of the spectrum can therefore be directly measured. The absolute intensity of positrons also gives independent information about the propagation characteristics of their parent protons.

The measurement of the energy spectrum of all electrons ($e^+ + e^-$) will be best performed with an electronic counter telescope that uses scintillators for charge determination, a sufficiently deep shower detector for the energy measurements and background rejection, and a transition radiation detector for proton rejection. With a geometric factor of ~$1m^2$ sr, and an exposure of several months, a very accurate measurement up to about 100 GeV is possible.

The identification of positions requires the addition of a superconducting magnet of sufficient strength and lever arm to separate positive and negative electrons up to at least 200 GeV. An exposure time of several months is needed for an accurate determination of the positron spectrum up to several 100 GeV.

5. SUMMARY OF PLATFORM REQUIREMENTS

We have identified three classes of space platforms classes II, III and IV) which provide long duration observations in space as an alternative to the free-flying dedicated observatories (Class I). Class II, small single discipline platforms, would typically consist of 3-4 pallets; Class III, large multiple discipline platform might consist of as many as 20 pallets; Class IV includes very large (50-100 meters or more) space assembled structures. We summarize the requirements for each class of platform in Table 4.2.

TABLE 4.2. PLATFORM REQUIREMENTS

X RAY AND EUV ASTRONOMY

Requirement	Class II	Class III	Class IV
Orbit	$<28^{0}$	$<28^{0}$	$<28^{0}$
Stabilization	1 arc sec/sec	1 arc sec/sec	1 arc sec/sec
Orientation	1 arc minute	1 arc minute	1 arc minute
Data			
TM Rate (bit/sec)	10^{4}	10^{5}	10^{6}
Storage (bit/day)	10^{9}	10^{11}	10^{11}
Maintenance	Required	Required	Required
Assembly	Not Required	NOT Required	Required
Checkout	Not Required	Required	Required
Environmental			
Vibration	Very sensitive	Very sensitive	Very sensitive
Contamination	Very sensitive	Very sensitive	Very sensitive
Power/Weight/Size	3 kw/5000 kg/ 3m x 3m x 3m	5 kw/10,000 kg/ 3m x 3m x 30 m	7 kw/30,000 kg/ 6m x 6m x 100m
Operation			
Ground	Required	Required	Required
Shuttle Attached	Desirable	Not Required	Not Required

TABLE 4.2. PLATFORM REQUIREMENTS

GAMMA RAY ASTRONOMY
(con't)

Requirement	Class II	Class III	Class IV
Orbit	$<28^0$	$<28^0$	$<28^0$
Stabilization	~0.1 min/min	~0.1 min/min	~0.1 min/min
Orientation	~1 deg	~1 deg	~1 deg
Data Rate	10^4 kbs	3 x 10^4 kps	10^5 kps
Maintenance			
Assembly	Minimal	Minimal	Minimal
Checkout			
Environmental Vibration Contamination	Not critical	Not critical	Not critical
Power/Weight/Size	100 w 1000-5000 kg 1 m^3	200 w 1000-10,000 kg 1-10 m^3	400 w 1,000-20,000 kg 1-100 m^3
Operations Ground Shuttle Attached	N/A	N/A	N/A

TABLE 4.2. PLATFORM REQUIREMENTS

COSMIC RAY PHYSICS
(con't)

Requirement	Class II	Class III	Class IV
Orbit	Not critical	high inclination designed for some experiments	
Stabilization			
Orientation	Instruments must be pointed away from earth		
Data TM Rate Storage	10-100 kbit/sec continuous		
Maintenance			
Assembly	None in orbit requiring man-activity except retrieval of passive detectors		
Checkout			
Environmental Vibration Contamination	Not critical		
Power/Weight/Size	100-500 watts	2000-10,000 kg	15-50 m^3
Operations Ground Shuttle Attached	N/A	N/A	N/A

CHAPTER III

ASTRONOMY PANEL

Panel Chairman: H. Warren Moos, John Hopkins University

Panel Members:
Bernard Burke, MIT
Ed Erickson, ARC
Francis Everitt, Stanford University
Ed Jenkins, Princeton University
Nancy Roman, NASA Headquarters
Jeff Rosendahl, NASA Headquarters

Panel Liasion (MSFC): Allen Gary

1. SUMMARY

Astronomical missions in space extend our perceptions of the universe beyond those obtainable from the ground in one of mankind's oldest sciences. The faintness and diversity of objects in the sky together with the many different ways we have of observing them dictate the need for long operating times in orbit. Astronomers have already defined a broad base of experimental disciplines which can be accommodated by the various Spacelab configurations aboard the Shuttle. We look upon the Space Science Platform (SSP) as a potential system for overcoming the time limitations of Spacelab flights. To achieve this goal, we recommend that the SSP be designed to accommodate Spacelab pallets containing instruments for which we can define a strong scientific need for extended times in orbit. For a vigorous program in astronomy, it is <u>absolutely essential</u> that the large costs of integrating payloads to a space vehicle and its support systems be borne only once; hence we strongly urge that the SSP be designed to eliminate, or at least greatly reduce, any interface incompatibilities which may arise when an experiment is transferred from the Spacelab environment to the SSP. While the SSP can also increase observing times by supplying power to extend the duration of Shuttle missions, we believe that this is of secondary importance.

In this report, we define a broad range of experiments which have a strong scientific potential and which could be installed on the SSP, preferably after some initial trials on the Spacelab. We assign the highest priority to developing an SSP which mimics the properties of Spacelab, permitting a modular transfer of experiments with minimum change. However, we have also looked beyond these projects to special categories of research which may require, because of their large size, a platform which has a virtually unrestricted potential for physical growth. A number of issues in engineering, management, and cost arise from our study of representative experiments. As a result, we have posed a series of questions which need to be addressed in formulating the applications of the SSP to the needs of astronomers. Finally, we recognize that some disciplines are better suited to, or absolutely require, the exclusive use of dedicated free flyers, and we give some examples accompanied by the reasons why they are unsuitable for either Spacelab or SSP.

2. INTRODUCTION

Some of the major themes and questions to be addressed by astrophysics in the 1980's are as follows:

The nature of the Universe
- How did the Universe begin?
- How do galaxies form and evolve?
- What are quasars?
- Will the Universe expand forever?

The origins and fate of matter
- What is the nature of stellar explosions?
- What is the nature of black holes?
- Where and how were the elements formed?
- What is the nature of cosmic rays?

The life cycle of stars
- What are the composition and dynamics of interstellar matter?
- Why and how does interstellar dust condense into stars and planets?
- What are the nature and cause of stellar activity?
- What is the interaction between stars and their environment?
- What is the ultimate fate of a star like the Sun?

Physical laws and principles
- What is the nature of gravity?
- Are there new laws and principles to be discovered under the extreme conditions studied by astronomers?

Since photons provide the primary source of information on the universe beyond our solar system (with the minor exception of cosmic rays whose origins are disguised by their circuitous paths through space) it is imperative that we extract as much information from these photons as possible. This requires that we measure the arrival rates of photons of all energies as a function of direction, energy, time, and polarization properties. The dearth of photons may require us to combine photons with dissimilar properties in various ways. Specific energy ranges and other characteristics are most helpful for particular problems; but to progress toward answering such questions as listed above, a diversity of instruments and approaches will be required. The SSP in conjunction with the Spacelab and free flyers appears to be an important component in attacking these problems.

Recognizing the preliminary nature of the concepts for the SSP at this stage, we have formulated a number of critical questions which must be investigated and thoroughly answered as the SSP concept is further studied and refined. We have divided these questions into three classes: engineering, management, and cost.

2.1 Engineering Questions.

- To what extent will it be possible to construct an SSP which mimics the Spacelab mechanically, thermally, and electrically?
- What is the maximum angular momentum that the control moment gyro can accommodate during telescope slewing?
- How stiff are the complete SSP structures? How does one achieve damping of low-frequency vibrations?
- Can one mount on the platform a long (200 m) instrument with 1000 kg masses at each end and use the platform to point it within, say, 1 arc min? Can smaller instruments be included on the same system on smaller pointing mounts? What would be the pointing accuracy and slew rate for this configuration? The same questions must be answered for a 1 km structure, as proposed for the gravity wave interferometer.

- To what degree is the platform pointing constrained by the need to have the solar panels nearly perpendicular to the sun-line? Are there methods of moving the panels to increase the allowed range?
- To achieve a stable thermal condition for large structures (e.g., a telescope), what are the merits of a sun-synchoronous orbit to insure continuous exposure to the Sun?
- How will multi-insturment platforms provide isolation for individual experiments with respect to pointing, electromagnetic interference (electric, rf, magnetic, etc.), contamination, and communication use? What are the costs, in all resources and in integration costs, of providing this isolation? How good will it be in each case? If time sharing is required, what type of duty cycle can we expect?
- What is the impact of installing very large structures on SSP's which are designed to accommodate Spacelab experiments?
- Is it essential to put 1 km long structures in geosynchronous orbit to eliminate problems from gravity gradient disturbances?

Several experiments may require large quantities of liquid helium for operation, possibly as much as 4 tons per year. At what level does it become more efficient to operate a closed cycle refrigerator? What are relative advantages of individual storage tanks, a central storage tank, and a refrigerator? What are trade-offs between an onboard refrigerator and visits to space platform to refill storage tanks?

2.2 Management Questions

- How many platforms will be available for Space Science? How many for astronomy?
- How frequently will the platform be revisited for such services as film exchange and cryogen supply?
- Will the same platform be used as a power supply for the Shuttle when it is docked? If so, what will be the power-sharing plan for experiments on the platform? What will the duty cycles be for experiments in the SSP?
- What provisions will there be for continuing discussions between experimenters and engineers as the SSP concept develops?

2.3 Cost Questions

- What are the problems involved with the in-space construction envisioned for the platform? How do the costs compare with the launch of an integrated system?
- What are the relative costs of pallets, cubes and beam machine structures in various applications?
- How will the cost of doing an experiment on the platform compare with the cost of doing it on an individual free flyer with integration and test costs included? How does the cost vary with instrument size?
- Is there substantial cost saving in constructing an SSP which is limited to Spacelab integrated instruments only?
- Is it economically efficient to produce cryogens on board a central utility?

3. THE ROLE OF SHUTTLE AND PLATFORM-BASED EXPERIMENTS IN THE 1980'S

The general approach in space astronomy has been to build simple instruments and test them on balloons or rockets. As the need increases for more detailed information and the greater sensitivity which permits us to observe objects farther away, more powerful instruments are flown on orbiting spacecraft. During the 1980's, we expect this evolutionary procedure to continue. Instruments will be developed for and proven on the Space Shuttle. With demands for better information, the instruments developed for the Spacelab or large instruments based on demonstrated concepts will be placed in orbit for long periods of time.

It is almost impossible to over-emphasize the importance of extended flight times to the discipline of astronomy: astronomers continually work on the edge of acceptable signal-to-noise ratios as they probe deeper into the Universe. Continued progress calls for both large optics and long integration times, correlative studies of many objects, studies of violent time dependent events and improved measurements of size and position. To a certain extent, these needs can be met by repeated spaceflights. In practice, small variations in experimental conditions from flight to flight and the prohibitive costs make this impractical. The SSP appears to be a desirable partial solution to these needs for extended flight times in orbit and for large instruments.

We have not made a detailed comparison of the SSP with free flyers. For simple Spacelab-type experiments we are not able to pinpoint the advantages of one type over another. The relative advantages, including interactive effects between experiments and cost,must be evaluated for a particular experiment in making a choice and will vary with the detailed design of the SSP. However, one obvious advantage will be the ability to add Spacelab experiments to the SSP in a simple modular manner. If proven Spacelab instruments can be used on their pallets without modification to provide extended observing times, substantial cost savings may be realized. Extended observing time would then be provided with only periodic visits to replenish films or cryogen or, occasionally, to exchange focal plane instruments ($\sim$200 kg). To this end, efforts should be made to make the SSP environment similar to that of Spacelab in order to simplify integration and minimize the impact of changes in the electrical, mechanical, and thermal designs.

The SSP concept, perhaps in a different form from the Spacelab compatible SSP, also appears to be extremely attractive for experiments of a very large size. Unlike the case of the Spacelab experiments for which a great deal of study and detail is available. there has been little study of these large instruments. We did not develop these concepts in the limited time available at the workshop. There is a need for additional study in this area after the SSP has been better defined. There is also a need to determine whether the SSP concept, as it develops, can cover both the flight of Spacelab class instruments and very large instruments.

As a secondary role for the SSP, we recognize the advantage of using it to increase the duration of Spacelab missions. Some experiments may not have the importance to justify their establishment as long-term experimental facilities but would still profit from somewhat longer observing times. Other experiments may require in-orbit support by personnel in space, and these projects would also benefit from the increased duration. We wish to emphasize, however, that if the role of the SSP were only to extend the Spacelab time, from the standpoint of astronomy, the value of SSP would not be commensurate with the cost and effort required for its implementation.

Finally, we note that there are experiments for which the SSP approach is completely inappropriate. Examples are some of the gravitational experiments discussed in Section III which require a free flyer designed to optimize the particular experiment and minimize disturbances to an extreme degree.

4. REPRESENTATIVE EXPERIMENTS

As a means of exploring the SSP concept, we have considered a representative set of experiments. These experiments, shown in Table 4.1 with some of the requirements, range from well-studied Spacelab-class instruments to very large instruments which will probably not be implemented for at least a decade. These experiments are discussed in detail in the following subsection. The subsection on gravity experiments details several experiments which cannot use the SSP.

4.1 PI Class Instruments

A number of moderate , Principal Investigator (PI) size instruments for Spacelab will be available shortly. As a result, they could be the first experiment placed on the SSP. Although the characteristics of the instruments are quite varied, they are generally light ($<10^3$ kg), of moderate volume (<diameter <1 m; length <5m), and they have small power requirements ($<$1kw).

Many of these instruments are still in the proposal stage. As examples, we describe three which could be proposed. The first is an ultraviolet photometric polarimeter which requires long observing times to study time-dependent events in quasars, Seyfert galaxies, novae, supernovae, dwarf novae, and X-ray sources. The experiment has been studied for an Explorer mission. The instrument is a telescope which feeds a 16 Å resolution spectrograph. The complete experiment package weighs approximately 70 kg. We estimate the package dimension to be approximately 0.5 x 2 m. The pointing requirement is 36 arc sec, and the data rate is $\sim 10^5$ bits per sec.

The second instrument is a long focal length EUV spectrograph for very high spectral resolution studies of the interstellar medium below 1200 Å, where reflection must be minimized. The package weight is $\sim$500 kg, with dimensions of 0.5 x 5 m. The pointing requirement is 0.1 arc sec for at least 1 hour, and the data rate is $\sim 10^5$ bits per sec.

TABLE 4.1

REPRESENTATIVE ASTRONOMY EXPERIMENTS FOR THE SSP

Experiment	Dimension[1]	Mass[2] (10^3 kg)	Stability[3] (RMS Range) (arcsec)	Data Rate (MBit/s)	Major Onboard Data Processing	Power (kw)	Orbit[4]	Special Requirements
PI Class	$D \leq 1$ $L \leq 5$	0.5-1	0.1-100	0-1	No	~0.1	LEO	Film Pickup Cryogens
Starlab	D = 1 L = 5(10)	2	0.02	3-30	Data Storage	~0.2	LEO	Film Pickup
DUVS (SWAT)	D = 1 L = 2	1	0.5	10^{-4}	No	~0.2	LEO	Film Pickup
UVOI	$L \sim 10^2$	5	0.1	10^{-2}	Yes	$\lesssim 1.0$	LEO	
SIRTF	D = 1.5 L = 10	2.5	0.1	3	No	1.0	Sun Synchronous/ LEO	Cryogen No Contamination
DAIT	D = 10 L = 30	4	0.5	3	No	1.0	Sun Synchronous/ LEO	Cryogens Low Contamination
LIRMI	$L \sim 10^3$	17	1	10^{-2}	Yes	3.0	GEO	Cryogens No Contamination
Submillimeter	D = 10	4	1	10^{-2}	Yes	2.0	LEO	Cryogens
VLBI	D = 30 L = 10	2	30	4-40	No	1.0	High inclination, preferably eccentric	Onboard position monitor
Solar-Gravity	D = 1 L = 10	1	0.01	10^{-2}	Yes	~0.2	LEO	
Gravity Waves	$L \sim 10^3$	16	3600	10^{-3}	Yes	<1.0	GEO	

[1] See text for abbreviations.

[2] D = Diameter, L = Length

[3] Platform stability should be adequate to allow Instrument Pointing System (IPS) or similar system to provide sub arc second pointing; remaining stabilization will be provided internally. Pointing should be within 1 arc minute. It should be possible to slew Spacelab-class instruments to any new position within ten arc minutes if platform motion is not required. Platform motion should permit reorientation to any new position within one 90 minute orbit.

[4] Low Earth Orbit (LEO): Geosynchronous Orbit (GEO)

A third example is the IR survey experiment being built for Spacelab II. This experiment consists of a small (~15 cm) cryogenically cooled telescope mounted on its own set of 2-axis gimbals. The telescope is approximately 1.5 m long, with the long tube being used to provide stray light baffling. As the Shuttle orbits the Earth, the telescope oscillates (at a rate of one sweep per minute) through a 90 degree arc perpendicular to the orbital plane, thereby sweeping out an appreciable fraction of the sky. Cryogens are supplied to the telescope from a 250 liter liquid helium dewar. Ten sensors are located in the telescope focal plane and cover the wavelength interval 4.5 to 230 μm. This telescope is optimized for the detection of extended sources ($\geq$30 arc min). The prime scientific wavelength bands are virtually identical to the Infrared Astronomical Satellite (IRAS) bands and the survey will complement the sensitive point source survey to be carried out by IRAS.

Similarly a number of moderate size instruments will be available to perform experiments which require the long observing times provided by the SSP or free flyers.

4.2 Starlab

An attractive feature of flying on Spacelab is the relative ease in preparing the instrument for space observations. Much of the overhead of the support systems can be taken over by standardized equipment associated with the Spacelab, and the payload operations can be run or supervised by personnel in space. Furthermore, the equipment can be modified between successive Skylab flights, thus permitting more operational flexibility and making specialized configurations more justifiable.

There is, however, a serious drawback of operating instruments aboard Spacelab. A vast majority of the proposed astronomical observing programs require a great deal of time, and when one draws comparisons with free flyers, the large disparity of time available becomes apparent. In this context, for instance, we may consider the coverage by the wide field camera on Starlab, and compare it with its counterpart aboard the Space Telescope (ST).

A principal aim of the Starlab camera is to provide a relatively large field of view(0.5 degree diameter) with an angular resolving power and limiting magnitudes which surpass those obtainable from the ground. For individual, small objects, the Starlab camera performance is inferior to that of the ST, but its 90 times larger field area serves well those programs which require more coverage of the sky, such as searches for new objects or imaging of sources with large angular scales. The differences between ST and Starlab are analogous to those of Earth resources satellite and conventional aerial photography; in both situations the contrast in resolution and coverage makes each mode serve different observing objectives.

In the regime in which photon statistical uncertainties dominate other sources of noise (e.g., detector dark current or readout noise, diffuse sky background light, cosmic rays, etc.), we find that, to a first approximation, the Starlab camera can survey point sources to a given limiting magnitude over 16 times as much solid angle per unit of exposure time as can the ST (a factor of 90 gain in field area divided by ratio of aperture diameters squared). One can probably increase this number by a factor of about two because of the extra slewing and camera preparation overhead the ST camera would need for taking the many multiple exposures. However, this strong survey advantage of Starlab is badly eroded by the low observing time duty factor which would be realized from successive Shuttle sorties. If Starlab could fly twice a year and each flight could last 2 weeks, one has, to first order an observing duty factor of 1/13. This reduces the coverage advantage of Starlab to only 2.5 times that of ST, which may not be a large enough gain to justify the building and use of this instrument. If one removes the restriction of operating Starlab only during Shuttle flights, on the other hand, the low duty factor is no longer a problem and Starlab has a clearly recognizable importance for field coverage. In reality, of course, both ST and Starlab have reductions in duty factor because of the need to share camera time with other instruments.

Beyond the limitations of observing time, there are technical problems which may be eliminated if we allow a telescope such as Starlab to travel aboard the SSP instead of Spacelab. Shuttle thruster firings result in impulsive corrections of the vehicle's attitude. The hierarchy of systems which offer finer degrees of stabilization, such as IPS and the image motion compensator internal to the instrument, must cope with the large frequency bandwidths from the disturbances which need to be corrected.

In general, the requirement of high frequency response is especially formidable for systems which rely on tracking faint star images due to the low signal to noise. If, on the other hand, the vehicle's attitude were controlled by control moment gyros (CMG), as is proposed for the SSP, disturbance bandwidths could be considerably reduced, provided the other experiments on board did not generate mechanical impulses of appreciable magnitude.

Another difficulty encountered with Shuttle thruster firings is the short-time environmental contamination by the propellant. Molecular column densities can attain values which are sufficient to compromise measurements of infrared emissions and the high resolution spectroscopy of sources in the far ultraviolet. Also, we may discover that other sources of contamination from the Shuttle are intolerable for certain classes of observation.

In stating our preference for control moment gyros for attitude control, we must be careful to specify that they be able to accommodate changes in angular momentum which are equivalent to fairly massive telescopes slewing at reasonable angular rates. For example, Starlab slewing at 6° per minute will require a reaction angular momentum on the order of 15 kg m^2 s^{-1}. If more than one telescope is on board, one should anticipate that they may need to be slewed simultaneously in the same direction.

4.3 Deep-Sky Ultraviolet Survey (DUVS)

Another instrument whose goals are better realized by nearly continuous observing is the Deep-Sky Ultraviolet Survey (DUVS) telescope now renamed Spacelab Wide Angle Telescope (SWAT). This proposed instrument should photograph fields 5 degrees in diameter with an angular resolution of approximately 2 arc sec. For complete coverage of the sky in any specified wavelength band, approximately 3000 exposures are needed. If two exposures are completed during each orbit, an entire survey could be completed in approximately 100 days if the telescope were allowed to run full time on an SSP. If, on the other hand, the DUVS relied entirely on observing during Spacelab flights of only 2 weeks duration, we would need approximately 7 such flights to record the same amount of data.

4.4 The Ultra-Violet Optical Interferometer (UVOI)

The purpose of an Ultra-Violet Optical Interferometer (UVOI) is to provide a large increase in precision of stellar distance and mass measurement, and to map the fine structure of galactic nuclei, quasars, and Seyfert galaxies. It is a Michelson stellar interferometer consisting of two 1-meter telescopes mounted at least 10 meters apart on a graphite fiber reinforced plastic structure. Light signals from the two telescopes are combined in an interferometric detector, with the two signal paths equalized and controlled to a fraction of the operating wavelength. Pointing with high stability must be achieved for long observing periods. From a scientific point of view there is a strong case for increasing the length of the interferometer arm from 10 m to ~200m. This would allow us to resolve structure of 0.1 solar diameters at a distance of 5 parsecs. Such an increase in size, while very desirable, cannot be accommodated by currently planned spacecraft, such as the Multimission Modular Spacecraft, because the increase in size raises the moment of inertia by more than a factor of 400. The maximum slew rate of a 10 meter system with the multi-mission satellite is 4 degrees per minute. With the same pointing control system the maximum slew rate of a 200 m instrument would be about 0.1 degree per hour. It seems possible that a large instrument of this kind could be mounted on a SSP.

4.5 Shuttle Infrared Telescope Facility (SIRTF)

Presently, observational infrared astronomy is severely limited over most of its wavelength range by atmosperic absorption and intense background emission from warm optics and the atmosphere. An infrared observatory placed above the absorbing and emitting terrestrial atmosphere with optics cooled sufficiently to reduce their radiation below the natural background would be an enormously powerful tool for astronomy. A general-purpose infrared observatory in space is a logical technical and scientific follow-on to existing airborne infrared telescopes and to the Infrared Astronomical Satellite(IRAS) that will perform an all-sky infrared survey with high sensitivity.

The Shuttle Infrared Telescope Facility (SIRTF) will be a cryogenically cooled, ~1.5 m diameter telescope designed for flights on Spacelab. This instruments spectral coverage will extend to 1 mm. Such a telescope, with optics cooled below 20 K, would observe against background radiation at least 10^6 times lower than ground-based telescopes. Over much of the three decades of the infrared wavelength range, SIRTF will provide a 1000-fold increase in sensitivity over presently available facilities.

An open-cycle, helium-cryogen system with 30-day capacity will cool the telescope to 10 to 20 K. Thus, even without cryogen replenishment, SIRTF could benefit from the extended Spacelab mission duration provided by docking the Shuttle to the Power Module. It is clear that the maximum effectiveness for SIRTF will be realized by mounting the instrument on a platform - such as the proposed SSP - which can supply cryogens for periods of several months or more. This latter operating mode without costly trips to Earth and back provides the observing time required for many important investigations. However the projected cryogenic requirement is very high. Consideration may have to be given to the use of a closedcycle refrigerator.

SIRTF places special demands on the environment of the SSP. In particular, care must be taken to minimize contamination of the cold surfaces of SIRTF, and to prevent extraneous radiation from reaching the detectors. Levels to be achieved would be the same as for operation on the Spacelab:

(1) Molecular contaminants: the CMG stabilization system of the SSP should be cleaner than the thrusters used for stabilizing the Shuttle. The column density of infrared emitting molecules (H_2, CO_2, CO, OH) must be less than 10^{11} molecules cm^{-2}. If angular gradients of this column density of more than 1%/120° are anticipated, then the column density should be lower. Higher column densities are tolerable at the risk of degrading performance. The flux of molecules (other than H_2 and He) must be less than 10^{12} cm^{-2} s^{-1} to prevent significant absorption by deposited contaminants.

(2) Particulate Sightings: Production of particles by the SSP (as a result of spallation by impact of micrometeroroids, particles in vented gas, etc.) should be limited so that an average of less than one per minute enters a 1.5×10^{-5} steradian (15 arc minute diameter) field of view along any line within 60 degrees of the axis of optimum viewing. A discernible particle is one with a diameter of 5 μm or more within a range of 10 km, moving with a velocity of less than 100 m s^{-1} relative to SIRTF.

(3) Radiated Power: Care must be taken to prevent power thermally radiated by the SSP from reaching the cold telescope and detectors. Fundamental limiting backgrounds for SIRTF are scattering and emission of the zodiacal dust, and emission from the telescope itself. The sun of thse backgrounds is strongly wavelength dependent and varies from about 3×10^{-13} to 7×10^{-11} watts cm^{-2} s^{-1} $steradian^{-1}$. Detectable emissions by the SSP should not exceed that from the fundamental sources of background.

(4) Transient contamination sources: The SSP must warn SIRTF at least 5 minutes prior to events that would exceed contamination specifications to allow time for closing up the telescope. Such events would include waste dumps, EVA's, arrivals, and departures of spacecraft.

4.6 Deployable Ambient Infrared Telescope (DAIT)

The Deployable Ambient Infrared Telescope (DAIT) would be a large (~ 10 m diameter) ambient-temperature telescope didicated to infrared and submillimeter astronomy. The DAIT would open up the infrared spectral range from 20 μm to 1 mm to observations with good angular resolution. The design goal would be ~ 2.5 arc second images (diffraction limited > 100 μm). The large aperture mirror emissivities of about 0.01 would ensure good sensitivity as well.

The scientific applications would emphasize the study of obscured objects, where dust opacity precludes observations at shorter wavelengths. Although the mirrors are at ambient temperature, cryogenic cooling of detectors would be necessary; with proper shielding, cold hold times of one year are feasible with current technology. Multiple focal plane instruments would be included; a typical instrument complement would consist of (1) a multiband infrared photometer/camera, (2) a high resolution echelle spectrograph with array detectors, and (3) a submillimeter heterodyne spectrometer.

Annual visits by the Shuttle to replenish cryogens and modify or change instruments would be required for continuous operation of the DAIT.

4.7 Large Infrared Michelson Interferometer (LIRMI)

The Large Infrared Michelson Interferometer (LIRMI) would utilize the technology of space fabrication of a long (on the order of 1 km) beam with light collectors at either end to permit high angular resolution observations at infrared wavelengths beyond about 50μm. Such a large instrument will require special care for mechanical stabilization and monitoring of the baseline between the two collectors, and in steering the device from one direction to another. The beam would have telescopes at either end, and possibly one in the middle to allow compensation for inclination changes. The telescopes, possibly 2 to 3 m in diameter, would track the same object with sufficient accuracy to keep the source centered within the main lobe of the beam of each telescope, an accuracy of 0.6 arc seconds for 2 m telescopes at 50μm wavelength. Baseline monitoring to $\lambda/10$ to $\lambda/100$ will be required.

At a 50 μm wavelength, a 1 km baseline will provide about 10 milliarc second spatial resolution. This is comparable to resolutions currently achieved by very long baseline interferometry techniques. The direct detection of a planet like Jupiter orbiting a nearby star would be possible in principle with such a system, although cryogenically cooled collectors would be required for this application because of the low flux levels.

4.8 Millimeter and Submillimeter Space Telescope

Atmospheric absorption and emission in the millimeter (mm) and submillimeter (sub-mm) wavelength range make many investigations impossible from the Earth. A 10 m telescope in Earth orbit would open up this wavelength band and could have a sensitivity of 8 mJy at frequencies of 500 to 2000 GHz, assuming 10 percent bandwidth with bolometers of 10^{-14}W H$^{-\frac{1}{2}}$ Noise Equivalent Power and a 1 hour integration time.

A Cassegrain reflector composed of several subpanels would be developed with its pointing system. Superheterodyne receivers and bolometers will be mounted at the focus and cooled by cryogenic temperatures. The half-power beamwidth of the telescope at 1000 GHz would be 2.6 arc sec; thus 1 arc sec pointing would be needed. At higher frequencies, the equipment would operate with reduced efficiency and angular resolution. The spectral line data would be processed on board by an autocorrelator with 1000 channels, the output of which would be telemetered to ground. The size of the instrument and pointing system, the desirability of refurbishment and upgrading, and the need for long observing times make this experiment an excellent candidate for a SSP.

4.9 Very-Long-Baseline Interferometer (VLBI)

Very-Long-Baseline Interferometry (VLBI) extends the angular resolution of radio telescopes to sub-milli arc-seconds and appears, potentially, to be able to yield angular resolutions in the micro arc-second range or better. By adding a space-based VLBI station to the existing ground-based network, one essentially can synthesize a high-quality radio telescope as large as the Earth. Furthermore, once the space-based VLBI methods are established, one can look forward to the eventual extension of the system to much longer baselines by launching VLBI stations to higher orbits.

The space VLBI station should have a radio telescope with a diameter of 20 to 30 meters, and an ability to observe at 3 cm wavelength, with some capability at 1.3 cm wavelength also. The telescope should be pointed to 1/10 beamwidth, and the position of the electrical center of the telescope with respect to the center of mass of the spacecraft should be measurable to 1/10 wavelength (stabilization is not a requirement, since the correction, if measure, can be applied during the reduction process). The data stream would be an integral multiple of 4×10^6 bits per second, with some time-sharing ability with other high-data-rate experiments. The time base would be provided by a hydrogen maser. Cryogenics, if available, could be used by maser amplifiers in the receiver, but for simplicity and cost reasons, non-cryogenic receivers could be used. To assure good coverage of the Fourier transform plane, an inclination of higher than 40 degrees would be preferred for the orbit.

4.10 Gravitational Experiments

In assissing the suitability of a SSP for gravitational experiments it is convenient to divide the experiments into two classes: (1) those which depend on measuring some kind of linear or angular displacement of a massive body, and (2) those which depend on measuring some kind of frequency shift, time delay, or angular deflection of electromagnetic radiation. Examples in the first class are the Gyro Relativity (GP-B) and Orbiting Equivalence Principle experiments; examples in the second class are the Orbital Redshift and planetary radar ranging experiments.

Listed below are twelve conceivable experiments on gravitation and general relativity which might be undertaken in the 1980's or early 1990's. Those marked with an asterisk have been described in the Astrophysics Project Concept Summaries and will be briefly described here where appropriate; the remainder will be described as we proceed.

Experiments depending on measurements on massive bodies

*(1) Gyro Relativity (GP-B)
*(2) Orbiting Equivalence Principle
(3) Spin-spin attraction experiment
(4) Twin-satellite experiment
(5) Measurement of $\dot{G}/G$ (rate of change of gravitational constant)
*(6) Gravity Wave Interferometer

Experiments depending on measurements on electromagnetic radiation

*(7) Orbital Redshift
*(8) Ranging experiments (Solar Probe, Mercury orbiter, Jupiter
(9) orbiter, Solar Polar, etc.)
(10) Clock comparisons
(11) Solar oblateness and starlight deflection experiments

(12) Experiments with radio interferometers
(13) Improved lunar laser ranging experiment

Experiments Incompatible With A Space Science Platform. We should note first that most experiments depending on measurements on massive bodies require a free flyer. A SSP is of no use for any of them except the gravity wave interferometer and perhaps an experiment to measure $\dot{G}/G$. This is because experiments depend on measuring exceedingly small accelerations or precessions and require drag-free spacecraft for successful operation. Examples are experiments (1) through (4), all of which require drag-compensation down to the 10^{-10} to 10^{-11}g level, as compared with the 10^{-3} or 10^{-4} g levels typical of a SSP. The twin-satellite experiment requires 2 counter-orbiting, drag-free satellites in nearly equal and opposite polar orbits and is therefore even more dependent on dedicated free flyers.

The radar ranging experiments by definition depend on radar ranging to deep space free flyers since they are designed to check gneral relativistic effects from the Sun. They too fall outside the scope of a SSP.

The Orbital Redshift experiment carries a hydrogen maser clock in a spacecraft with a highly elliptic orbit (300 km perigee, 36,000 km apogee). Thus an orbital version of the experiment could improve the accuracy of the check of the Einstein redshift formula (and hence of the Einstein equivalence principle) from 1 part in 10^4 by as much as two additional orders of magnitude to 1 part in 10^6.

The clock comparison experiments (9) would consist in launching one or more other types of clocks along with the hydrogen maser - for example, superconducting cavity and cryogenic crystal clocks. Different types of clocks have been shown to depend for their ultimate time standard on different combinations of the fundamental constants h, c, e, and m (Planck's constant, the velocity of light, and the charge and mass of the electron). On certain hypotheses their rates might be expected to vary differently in a changing gravitational potential; the aim would be to search for any such differential variaion in rate.

Both the Orbital Redshift and the clock comparison experiments require a satellite in a highly elliptic orbit. They are therefore imcompatible with a SSP in near circular orbit, but could be done on a platform if other experiments created a requirement for a SSP in a highly elliptic orbit.

Experiments Probably Compatible With Space Science Platform Both Very-Long-Baseline Interferometer (VLBI) and Lunar Laser Ranging (LURE) have been applied in a number of gravitational experiments. By mounting a radar antenna or laser receiver on the SSP or other spacecraft one may be able to effect improvements in the two programs and hence in their applications to gravitational physics.

Three experiments remain: the measurement of $\dot{G}/G$, the solar oblateness and starlight deflection experiment, and the gravity wave interferometer. We take them in that order.

According to Dirac's large number hypothesis, the various fundamental constants are related in such a way that the gravitational constant may be expected to change with time at a rate inversely proportional to the age of the universe; in other words $\dot{G}/G$ will be about 1 part in 10^{11} per year. Per year. Present measurements are within a factor of ten of detecting such a variation in G if it exists. Two kinds of space experiments have been suggested for measuring G/G: (1) timing experiments in which two bodies orbit around each other and one looks for a change in orbital period and (2) a differential Cavendish experiment in which one looks for a change in torque on a torsion balance. Both of these experiments are exceedingly difficult even by the standards of gravitational physics experiments. The first would presumably require two free flying bodies in deep space, observed by another free-flyer near enough to see, but not near enough to disturb, the two orbiting bodies. It is manifestly incompatible with SSP. However, the second might be mounted on an Earth-oriented SSP though it would be better on the quieter environment of a free flyer, especially since the principal advantage of doing it in space is to get away from the seismic disturbances on Earth.

The solar oblateness and starlight deflection experiment would consist in taking into orbit a specialized solar telescope, similar to that designed by H. A. Hill and his colleagues of the University of Arizona, to measure the optical oblateness of the Sun and the deflection of starlight by the Sun's gravitational field. The point of doing it in space is to get away from atmospheric turbulence and to simplify design of the star detector (which no longer needs to integrate out background scattering). The solar telescope might be of order 10 m long; the experiment might be done with the Solar Orbiting Telescope (SOT). It appears to be compatible with a SSP. A long duration flight is desirable to check whether there are any periodic or random changes in apparent oblateness, as Hill's observations suggest.

The final experiment is a Gravity Wave Interferometer. It may consist of four nearly free floating masses, each of weight one ton, located at the four ends of a cross-shaped, large space structure approximately 1 km on an arm. The distances between each mass and the center would be measured by multiple reflection laser interferometers (effectively Michelson interferometers). A device of this kind could be made extremely sensitive to gravitational waves, especially ones of low frequency (100 Hz to 10^{-4}Hz).

Evidently the gravity wave interferometer requires a SSP because of its large size. The platform should probably be a dedicated one but might be combined with the infrared interferometer, identified elsewhere in this report, which has comparable dimensions. The 1 km length is not a requirement; however, the sensitivity of the instrument in theory scales as the square of its dimension, so that large size is a major advantage.

It seems likely that a structure of this enormous size would have to be put in geosynchronous orbit or deep space to get away from the extremely serious disturbances from gravity gradients, the Earth's magnetic field, and thermal flexure at orbital period as the apparatus moves in and out of the Earth's shadow.

The Gravity Wave Interferometer fires the imagination and offers the prospect of an important experiment which can be done with techniques developed for the SSP while being impossible on Earth because of seismic disturbances. It is important to emphasize, however, that its design is, at present, at an exceedingly rudimentary stage. No one has actually operated a laser interferometer fravity wave detector of any size on Earth, though some of the components for such instruments have been developed. It seems very unlikely that a 1 km device of this kind could be seriously tried before the 1990's.

The suggestion has occasionally been made that there would be advantages in flying a gravity wave antenna of the Weber bar type in space. On the face of it, this seems unlikely. The resonant frequencies of such bars are of order 900 to 1600 Hz, and it is possible to filter out ground vibrations of this frequency regime very effectively. If space were to offer any advantage, it would probably be only in a free flyer.

CHAPTER IV

LUNAR AND PLANETARY PANEL

Panel Chairman: William Baum, Lowell Observatory

Panel Members: William Brunk, NASA Headquarters
John J. Caldwell, SUNY
Michael Klein, JPL
Harold P. Larson, University of Arizona

Panel Liasion (MSFC): David Reasoner

1. BROAD SCIENTIFIC NEEDS OF PLANETARY SCIENCE IN THE 1980's

Planetary exploration with spacecraft was initiated in 1962 with the Mariner 2 mission to Venus. During the past two decades, the planetary exploration program has progressed steadily toward the goals of improving our understanding of:

- The origin and evolution of the solar system
- The origin and evolution of life
- The earth by comparative studies of the other planets

During the 1960's and 1970's, emphasis was placed on initial exploration of the planets to discover what they are like today. All major bodies in the solar system have been studied with ground-based telescopes. By the end of the decade, all of the planets out to and including Saturn will have been observed from flyby spacecraft. Venus and Mars will have been studied extensively from orbiters. Their atmospheres have been penetrated with probes and small portions of their surfaces have been imaged and studied from landed spacecraft. Mars has been surveyed much more completely than any other planet.

In the 1980's, deep space missions will emphasize second generation exploration of those planets we have already observed from flybys, and missions to some of the smaller bodies of the solar system. They may be as important for understanding the formation of the solar system as the large ones.

Important contributions to planetary science will also be made from observations from the vicinity of the earth. Such observations have in the past been principally made from gound-based observatories, aircraft and rockets. In the future, the use of Earth-orbiting vehicles will increase the capabilities of the UV and visual instruments and utilize the superior imaging capability of the space environment. Similarly greater sensitivity in the infrared will be achieved and new regions of the far infrared and submillimeter spectrum will become available for observation for the first time.

The following paragraphs raise some of the fundamental and challenging questions that remain to be answered by a vigorous program of exploration and continued reconnaisance from the vicinity of the Earth. The pace of discoveries from the past decade of research has been formidable and there is little doubt that more answers, and new surprises as well, will be forthcoming. The facilities and experiments described in this report will play an important role in this research; and some of them can be utilized with greater efficiency if they are aboard an orbiting Space Science Platform.

1.1 Completion Of A First-Order Description Of the Solar System

A prerequisite for understanding the origin and evolution of the Solar System is an accurate description of the current state of its members. Despite the level of sophistication of modern astronomical observations this basic task is not yet complete. Recent unexpected discoveries include:

(1) The recently discovered rings of Uranus are composed of dark particles. The rings are radially thin, with relatively thick gaps. One ring has an irregular shape. None of these characteristics apply to Saturn's well known system.

(2) The periods of rotation of Uranus and Neptune were recently revised by more than 10 times the previously quoted standard error.

(3) Pluto has recently been found to be a double planet, with the satellite being very close and quite comparable to the primary.

These discoveries, as well as future ones, can be followed-up effectively with observations in Earth orbit.

1.2 A Search For Extra-Solar Planetary Systems

In the decades ahead, one of the most exciting adventures in astronomy, particularly from space, will be the search for planets around other stars. If it is found that ours is not the only planetary system in the Universe, the impact on human philosophy will be as great as that of any astronomical discovery of any time. The challenge to learn about these newly discovered "other worlds" could well become the driving force of space science. There are many tantalizing clues that this search ultimately will not be in vain. Approximately half of all stars occur in double or multiple systems. Known stellar secondary stars range downward in mass and luminosity to the limits of detection. There is every reason to believe that this sequence continues beyond present detection limits to the planetary class. Studies of stellar rotation indicate that single late-type stars have systematically low rotation rates, suggesting that angular momentum has somehow been removed from them, perhaps residing in planetary systems. Young stars in the process of formation have been inferred to have disks, from which planetary systems may eventually form. It remains, however, to obtain definitive evidence that objects comparable to our planets actually exist.

1.3 Comparative Atmospheric Circulation Among The Planets

Improving our understanding of the way our atmosphere responds to stress is clearly imperative in an era when our civilization is constantly stressing the environment in diverse ways. Studies of terrestrial climate and its modification have benefited in two ways from planetary studies:

(1) Models can be applied to other planets with known circulations to test the models' performance under diverse conditions. This increases confidence that they are valid for studying the terrestrial climate under different forcing conditions than are present here today.

(2) Many physical processes which occur here also occur in other atmospheres in more extreme form. Studying them leads to a better fundamental understanding of such processes, which might otherwise even be missed here.

1.4 Characterization Of The Primitive Solar Nebula

Our understanding of the origin and evolution of our planetary system is based upon measurements of solar system objects as they exist today. However, the evolutionary histories of these bodies are very different because of their enormous differences in mass and because their orbits are distributed over a wide range in solar distance. By collecting and intercomparing data on the various compositions and physical states of the planets, their satellites and the smaller bodies of the solar system, we are able to test models of the original composition and physical state of the primeval nebula. Some of the fundamental questions in this process are: how are differences in composition, states of differentiated material, and apparent ages of the terrestrial planets and satellites related to the temperature and pressure distribution in the solar nebula during planet formation; are the atmospheres of the giant planets primordial material; are comets "frozen" samples of primordial material; how does the observed gradient in the physical states of the Galilean satellites of Jupiter relate to our understanding of the evolution of the solar nebula.

1.5 Condensation Processes

The formation of planetary and asteroidal sized bodies by condensation of a solar nebula is a complex chemical event. The observed compositions of objects of all types throughout the solar system provide one means to reconstruct this process. During the previous decade, detailed chemical models based upon equilibrium condensation of a solar composition cloud have been developed are are in good agreement with the gross properties of solar system objects (densities, compositions). Refinements are required, especially for the outer solar system where data are fewer. Elemental and isotopic abundances, as determined through spectroscopic measurements of gaseous and solid constituents, constitute the primary data for testing these chemical models. Thus, such diverse materials as ices on satellites, basaltic achondrite mineral assemblages on asteroids, and gaseous hydrides in planetary atmospheres all bear on this topic. Many results of this type have already accumulated, but the greatly enhanced potential of IR observations from an Earth-orbiting facility will extend this knowledge to a larger population of objects, thereby providing independent and more stringent tests of condensation theories.

1.6 Extraterrestrial Origin Of Organic Matter

The conditions permitting the abiologic synthesis of organic molecules are of fundamental significance to understanding the chemical emolution of more complex systems, including life forms. Evidence for this process is found in the constituents of the interstellar medium, in the organic component of primitive carbonaceous chondrite meterorites, and perhaps in some of the as yet unidentified colored components of the Jovian clouds. Planetary observations directed at this problem include high resolution spectroscopic observations of planetary atmospheres to reveal trace constituents associated with organic synthesis reactions, or observations of asteroid surfaces to reveal mineral assemblages spectrally identical to carbonaceous chondrites. Definitive experiments can be conducted at IR wavelengths, and initial results from gound-based and airborne observatories have been promising, but only an Earth-orbiting facility can combine the resolution and sensitivity of ground-based instrumentation with the advantages of space observations (lack of atmospheric interference and reduced thermal background levels). It is therefore expected that these new opportunities to study this cosmochemically significant process within the context of solar system origin and evolution will be vigourously exploited in the next decade.

1.7 Evolution Of Satellite Systems

The evolution of satellite systems plays an important role in our understanding the evolution of the solar system as a whole. It is possible that these systems can be studied as "miniature solar systems", thereby giving us the opportunity to gather data and test our evolutionary models on bodies that have evolved on timescales shorter than the solar system near much smaller and cooler primary bodies (the Jovian Planets).

The dynamical processes that produced the systems of rings have yet to be explained. Solutions to this problem have an important impact on our knowledge of the distribution of angular momentum in the outer portions of the solar nebula.

2. NEEDS PROBABLY BEST SATISFIED BY SHUTTLE-ATTACHED PAYLOADS

To discuss this question in relation to planetary studies, one must consider the ensemble of techniques available for making the important observations:

(1) Ground-based telescopes (including airborne and balloon-borne)
(2) Deep space probes (including flybys, orbiters, landers and sample return)
(3) Free-flyers in Earth orbit (including pre-shuttle {IUE} and post-shuttle {ST} launches)
(4) Space platform observatories
(5) Shuttle-attached payloads.

Observations in category (1) are the cheapest and most versatile that can be made. They also accomodate the most complex instrumentation. The limitations are universally understood: restricted spatial resolution, restricted wavelength coverage, and restricted geometrical aspect.

In category (2), observations permit the ultimate in spatial resolution and in accurate sampling. The limitations include cost and also a perspective problem. Probes are often too close to study planet-wide phenomena. This is a strong reason for retaining other options for planetary work.

Categories (3), (4) and (5) all offer the advantages of space compared to ground observations: spatial resolution and wavelength completeness. Category (3) missions permit precise pointing, with no external mechanical interference and hence permit an experimenter to concentrate on resolution. For this category, there are no extrinsic priority problems, and long duration missions are generally practical. The disadvantages of this mode are that repairs, replacements of instruments and refurbishment of consumables such as cryogenics are restricted.

Category (4) is an advance over (3) in that shared and therefore efficient housekeeping functions are permitted. Disadvantages of (4) are that mutual interference, both electromagnetic and vibrational must be dealt with and priority decisions for pointing must be made. Attached multiple instruments can not all have freedom to choose their pointings over 4π steradians, and in fact will probably be limited to something less that 2π steradians for extended intervals.

Category (5) has the advantage of being inevitable, since NASA is committed to the facility. There are also the advantages of hands-on operation and material retrieval. One important class of retrieval missions is film instruments. This is the most efficient means of recording spatial data that now exists or soon will. Disadvantages include short duration, restricted pointing ($< 2\pi$ sterad), contamination for infrared observations, unintentional crew interference, loss of precise pointing for significant intervals, and the necessity to track astronomical targets, because the shuttle will not be in general inertially stabilized. The latter characteristic can only be described as regressive. The limits on size and weight of instruments are clearly restrictive.

On this total context, the class of experiments which would preferably be attached to the shuttle is small. Such experiments would be short, have large pointing tolerances and not require frequent repetition. A few such experiments are identified in the next section, as adjuncts to platform-advocated studies. These include certain laboratory experiments, as yet undefined, and exploratory comet photography.

3. TYPICAL EXPERIMENTS FROM PLATFORMS

In the following section we describe some of the instruments that are likely candidates for inclusion on a Space Science Platform in the 1980's. We note that these instruments were originally conceived either as Shuttle payloads or as free-flying satellites, and that we have largely constrained our thinking to the direct transfer of these instruments to the space platform with few, if any, modifications. It is very likely, however, that second generation instruments could be made more versatile, more sophisticated, or more sensitive if the constraints on weight, power, size, and maximum duration were realized through the utilization of a platform. Similarly, a compatible cluster of experiments on a single platform, sharing common power and orientation systems, could be very cost effective.

Several observational techniques that are condidates for a Space Science Platform are listed in Table 3.1. The primary scientific goals and the relevant solar system objects are identified for each technique along with the specific instruments, which are discussed in the body of this section. The last two columns give a brief indication of the advantages for implementation from space.

TABLE 3.1

PLANETARY SCIENCE INVESTIGATIONS FROM EARTH-ORBIT

Technique	Scientific Goals	Facility Required	Objects	Reasons for Earth-Orbiting Platform	Advantage of Space Platform
High resolution IR spectroscopy	Atmospheric composition, isotope ratios.	SIRTF	Jovian planets, Titan, comets	Telluric obscuration, thermal background.	Long integration time
Low resolution IR spectroscopy	Surface composition	SIRTF	Asteroids, satellites, pluto.	Telluric obscuration, thermal background	Long integration time, larger population accessible.
IR photometry	Classification, identification of planetary-size extra-solar system objects.	SIRTF	Asteroids, satellites, IR sources.	Telluric obscuration, thermal background	Long integration time, larger population accessible.
Submillimeter spectroscopy	Atmospheric composition circulation, molecular distribution	10-m dish	Outer planets, Venus, comets	Telluric obscuration	Duration and synoptic coverage
Submillimeter continuum	Thermophysical properties of surfaces	10-m dish	Venus, Mars, satellites, asteroids	Telluric obscuration	Duration and synoptic coverage
Astrometry	Detect extra-solar system planetary objects	Dedicated meter-class telescope	Nearby stars	Image quality	Repetitive observations with long time baseline
Imagery	Meteorology, cloud morphology, comets	STARLAB, DUVS	Venus, Jupiter, Saturn, comets	Spatial resolution, UV accessibility	Readiness for targets of opportunity (comets)
Sample Collection	Interplanetary medium composition	PI	Micrometeroids	In situ measurements	Long collecting periods
Planetary processes	Impact, sputtering, regolith formation, chemistry	PI	Asteroids, Moon, mercury, solar nebula	Zero g, vacuum environment	Long duration
Km-wave radio observations	Planetary magnetospheres and plasmas	Large antenna array	Outer planets, nearby stars	Terrestrial ionospheric interference	Uncertain

3.1 Astrometric Telescope For Extra-Solar Planetary Systems

Scientific Rationale: For rather complex reasons, direct image detection of extra-solar planets appears less likely than indirect detection by virtue of the wobble, in both radial velocity and position, of the associated star. The quest for radial velocity variation is worth pursuing from the ground and would not particularly benefit from instruments in space. The quest for astrometric detection, however, should benefit enormously from instruments in space, and astrometry now appears to be the most sensitive approach of all.

If, for a criterion of detectability, one imagines each star to possess a "Jupiter" (a planet of Jupiter's mass and orbital semi-major axis), there are more than 500 candidates brighter than 16th magnitude that should have a resulting wobble exceeding 2 milliarcseconds peak-to-peak. Such limits appear feasible for a dedicated telescope aboard the Space Science Platform. The field of each selected candidate would be imaged several times per year for at least a decade.

Instrument Description. A detailed study of engineering tradeoffs would be required to arrive at optimum telescope parameters for an "Other Worlds" search, but we tentatively visualize a dedicated telescope with an f/30 parabolic primary mirror of $\sim$1.5-meter aperture, followed by a flat secondary. Such a telescope is quite a bit larger than STARLAB but, because of the flat secondary, does not have tight requirements on optical alignment. At the focal plane, the field of interest is at least 10 cm in diameter. One detector concept being explored on the ground utilizes a moving Ronchi ruling in the focal plane, followed by a number of small positionable detectors to pick up the modulated signal from selected stars in the field. Alternatives, such as a mosaic of CCD's on a cervit plate, need to be examined. Photoemmissive devices will in general lack the required stability of imaging geometry.

3.2 Ultraviolet/Optical Telescope

Scientific Rationale. Among the instruments planned for astronomical observations aboard Shuttle is a meter-class ultraviolet/optical telescope called STARLAB. A basically similar telescope would be of great value to planetary science aboard the Space Science Platform, performing observations (1) that benefit from the time-continuity not available with STARLAB on the Shuttle, or (2) that require an instrument capability not included on the Space Telescope, or (3) that planetary missions will not accomplish in the foreseeable future. These observations include (a) synoptic studies of planetary atmosphere dynamics, (b) high-resolution spectroscopy of planetary atmospheres at high spatial resolution, (c) compositional classification of planetary and satellite surfaces by spectrophotometry and polarimetry at high spatial resolution and (d) a systematic search for satellites and rings around objects beyond Mars. Altogether, these observations will account for a substantial fraction of the total time available with a STARLAB telescope aboard the Space Science Platform.

Our present understanding of the dynamics of planetary atmospheres was reviewed at a NASA workshop held at Snowmass, Colorado, in July 1977.

The report (JPL Publication 78-46) particularly stresses the strides that are being made in understanding dynamic processes in the Earth's atmosphere by the study of the atmosphere of other planets. Such studies are concerned with atmospheric circulation patterns, cloud forms and motions, diurnal effects, seasonal variations, and evidence for climatic changes. On Mars, for example, we particularly need to verify or refute the predictions of current dynamical models, refine our knowledge of polar and dust storm processes, and determine the paleoclimate. Oddly, neither long-term Earth-based monitoring nor recent orbiter imaging of Mars have adequately resolved these fundamental meteorological problems. Averaged over the mission, for instance, Viking orbiters have viewed ∿1% of Mars per day. For 3 or 4 months during each of several successive Martian apparitions (to sample all seasons), we need a full disk view in two colors about every two hours at diffraction-limited STARLAB resolution. In a similar way, monitoring schedules for Jupiter and Venus can also be defined.

The high resolution spectrograph aboard the Space Telescope will be an ultraviolet instrument. It will not cover the spectral range suitable for investigating abundances and excitation states in planetary atmospheres. Planetary spectroscopic data also need to be accompanied by good spatial resolution and temporal monitoring. On Jupiter, for example, we see to differing depths that depend on the local nature of the underlying clouds. To utilize existing laboratory f-values and to link Platform observations with Earth-based observations we suggest a high-resolution echelle spectrograph equipped with a CCD detector. This would provide data for a number of important spectroscopic features including hydrogen quadrupole transitions and methane and ammonia bands.

The mineralogical composition of surfaces can be distinquished by their spectrophotometric "signatures" across the visible and near-infrared spectrum as well as by their polarization properties. The pyroxine band at 0.94 μm is one of the best known spectral features of that kind, but compositional discriminants can be found across the entire spectrum. Important work to date has included spectrophotometric mapping of the moon, and the compositional classification of asteroids. Amongst the latter, one finds evidence for a compositional gradient radially outward in the solar system, presumably preserving the condensation history of the early solar system. Photometric studies of outer-planet satellites reveal albedos and color differences on different faces, but spatial resolution is lacking. A near infrared imaging system on STARLAB aboard the Platform would resolve a useful number of compositional domains on a number of largely airless bodies in the solar system, including the Galilean satellites, Pluto, and Ceres. It would also resolve compositional detail in lunar regions of particular interest.

If Neptune has rings, they will be difficult to discover by the occultation technique that worked so well for finding the rings of Uranus, because Neptune is unfavorably oriented. It will also be difficult to find out in a statistically meaningful way whether the larger asteroids commonly have satellites like those recently discovered around Herculina and Pluto. Rotating subsystems may be a common feature of the outer solar system. If so, they have implications concerning the distribution of angular momentum in the solar nebula. A CCD imaging camera on STARLAB aboard the Platform should have an adequate opportunity to conduct an imaging survey of objects in the outer solar system.

Instrument Description. As currently planned for operation aboard Shuttle, STARLAB is an f/15 Ritchey-Chretian telescope of 1-meter aperture. With refractive correctors, it will provide a flat field 0.5-degree in diameter with images smaller than 0.3 arc-second. Without the correctors, it will provide critical imaging over a field of a few arc-minutes. At the focus (behind the primary mirror) is a cluster of auxilliary instruments, with a movable flat mirror to direct the image into the one selected.

Mounted on the Space Science Platform, this same telescope system would largely meet the scientific requirements outlined above if designed for long life and if equipped with the appropriate auxilliary instruments. The main exception would be to substitute a secondary mirror providing f/30 instead of f/15.

The minimum auxilliary instruments would include a cooled CCD camera, an echelle spectrograph with cooled CCD output, and an image acquisition/guiding system. Present CCD's with 15 μm pixels would adequately read diffraction-limited images over the wavelength range of main interest. If an infrared imaging system becomes available to reach longer wavelengths than a CCD, it may better satisfy the spectrophotometric requirements for surface composition studies.

3.3 Infrared Telescopes (SIRTF, LIRTS)

Scientific Rationale: Two facility-class telescopes currently under study for Shuttle service have great potential for planetary observations at IR wavelengths (2 - 500 μm). Present ground-based IR observations are increasingly limited by two natural obstacles: obscuration by the terrestrial atmosphere, and obscuration by the thermal background radiation. Some of these difficulties can be reduced by observing from high altitude facilities such as aircraft and balloons, but only an Earth-orbiting, cryogenically cooled telescope can eliminate both types of obscuration. The SIRTF ($\leq 20^\circ$K, 1.2m aperture) offers unprecedented sensitivity for producing high resolution spectra of planets, comets, and the atmosphere of Titan. The LIRTS ($\sim$300K, 3m aperture) also eliminates telluric obscuration, but background levels are so much higher than on the SIRTF that, in spite of its larger aperture, the LIRTS is not in general as sensitive, although the disparity is sometimes not large and should be separately evaluated for every different combination of spectral resolution, field of view, spectral bandwidth, etc. Both telescopes operate with a cluster of instruments sharing the focal plane. The various spectrometers in these instrument complements are most relevant to planetary studies, although detection of small, very weak objects may use IR photometric capabilities as well, where sensitivities (on the SIRTF) exceed ground-based limits by as much as 10^3. The discussion below outlines some solar system spectral studies that can be conducted with these IR telescopes.

3.3.1 High Resolution Spectroscopy Of Planetary Atmospheres. Historically, the detection of planetary atmospheric constituents has been the exclusive domain of ground-based spectroscopic observations, but planetary fly-bys, orbiters and atmospheric entry probes have increasingly dominated studies of the terrestrial planets. For the Jovian planets, however, there still remains a vital role for remote spectroscopic measurements oriented to reconnaissance of spectral regions never before observed, or to regimes of spectral resolution and sensitivity that cannot be achieved with space instrumentation.

Planetary observations from Earth-orbit can provide the following specific results. A systematic determination of elemental (H, N, C, P, S, O, Si, F, etc.) and isotopic (D, C^{13}, N^{15}, etc.) abundance on Jupiter, Saturn, Uranus, Neptune and Titan is possible using high resolution spectroscopy. A search for trace atmospheric constituents (hydrides, simple hydrocarbons) down to the ppm-ppb level will also be conducted with the same data sets. Thse results will bear directly on numerous goals identified in Part I. Progress that can be anticipated can be inferred from present knowledge of the atmosphere of Jupiter. In 1969, only 3 constituents were identified in its atmosphere. Now there are 13 with some of the recent detections (PH_3, CO) being very surprising. These results have significantly influenced models of Jovian atmospheric chemistry and meteorology and, predictably, they have raised as many questions as they have resolved. Comparative spectral measurements of thse objects will therefore continue to be a major goal of planetary astronomy.

3.3.2 Low Resolution Spectroscopy Of Surfaces. Many minerals reveal their most diagnostic spectral features at IR wavelengths, but astronomical observations of asteroids and satellites at these wavelengths are even more difficult than for the planets due to reduced flux levels. A SIRTF class telescope is an optimized facility for these studies, and only low resolving power ($\sim 10^2$) is required to reveal the broad absorptions of minerals. Some of the specific experimental goals are:

(1) Location of sources of primitive carbonaceous chondrite matter on asteroids. The CH and OH spectral signatures at 3 μm indicative of this type of mineral assemblage can be sought on a large population of asteroids. Present capabilities are limited to photometric observations of only the largest and brightest asteroids (i.e. Ceres, Pallas). These results will bear directly on the extraterrestrial source of organic matter, including resolution of cometary versus asteroidal origins.

(2) Search for ices on satellites. The relatively unevolved compositions of satellites in the outer solar system can be directly related to the condensed volatile (icy) phases of the solar nebula. The Galilean satellites and the larger satellites of Saturn are accessible with ground-based techniques, but their smaller satellites and those of Uranus and Neptune require the sensitivity of a SIRTF-class telescope.

(3) Relationships between meteorites and asteroids. Comparative spectral studies of meteroites and asteroids permit the detailed chemical and thermal histories seen in the former to be ascribed to probable

source bodies in the solar system. Low resolution (10^2) broad spectral bandwidth (2-20) μm) measurements of many objects are required to demonstrate convincing associations.

Instrument Description: No single spectrometer can need the diverse requirements on spectral resolution, wavelength coverage, field of view, etc. for the wavelength region assumed here (2 - 500 μm). The SIRTF focal plane instruments team has identified several spectrometers that collectively provide this coverage, including Fourier, echelle, and conventional grating designs. In general, the Fourier spectrometers are optimally suited for very high resolving powers (10^4-10^5) at any wavelength, for all work beyond about 100 μm, and for all fields of view substantially wider than the diffraction limit. For moderate resolving power (10^3), diffraction limited fields of view, below 100 μm an echelle spectrometer is attractive, while for low resolving power (10^2) below 100 μm at the diffraction limit a multi-channel grating spectrometer is preferred. The SIRTF interim report (April, 1978) compares the performance of these instruments on the SIRTF with respect to flux levels available from representative solar system bodies.

Both the SIRTF and the LIRTS were originally conceived for the Shuttle sortie mode, but there are advantages to converting them to free flyers. Thus, their deployment on a Space Platform is potentially very significant to their scientific productivity. If the cryogenic life of the SIRTF can be significantly lengthened on the Space Platform, for example, longer integration times and broader spectral coverage can be achieved, with potentially useful influence on the planning of spectral measurements from deep space probes. The large number of satellites and asteroids that can justifiably be observed spectroscopically will require substantial amounts of telescope time. By operating the SIRTF on the Space Platform, a larger fraction of this population will be accessible with potential influence on the targeting of asteroids for follow-up fly-by and sample return missions.

Another potential advantage of Space Platform operation is reduced contaminant levels compared to the Shuttle environment. This could be compromised however, if another experiment sharing the Platform ejected molecular or particulate wastes. Other environmental perturbations that could adversely affect SIRTF operation are excessive vibrations and electromagnetic interference. Pointing conflicts with other experiments would detract from the observing efficiency possible with the Space Platform. Thus, operation of the SIRTF on the Space Platform is attractive, but full committment to this mode must await more complete definition of the characteristics of its neighbors and the priorities associated with resolving conflicting demands.

3.4 Submillimeter Telescope

3.4.1 Scientific Rationale. A submillimeter telescope in Earth orbit would open up a new and unexplored spectral region for investigations of planetary atmospheres, comets, and the surfaces of the small solar system bodies such as the natural satellites, and the larger asteroids. Ground-based observations are extremely limited by the atmospheric opacity which varies by orders of magnitude with altitude and wavelength across the submillimeter spectrum. Yet the solar system objects are among "the brightest" objects in the sky at these wavelengths; all of the planets and several of the satellites and larger astroids can be observed with high signal-to-noise.

Although a 10-m class submillimeter telescope could be orbited as a free flyer, attachment to a space science platform would benefit the operation of the facility if (a) pointing stability could be improved, (b) cryogenic receivers could be readily serviced, and (c) greater flexibility could be realized in the combinations of receivers and data systems.

Typical investigations in the field of Planetary Science would include:

(1) Spectroscopic studies of planetary atmospheres to search for molecular species would be conducted. Follow-up studies would be made to study the distribution and circulation of these molecules in the planet's atmosphere. We note that both Venus and Jupiter would be resolved with a 10-m telescope so that the circulation and meteorology of their atmospheres could be studied. Strong transitions of CO have been measured in Venus' atmosphere; observations of the higher level transitions could be made with better spatial resolution. Strong transitions of H_2O in the sub-millimeter spectrum offer the possibility of detecting this very important trace constituent. Searches for other molecules, especially those produced by non-equilibrium processes, would be made in the atmospheres of the giant planets. Molecular abundance determinations as well as measurements of their distribution in temperature and pressure in the planet's atmosphere would help answer fundamental questions relating to the origin, evolution and currently active processes in planetary atmospheres.

(2) Spectroscopic studies of the composition of comets, with special effort devoted to the detection of parent molecules such as H_2O, NH^3, HCN, etc. The submillimeter rotational transitions of these molecules are orders of magnitude stronger than those at wavelengths >1 mm where previous observations have been concentrated. A platform-based facility would permit studies of the temporal development and spatial distribution of various molecular species during the approach and recession stages of a cometary apparition.

(3) Continuum measurements at submillimeter wavelengths of satellites and the larger astroids would provide new information on the temperature and physical states of the surfaces of these bodies.

3.4.2 Instrument Description. The submillimeter telescope envisioned for use on a space science platform is of the 10-m class described in the report of the Submillimeter Space Telescope Working Group (April 1978:JPL 740-3). The antenna would be carried into orbit aboard the shuttle and deployed on orbit. Surface accuracies of $\sim 20 \mu m$ rms are planned so that diffraction limited operation to 0.3mm could be obtained. Coherent receivers would be employed at $\lambda > 0.3$mm, whereas the system could be instrumented with bolometers at the shorter wavelengths. Both spectroscopic and continuum receivers would be employed with bandwidths as wide as practical. Because molecular lines are subject to pressure broadening in planetary atmospheres, our spectral-line receivers require greater total bandwidths than those typically employed for interstellar spectroscopy. Total bandwidths should be $\gtrsim 500$ MH, but spectral resolution requirements are quite modest: $\Delta\lambda \sim 10^{-3} \lambda$.

Spatial resolution will be of the order ~1" to ~15". Consequently, the antenna pointing system requirements will be of the order ~0.5" or better.

3.5 Widefield Comet Camera.

From calibrated images of comets in bandpasses corresponding to resonance transitions of specific atoms, molecules, radicals and ions, one can infer their concentrations and production and loss rates. Such quantities are essential for inferring the composition of comets and the microphysical processes which occur on their surfaces during their active phase. Ultraviolet images of comets are therefore a valuable analytical tool. Filters at 1216 Å (H) and 3100 Å (OH) would be particularly useful from previous experience. It may be prudent to defer further specific choices until the IUE cometary program produces results.

Short wavelength images of comets generally suffer somewhat from dust extinction, preventing the study of mass motions of cometary material near the nucleus and orbital plane. Longer wavelength images are much less affected by dust.

Imaging comets from space offers several strong advantages over ground-based observations. First, the ultraviolet is not accessible from the ground. Second, at 7000 Å, the sky brightness is an order of magnitude fainter in space than on the ground. Since comets are generally faint, this advantage is important.

However, comets often achieve very large angular sizes, of the order of arc seconds or more. Most space systems don't have this capability. For example, Starlab has a field of 0.5 degrees, and other systems have less, usually much less. There is therefore an important use for a wide field imaging system, with ultraviolet and red capability.

NASA astrophysics planners have identified a useful space mission called the Deep-Sky Ultraviolet Survey (DUVS). It features a 0.8 meter folded Schmidt-Cassegrain system with an image-intensified ultraviolet-sensitive film or electronograph. It is all-reflecting, and therefore can function over a wide wavelength range. It can record 5° fields with 1 to 2 arc sec resolution.

It is currently intended for use in the Shuttle sortie mode. It is designed for speed: specifically to be able to survey the entire sky in several passbands in four sorties. The astrophysicists have identified several areas of stellar and galactic astronomy that could benefit from such an instrument. The imaging of comets should be added to this list. We note particularly that the return of Halley's comet in 1986 occurs during the time when DUVS may be active.

During the Halley apparition, significant Shuttle activity will be dedicated to it. Part of this could be a synoptic series of images with the DUVS system with detectors and perhaps secondary mirror modified to improve the spatial resolution, but operated essentially in the nominal DUVS mode. It should be noted that DUVS spatial resolution is detector-limited. It could readily be improved to about 0.5 arc sec for a dedicated mission. This should be compatible with Shuttle pointing.

Heretofore, no connection with the Space Platform has been made. However, if the above described venture does yield good science, these will be a firm basis for evaluating whether the system should be modified permanently, after the DUVS nominal mission is complete, for installation on the platform, to await targets of opportunity.

In summary, this concept is not a driver for creation of a platform, but has the potential for using one to advantage.

3.6 Large Meter-Wavelength Arrays

Comprehensive studies of planetary magnetospheres and co-rotating plasmas can be made by remote observations of the radio bursts that are observed at long radio wavelengths. The synoptic measurements of Jupiter's "radio storms" at decametric wavelengths provided the empirical evidence of Io's strong interaction with the Jovian magnetosperic medium. Continued study of the Jovian magnetosphere with greater spatial resolution and initial remote reconnaisance of the magnetospheres of the other giant planets (subject to the confirmation by Pioneer and Voyager that these planets do indeed possess Jovian-like magnetospheres) would be possible with a large meter-wavelength array in Earth orbit.

This prospective array should be sufficiently large to provide directivity to discriminate against other natural sources of emission (e.g. solar, galactic, terrestrial); at wavelengths from several hundred meters to kilometers. The physical size of the array could be very large compared to the probable size of the space platform. For this reason it seems most likely that the array would be a free flyer.

3.7 Micrometeoroid Studies

These tiny objects constitute a significant but mostly unstudied component of the interplanetary medium. Opinions about their origins are necessarily somewhat speculative. Tentative hypotheses present them as particles being expelled by solar radiation pressure, as cometary debris in heliocentric orbits or as interstellar grains in hyperbolic orbits.

A simple, gated passive collector mounted to a space platform could effectively preserve incoming directional information, and greatly improve the existing statistics on trajectories. Such an experiment is exceptionally attractive because there are zero telemetry or power requirements. The pointing requirements are modest in relation to other astronomical experiments. Perturbations due to neighboring experiments would undoubtedly be insignificant. However, the pointing would have to be stable over the duration of the exposure to achieve the directional goals. A straightforward device that exposes new collector areas every time the platform experiences a major reorientation can be envisioned. The LDEF, which is gravitationally stabilized in the Earthward direction, would be unsuitable for this work.

An intrinsic feature of the space platform, that is also requisite for this type of experiment, is the long time baseline available for sample collecting. This is particularly important in the mass range 10^{-6} gm.

3.8 Planetary Processes Laboratory

A space platform offers zero gravity and zero or very low pressure conditions which approximate better than terrestrial laboratory conditions the early solar system environment. Chemical experiments, as yet undefined to test planetary formation models, may be profitable in this situation. However, it should first be established that such experiments require the long duration capabilities of the platform, as opposed to the Shuttle sortie mode. A second category of experiments for such a laboratory is impact cratering, but this is almost certainly achievable from the Shuttle sortie.

This facility is therefore also not a driver for space platform construction, but is a potential user.

3.9 Instrument Test Facility

Deep space missions currently require elaborate pre-launch testing to ensure an acceptable probability for mission success. The major obstacle that must be overcome on present missions occurs after all these tests - the trauma of launch.

An efficient method of reducing this effort, which makes use of the Shuttle capabilities, is to test the instrumentation for such missions in space after launch but before trans-planetary insertion. The space platform may have distinct advantages over the nominal shuttle sortie mode for this task, both because instrument degassing time may be too long and the Shuttle environment too polluted for precise work.

In general, instruments designed for flyby or orbiter operation are not well suited for general astronomy, because the signal levels are very different. Therefore, calibration measurements may be the only operationally useful data that are collected, other than engineering data on specific components that may require replacement or adjustment. Such operations do not require any pointing capability.

There are some exceptions to the previous paragraph; for example, Voyager imaging of the Earth and Moon. However, such data would be a bonus, over and above the aims of this facility, and would require more complex operations.

4. PLATFORM REQUIREMENTS

The platform requirements are summarized in Table 4.1.

5. SUMMARY

The Space Science Platform is potentially advantageous for planetary science investigations if:

(1) Environmental perturbations (contaminant levels, vibrations, EMI) are kept substantially below Shuttle levels.

(2) Substantially increased continuous operation (minimum factor of 5) is possible of cryogenic systems and for measurements requiring long integrations or extended synoptic coverage.

(3) Competition among pointing facilities is minimized (idle time 20%).

(4) Telescope pointing for IR telescopes is at least as good as on Shuttle (0.25 arc sec) and pointing of UV and optical telescopes approaches that of the Space Telescope (0.002 arc sec).

TABLE 4.1

PLATFORM REQUIREMENTS FOR PLANETARY SCIENCE

REQUIREMENT	TELESCOPE						MICRO-METEROID COLLECTOR
	SIRTF	LIRTS	STARLAB	SUB-MILLIMETER	ASTROMETRIC	DUVS	
Orbit							
Altitude	300-400 km	300-400 km	300 km	400-500 km	300-400 km	300 km	>200 km
Inclination(1)	28-57°	28-50°	28°	28°	28°	28°	28°
Stabilization							
Platform	← 1° →						
Instrument(2)	0.1 arc sec	0.1 arc sec	0.01 arc sec	0.5 arc sec	0.001 arc sec	0.2 arc sec	1.0 degree
Orientation							
Platform	← 1° →						
Instrument(2)	1.0 arc sec	1.0 arc sec	1.0 arc sec	1.0 arc sec	1.0 arc sec	10 arc sec	1.0 degree
Data Telemetry							
Down link	4 Mb/sec	4 Mb/sec	4 Mb/sec	0.1 Mb/sec	1 Mb/sec	NA	NA
Up link	25 kb/sec	25 kb/sec	25 kb/sec	25 kb/sec	25 kb/sec	25 kb/sec	25 kb/sec
On-board storage	50 Mb disk	50 Mb disk	50 Mb disk	10 Mb disk	10 Mb disk	Film storage	NA
Maintenance/Checkout							
Function	Cryogen refill	Cryogen refill		Cryogen refill		Film Retrieval	Collector retrieval
Frequency	1-3 mo.	3-6 mo.		3-6 mo.		To be Determined	6 mo.
Environment							
Vibration	← ≤0.1 g →						
Contamination	← Free of scattering, absorbing or emitting material during observations →						
Power(3)	<4 kw	< 4 kw	<4 kw	<4 kw	<4 kw	<4 kw	
Operations							
Ground	← Acquisition, tracking, real-time data monitoring and processing →						
Shuttle	← Instrument replacement →						

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(1) For good coverage of the ecliptic. (2) IPS + image motion compensation. (3) Dominated by IPS.

CHAPTER V

SOLAR PHYSICS PANEL

Panel Chairman: Ron Moore, Cal Tech

Panel Members: David Bohlin, NASA Headquarters
Robert Howard, Hale Observatories
Stuart Jordan, GSFC
Neil Sheely, NRL
Einar Tandberg-Hanssen, MSFC
George Withbroe, HCO-SAO

Panel Liasion (MSFC): Ed Reichmann

1. INTRODUCTION AND OVERVIEW

The Sun confronts the discipline of solar physics (along with astrophysics and solar/terrestrial physics) with several fundamental problems which are now generally recognized and identified in borad outline. Physically and observationally, these problems fall into the following five different but related categories (the names of which are somewhat arbitrary):

- Structure of the Core: The neutrino problem (nuclear energy release); solar oblateness (possible rapid rotation of the core); g-mode oscillations.
- Solar Cycle: The solar dynamo; differential rotation; structure of the convective envelope; the 5-minute p-mode oscillations.
- Structure and Evolution of the Solar Atmosphere: Emergence of magnetic fields, active regions and fine-scale magnetic fields (emerging flux regions, chromospheric network, filigree); large-scale magnetic field structures (coronal holes and arcades); atmospheric heating and mass flow (corona and solar wind).
- Flare and Transients: Precipitous conversion of magnetic energy to plasma energy (MHD and plasma instabilities, particle acceleration, bulk mass ejection, shock waves).
- Solar Outputs (Solar-Terrestrial Relations): Radiation (total and spectral solar irradiances); solar wind (high speed streams, magnetic sectors); flare/transient mass ejections (interplanetary plasmoids; shock waves).

Observations during the past decade, both from space and from the ground, have led to an increased understanding of and interest in each of the above areas. For example, the results of the neutrino capture experiment and conflicting results of measurements of the oblateness by two different groups leave the structure of the core still very much an open question. Conversely, observations of the 5-minute oscillations have convincingly demonstrated that these "surface" oscillations are high-harmonic global modes of the Sun which are driven by the convective layer, and hence can be used to deduce the internal structure and rotation of the convective layer. Ground-based observations of the solar magnetic field in the last five years indicate that, at the level of the photosphere, most of the flux is contained in sub-arc sec bundles having field strengths of the order of 1000 gauss. Owing to the greatly improved spatial resolution (1-5 arc sec) at EUV, XUV and soft X-ray wavelengths, Skylab brought many new advances in understanding of the structure and evolution of the solar atmosphere (e.g., structure of active regions and coronal holes) and of flares and transients (e.g., configuration and energy balance of the ten million degree thermal flare plasma; coronal transients). Finally, indirect evidence from correlations between the solar outputs (flare activity, solar wind sector boundaries) and terrestrial weather and climate have led to a new awareness of the importance of accurately measuring and monitoring the solar outputs for solar-terrestrial studies.

The solar missions planned for the next five years certainly will make significant advances in many of these areas. For example, the Solar Maximum Mission (SMM) will provide basic new information on the impulsive phase of flares, in particular the spatial locations and patterns of the hard X-ray emission. However, the SMM spatial resolution in both hard and soft X-rays will be only about 8-10 arc sec, whereas Skylab and ground-based observations have shown that there is significant structure in the flare kernal well below this limit. Spacelab will bring development of larger X-ray, XUV and EUV telescopes for observations from space with arc sec or sub-arc sec resolution at these high energy wavelengths. In addition, Spacelab will allow optical (visible and UV) telescopes with very high spatial resolution (0.5 - 0.1 arc sec) and magnetographs which have been too large for previous space missions. Thus, it is clear that observations from the new generation of SMM and Spacelab experiments should lead to several major advances in our understanding of the Sun, particularly concerning the energy build-up and release in flares and the fine structure of the "steady state" solar atmosphere.

While Spacelab will be excellent for developing new solar experiments which observe the Sun with unprecedented resolution and precision, the fact remains that a Spacelab mission will last for at most two weeks. This limitation is severe for observing those solar phenomena which have either low occurrance rates or long evolutionary time scales. On the one hand, for example, complex active regions which produce very large flares occur only a few times a year even at solar maximum and so cannot be trusted to occur during the one or even two dedicated solar Spacelab missions per year. On the other hand, active regions, large-scale magnetic fields, the solar cycle, and perhaps the solar irradiance evolve on time scales from months to years to decades, and hence cannot be adequately studied by observations in a few one or two week time intervals per year. Thus, the greatest advantage of a Space Platform for solar physics is the long observing time which allows:

(1) observation of rare, but important, events such as very large flares or transients; and

(2) observation of the evolutionary aspects on time scales of months to years.

The other basic capabilities of a Space Platform (i.e., increased available power, weight and space over that of the Shuttle/Spacelab, frequent access for experiment maintenance, and the possibility of manned operation) are primary advantages to solar physics in that they make possible the extended experiment operation.

In the remainder of this report, we outline several solar physics experiments which would be considerably improved by deployment on a Space Platform. In order of approximate increasing complexity and sophistication, these are:

- Solar Gamma Ray Spectrometer;
- Moderate Resolution Telescope for Magnetic and Velocity Observations;
- Lyman Alpha/White Light Coromagraphs;
- XUV and Soft X-Ray Telescopes;
- Hard X-Ray Pinhold Telescope; and
- Solar Optical Telescope (SOT).

All of these experiments will or could evolve from similar experiments flown on other space missions, including Skylab, SMM and Spacelab.

The above experiments will be defined and their requirements for a Space Platform presented below. A summary of these requirements is presented in Table 1.1. In addition to these "dedicated" experiments, we stress here that it will be very important to utilize the Space Platform for monitoring the Sun, both for long-term studies of the solar output and for complementing and aiding the operation of the more sophisticated solar experiments. Such monitoring should include measurement of the solar constant, broad-band spectral measurements of the solar XUV flux and its variations, and a moderate resolution XUV image of the Sun to show the position and general state and evolution of active regions and coronal holes. We assume that such monitors will be developed for Spacelab or other solar space missions, that they will be available and that their requirements for operation on a Space Platform will be modest.

2. SOLAR GAMMA RAY EXPERIMENT

2.1 Scientific Rationale

One of the fundamental discoveries of the OSO-7 mission was the emission of gamma rays from the solar flares of August 4 and 7, 1972 (Chupp et al., Nature 241 (1973) 333). Such gamma rays result from the interaction of the highly energetic plasma accelerated by solar flares with the solar atmosphere around the flare site. Thus, observations of gamma rays provide unique information on the flare mechanism itself, in particular, the number density, energy spectrum, chemical composition and acceleration process of ultra-high energy particle streams from flares. As such they constitute an extremely fundamental, important probe of flares.

Large solar flares are, however, a rather infrequent event even during the solar maximum period, and very large flares thought to be capable of the production of solar gamma rays are more rare still. Thus, their observation requires long orbit stay times of a fairly massive detector package, which makes the use of a space platform ideal for this experiment.

Specific experiment objectives would be:

- To compare the timing of prompt gamma-ray lines such as at 4.44 and 6.129 MeV with the 2.223 MeV line, to infer the acceleration of protons and nuclei in relation to electrons.
- To infer the energy spectrum of the accelerated particles by study of line ratios such as 1.434/0.847, 15.11/4.44 and 2.223/8.44 MeV.
- To measure the temperature and density of the positron annihilation region by analysis of the line width of the 0.511 MeV line.
- To measure the ^{3}He enrichment by comparing the width of the 2.223 MeV line with other lines.
- To measure the C:O:Mg:Si:Fe ratios by comparison of the intensities of the narrow gamma ray lines with the continuum.

TABLE 1.1

SUMMARY OF PLATFORM REQUIREMENTS FOR SOLAR INSTRUMENTS

Instrument	Optimum Orbit/Duration	Stabilization	Orientation	Data-Telemetry	Maintenance Checkout	Environment	Power	Operations
Monitors	Sun synchronous Weeks-Months-Years	Pointing Gimbal 1	Sun-center Pointing	Vidio Mbps		Free of optical contamination	500 watts	Ground commands
X-Ray Spectrometer	Inclination not critical/ Months-Years	Platform Stability	Sun-center Pointing	P.E. kbps	Possible cryogenics	Radiation free	100 watts	Ground inspector of data
Moderate Resolution Solar Magnetic - Velocity Studies	Sun synchronous Weeks-Months-Years	Pointing Gimbal	Solar Pointing	Vidio Mbps		Free of optical contamination; low vibration levels	500 watts	Ground commands
Lyman-α and White Light-Coronagraphs	Orbit 200 km Inclination not critical/ Weeks-Months-Years	Pointing Gimbal 1	Solar Pointing	P.E. Mbps Film Kbps		Clean Platform atmosphere	1000 watts	Film retrieval
EUV and X-Ray a) Wide field of view b) Spectrographs	Orbit 400 km syn Syncronous/ Weeks-Months-Years	Pointing Gimbal 1	Solar Pointing	Film kbps P.E. Mbps		Free of optical contamination; 10^{-} Torr for detectors	1000 watts	Film retrieval
Hard X-Ray	Sun Syncronous/ Weeks-Months-Years	Subsatellite to 1	Sun Centered	Proportional Mbps Counters	Sub-satellite	Minimized propellant in optical path	1500 watts	Propellant Re-Supply
High Resolution Solar Optical Telescope	Sun Syncronous/ Weeks-Months	1	Solar Pointing	Film and 50 Mbps Vidio	Payload Change-out	Platform isolation clean platform atmosphere	2000 watts	Ground Control film retrieval

2.2 Experiment Description

The gamma ray experiment planned for the Solar Maximum Mission (1979-81) lacks the high spectral sensitivity (requiring large mass, cryogenically cooled detectors). Conversely, the large gamma ray balloon payloads currently being developed cannot achieve the long observing periods to statistically enhance their ability to catch gamma ray flares. Only the space platform offers the chance for both large mass capability and long orbit stay-time.

The essential gamma ray experiment characteristics for use on a space platform would be a fairly large (1 m dia x 1.5 m long), massive (500-1000 kg) package requiring only rather coarse (± 1/2 to 1 deg) sun-center pointing. The instrument would be largely passive, requiring nominal in-orbit servicing except for perhaps cryogenic cooling of its detectors. Either large area NaI or CsI arrays would be used as detectors.

2.3 Platform Requirements

- Orbit: 100% sunlight optimum, but anything down to 50% is acceptable.
- Stabilization: Station-keeping stability of platform probably acceptable.
- Orientation: Sun-center ± 1/2 deg.
- Data: Continuous recording during sun-observing periods at ~ 2 kbps; either store on-board and transmit only actual events, or transmit continuously to ground.
- Maintenance/Checkout: Minimal maintenance other than possible recharging of cryogenics; checkout by telemetry.
- Environment: Not sensitive to modest vibration levels or contamination from thruster exhausts; would be sensitive to radioactive materials.
- Power: 50 watts
- Operations: Ground inspection of data record; no real-time intervention by ground or crew required.

3. MODERATE RESOLUTION TELESCOPE FOR MAGNETIC AND VELOCITY OBSERVATIONS

3.1 Scientific Rationale

There is a need for a moderate resolution (1-2 arc sec) wide-field optical telescope for studies of solar magnetic and velocity fields. (Such an instrument will soon be proposed for Spacelab.) For many important problems, the 0.1 arc sec capability of the SOT (see Section 7) is not needed and the 6 arc min SOT field of view is too small. In addition, large amounts of observing time are required for an extremely important class of problems concerning these magnetic and velocity fields. The following magnetic and velocity field phenomena can be studied with the same instrument, either separately or nearly simultaneously.

3.1.1 The Large-Scale Solar Magnetic Field Patterns. Long-term, global-scale monitoring of magnetic fields on a time scale of 5-10 minutes and an angular resolution of 1-2 arc seconds will provide an invaluable data base for the study of the solar dynamo, since the behavior of these surface fields are one of the few observables of this process. The surface magnetic fields of the Sun are also the fundamental cause of all non-steady state solar phenomena, and thus critical to any attempt to really understand these events. Such observations are severely limited when made from the ground because clouds typically prevent such continuous periods of observation, and atmospheric turbulence prevents high resolution magnetic observations for more than an hour or so. This experiment would complement the high resolution observations to be made from SOT.

3.1.2 Coronal Magnetic Feilds. Complete, moderate resolution magnetic observations will enable, using computational techniques already in existence, the construction of detailed magnetic field extra from the photosphere into the solar corona. Comparisons of such derived fields with X-ray and XUV coronal observations will enable the study of the coronal magnetic fields to coronal holes and other coronal features, which in turn bears on the problems of the origin of the solar wind and the interplanetary magnetic field structure.

3.1.3 The Five-Minute Oscillations. By studying the 5-minute oscillation wave modes that are present in the convection zone, it is now possible to determine the solar rotation rate as a function of depth, which is closely related to the dynamo process. So far, the results are only approximate, but the potential for exciting new results is very high given sufficiently improved observations. Platform observations will allow the long periods of uninterrupted observations, which are essential for accurate rotation determinations. This field is still new and the possibilities are not yet fully explored, but it may be reasonable to expect that subsurface variations, if any, in the structure of the convection zone, under active and quiet regions, could be detected.

3.1.4 Flare Waves. We may expect that sensitive, large-scale velocity observations might detect surface waves originating from flares or other transient disturbances. At times, flare-associated waves are seen propagating across the chromosphere, but good velocity measurements would provide a valuable additional seismic probe of the convective envelope. It might be possible to detect flares on the other side of the Sun with such observations, which would serve as probes of the outer layers of the solar atmosphere just as earthquakes probe the terrestrial mantel.

3.1.5 Large-Scale Solar Circulation. Global-scale velocity circulation patterns in the solar atmosphere have recently been detected. Little is yet known about these low-amplitude motions, but it is obvious that long-term observations of these flow patterns will be an important contribution to the study of the solar convection zone, and perhaps the dynamo, process as well.

3.2 Experiment Description

Angular resolution of 1-2 arc seconds is required, for which a Questar-type telescope of aperture 5-6 inches is more than adequate. A field of view of nearly 1/2 degree is required. A filter similar to that proposed for the SOT magnetograph is required. A CCD detector would be needed with $\sim 10^6$ picture elements.

3.3 Platform Requirements

- Orbit: High inclination orbit so as to give frequent long intervals of uninterrupted sunlight.
- Stabilization: About 1/2 - 1 arc second for intervals of a few minutes, thus requiring a dedicated solar pointing gimbal.
- Orientation: Sun pointing with absolute orientation of ± 10 arc seconds.
- Data: Telemetry rate of ~ 10 MHz. The fast mode would be one frame each ~ 3 seconds. The slow mode would be one frame each ~ 5 minutes.
- Maintenance/Checkout: Minimum maintenance required.
- Environment: The filter may require special care during launch to avoid damage from vibration. Scattered light in the vicinity of the platform should not be a problem.
- Power: Low, perhaps 200 W at 28 v.d.c.
- Operations: Occasional commands to switch between fast and slow mode, or from magnetic to Doppler observations.

4. LYMAN ALPHA CORONAGRAPH/WHITE LIGHT CORONAGRAPH

4.1 Scientific Rationale

A pair of instruments that could obtain unique, exciting new scientific information about the structure, heating and mass flow in the corona are a Lyman alpha coronograph and white light coronograph. At the present time there is no reliable method for measuring coronal temperatures beyond a few tenths of a solar radius above the surface. However, measurements of coronal temperatures out to several radii can be made using the profile of the hydrogen Lyman alpha line. Furthermore, combining measurements of the intensity of the coronal Lyman alpha line with the brightness of the white light corona allows determination of the geometry of coronal structures, the coronal hydrogen and electron densities and solar wind velocities in the observed regions. These measurements can be used to determine (1) the region where the solar wind is accelerated; (2) the physical conditions (geometry, temperature, density, velocity) in the acceleration region; (3) the location of the coronal temperature maximum; and (4) the coronal temperature-density profile. Such measurements will provide the fundamental data needed to specify the coronal energy balance and place critical constraints on coronal heating and solar wind acceleration mechanisms.

One of the major difficulties in analyzing coronal data is the problem of determining the geometry of the feature being observed. One of the few methods of determining this geometry is through measurements over a period up to at least a week as a given feature is carried across the solar limb by solar rotation. (For long lived features, such as coronal holes and streamers, observations over an entire solar rotation (28 days) are especially useful.) Even more demanding, the study of the evolution of coronal structures requires long term observations (weeks to months). Hence, in order to realize the full scientific potential of a Lyman alpha/White Light coronagraph combination, long term operation such as could be obtained on the Space Platform, is vital.

Flight of Lyman alpha/White Light coronagraphs in earth orbit during the polar passage period, mid-1986 to mid-1987, of the Solar Polar Mission would be particularly valuable because of the opportunity to get stereoscopic measurements of coronal structures. Other complementary instruments include (1) a coronal emission-line polarimeter for measuring the direction of coronal magnetic fields; and (2) an XUV or soft X-ray instrument which could determine the temperature-density structure in the lower corona (heights within a few tenths solar radius of the surface) where coronographs cannot make measurements.

4.2 Experiment Description

A typical Lyman alpha coronograph will have a mass of 130 kg, size 50 x 50 x 300 cm, field of view 1.5 x 1.5 solar radii, spatial resolution of 10 to 60 arc sec and use a photoelectric detection system. A typical white light coronagraph will have a weight of 100 to 150 kg, size 75 cm x 75 cm x 200 cm, field of view of 12 solar radii, spatial resolution of 5 to 10 arc sec and use film as a recording medium.

4.3 Platform Requirements

- Orbit: Greater than 200 km height (inclination not critical).
- Stabilization: Both telescopes require a pointer such as IPS, with a pointing accuracy of 10 arc seconds and pointing stability of 2 arc seconds.
- Orientation: A capability of observing during the entire sunlight portion of the orbit is highly desirable.
- Data: For the White Light coronagraph, film is the probable recording medium. For the Lyman alpha coronagraph, the telemetry rate is about 100 bps. Ideally the data should be down-linked in real time or, if stored on board, downlinked within an orbit or two for "quick look" purposes on ground. Data quality must be high (all bits transmitted by instrument to spacecraft will be significant).
- Maintenance/Checkout: Checkout by Shuttle crew possible. Film camera changes required for White Light coronagraph during Shuttle visits.
- Environment: Coronagraphs require a clean environment to reduce stray light due to scattering by particulates and gas molecules along the line of sight to the Sun. A clean environment is also needed to avoid contamination of optical surfaces.

- Power: The power requirements exclusive of thermal control systems is about 100 watts for each instrument. How much power is required for the thermal control system will depend on the severity of the thermal environment on the Space Platform.
- Operations: Normally the experiments will be operated from the ground by command. Real time commanding and data are desirable. During visits of the Shuttle the experiments could also be operated by payload or mission specialists.

5. XUV AND X-RAY INSTRUMENTS

5.1 Scientific Rationale

The scientific objectives involve two complementary modes of operation. First, a wide-field, high-spatial resolution XUV spectroheliograph and X-ray heliograph are essential for observing the structure and evolution of chromospheric, transition-region and coronal plasmas. Second, narrow-field, high-resolution XUV and soft X-ray spectragraphs are necessary to determine the physical characteristics (temperature, density and velocity) of the evolving plasma. These two types of instruments yield data that should permit one to determine both how the sun's inner corona and transition zone evolve and the mechanisms responsible for that evolution.

In conjunction with a photospheric magnetograph and a coronograph, the XUV spectroheliograph and X-ray heliograph would be a powerful combination for studying the way in which bipolar magnetic feilds emerge and interact to form large-scale structures such as coronal holes, coronal arcades and streamers. Simultaneous observations in emission lines ranging from chromospheric to coronal temperatures would insure that atmospheric material could be traced even as it is heated or cooled.

Long-duration missions are essential to accomplish these objectives. First, synoptic observations for periods of several weeks to months will be necessary to trace the evolution of active regions from their birth to their decay. Second, to study rare events with convincing statistics, observations will be required over years, especially to compare the behavior of such events at different phases of the sunspot cycle. Thus, for example, several years of observations might be required before one will understand the physical processes that lead to geophysically important flares.

5.2 Experiment Description

Upgraded versions of the Skylab/ATM XUV spectroheliograph (S-082A) and X-ray heliographs (S-054 and S-056) would satisfy the requirements for the wide-field of view (full disk) instruments. A spatial resolution of approximately one arc sec is essential for observing the detailed way in which the XUV and X-ray structures change.

Simultaneous, high-resolution, full-disk observations at several wavelengths in both a synoptic mode (~ 16 exposures/day) and a flare/transient mode (~ 6 exposures/minute for occasional hourly intervals) will require a large data-recording and storage capability. These requirements suggest film as the recording device.

The grazing incidence solar telescope (GRIST), currently being studied by the European Space Agency, could serve as the desired narrow-field XUV spectrographic instrument. This instrument uses a large Wolter Type II telescope to feed two or three focal plane instruments such as a high-resolution, grazing incidence spectrograph and an EUV spectrograph. The overall experiment size is roughly 2 x 2 x 5 meters. The spatial resolution will be 1 arc second. (See ESA documentation for more details.)

The soft X-ray facility, currently being proposed for a future Spacelab flight, could serve as the desired narrow-field soft X-ray spectrographic instrument. This instrument was a large Wolter Type I telescope (based on HEAO-B technology) to feed a number of focal plane instruments such as crystal and grating spectrographs and imaging cameras. The overall instrument size is roughly 1 x 1 x 7 meters. The spatial resolution will be 1 arc sec.

5.3 Platform Requirements

Orbit: Height of at least 400 km to minimize absorption of XUV solar radiation by terrestrial atmosphere; inclination not critical, but continuous sunlight would be useful for some studies.

- Stabilization: Better than 1 arc second, but probably 0.1-0.3 arc second would be desirable during each exposure.
- Orientation: Solar pointing.
- Data: If film recording is used, means should be provided for film changes by frequent astronaut visits. The telemetry could be comparable to that of Skylab with occasional operation by ground commond possible.
- Maintenance/Chcekout: Same as ATM.
- Environment: Minimal out-gassing and thruster burns.
- Power: Typically 100-200 watts per instrument.
- Operations: Ground command necessary on occasions where high frame rate modes desirable (automatic operations possible for synoptic mode); crew attention necessary for film changes and retrieval. Manned observations sometimes desirable for special experiments, but not always essential.

6. HIGH-RESOLUTION, HARD X-RAY EXPERIMENT (PINHOLE CAMERA)

6.1 Scientific Rationale

High-resolution data in the hard X-ray domain ($\lambda \lesssim 1$ Å, $E \gtrsim 2$ keV) can give information on non-thermal conditions in the plasmas to be studied. Imaging with grazing-incidence, focusing X-ray telescopes is possible for soft X-rays; for very hard X-rays a pinhole-camera technique is the logical solution. The pinhole mask, which will consist of lead, need only scatter the radiation rather than totally absorb it. By using a large number of pinholes the collecting area of the telescope is significantly increased. The many overlapping images must be combined into a single image by deconvolution techniques.

The high spatial resolution data, whose acquisition is discussed below, are imperative for the study of non-thermal conditions in flares; the site of particle acceleration during the basic flare process; and the distribution of trapped electrons in the Sun's corona. Consequently it is necessary to measure the hard X-ray flux from flares and from the corona in the energy range $2 < E < 70$ keV, with angular resolution of about 1 arc sec. To the extent it is possible to use the mask as an occulting disk, the instrumental set-up can be used also as a White-Light coronograph that can observe the corona with higher spatial resolution and closer to the photosphere than is possible at other than at a natural solar eclipse.

To have a reasonable chance to observe a very large energetic flare with an intense hard X-ray signature, the mission must be planned to last several to many months. Consequently, mounting the instrument on a semi-permanent space platform would greatly increase the probability of obtaining very high quality data.

6.2 Instrumental Description

The telescope consists of an opaque mask with pinholes (of diameter d) and a detector array at a distance D from the mask. The real, inverted image formed by the pinhole camera has an angular resolution given by the ratio d/D, and the depth of focus in infinite. Position-sensitive Xenon proportional counters will be used to detect photons up to ~70 keV energy. Specific numbers can be given, e.g., a 10 m diameter mask with 5 mm pinholes situated 1 km from a 1 m x 1 m (3 arc min field of view) position-sensitive detector will give an angular resolution of 1 arc sec (2.5 mm spatial resolution on the counter assembly). The mask requires about 2 g cm^{-2} lead absorber, leading to a total weight of about 1600 kg.

To maintain the high spatial resolution it is necessary to know the mask pointing and orientation relative to the image at all times. With the mask mounted on a platform and the detector assembly as a sub-satellite it seems possible to maintain detector separation and alignment with the mask by means of a low energy, pulsed gas-control system. The required station keeping is secured by means of optical laser alignment techniques.

An initial, more modest telescope, whose station-keeping between mask and detector is much less severe, could consist of a 1 m diameter mask with 0.5 mm pinholes placed 100 m away. Angular resolution of 2 arc sec could be obtained under these circumstances on a 0.5 m x 0.5 m (15 arc min field of view) porportional-counter area with spatial resolution 0.25 mm, i.e., about 4×10^6 pixels. By mounting both the mask and detector on the space Platform, the station-keeping problems might be vastly reduced.

6.3 Platform Requirements

- Orbit: 100% sunlight optimum, but anything down to 60% acceptable.
- Stabilization: Detector relative to mask X-Y ± 1 arc sec (rms). Mask position ± 10 cm (rms). Pitch and Yaw ± 1/2°. Roll± 1 arc min.
- Orientation: Sun pointing ± 1 deg.
- Data: 500 k bps
- Maintenance/Checkout: Fuel consumed by subsatellite must be resupplied.
- Environment: Consideration must be given to contamination from thruster exhause for use as coronagraph.
- Power: 500-1500 watts, depending on station-keeping option selected.
- Operation: Mask attached to platform; detector considered a subsatellite with attached dry gas station-keeping propellant.

7. THE SOLAR OPTICAL TELESCOPE (SOT)

7.1 Scientific Rationale

The Solar Optical Telescope (SOT) is a multi-user, facility-class telescope with an aperture diameter of 1.25 m which will give diffraction-limited resolution of 0.1 arc sec at 5500Å (72 km on the Sun; less than one scale height). It operates from 1100Å to 11,000Å and so can observe solar phenomena from the low photosphere up through the chromosphere and transition region to the base of the corona. In its "basic" form, the SOT focal plane instruments will include narrow-band filters, polarimeters and high-resolution spectrographs. This basic SOT has been studied extensively and is a serious candidate for development as a facility-class instrument for operation on the Spacelab. However, a more highly evolved, "full-up" version of SOT has also been proposed for Spacelab operations, which would impose heavy demands because of greater weight and power requirements. If a Space Platform becomes available in the late 1980's, it may be better equipped to provide these support requirements of this advanced, full-up SOT than Spacelab.

All of the science problems for SOT share two features: (1) They are different aspects of determining the temperature, density, states of ionization and excitation, non-thermal velocity and magnetic field of the solar plasma as a function of surface position and time from the low chromosphere to the base of the corona, with sufficient resolution to permit definitive studies of the transport of energy and mass from the solar convection zone into the corona and beyond. (2) They are problems which can be addressed with the payload of the basic SOT, though in some cases the problems require, ideally, more observing time than early Spacelab missions will provide. (If the full complement of instruments planned for the full-up SOT is flown, then an even longer list of problems encompassing coronal physics can be provided).

Some scientific problems to be addressed with SOT are:

- Photospheric turbulence and the generation of acoustic waves
- Wave propagation and non-radiative heating in the photosphere
- Penetrative convection and the generation of gravity waves
- Supergranulation flows and their evolution with time
- Small-scale magnetic fields and correlated magnetohydrodynamic phenomena
- Physics of sunspots
- Chromospheric heating
- Transition region structure and dynamics
- Flare phenomena in the chromosphere and transition region
- Prominences
- Active region loops (cool components).

A number of requirements of the full-up SOT are, at best, just met by the currently baselined Spacelab. These fall into the general categories of weight, power, telemetry rate and, most important of all, duration for required observations. In general, when the event to be studied is comparatively rare, when good statistics are needed, or when the solar features evolve slowly in time, more than 14 days of observing time are required. In particular, the following studies require or would greatly benefit from the extended observing period available from the space platform:

- Evolution of supergranulation flows
- Evolution of small-scale magnetic fields
- Physics of sunspots
- Flare phenomena in the chromosphere and transition region
- Prominences
- Active region loops (cool components).

7.2 Experiment Description

The SOT Telescope: The SOT telescope consists of a 3.8 m diameter, 7.3 m long, semi-monocoque, aluminum truss structure, at the aft end of which is mounted a 1.25 m, f/3.6 parabolic aperture primary mirror. The primary mirror assembly (PMA) provides active alignment, focus, sub arc-second pointing, rastering, image motion compensation and offset of ± 1 solar diameter (32 arc min). A Gregorian secondary pod includes the secondary mirror, heat rejection mirror and a tertiary mirror to feed user instruments attached to the side of the SOT truss. This Gregorian pod can be retracted for the deployment of other instruments into the prime focus for greater operational versatility.

The Full-Up SOT Observatory: The full-up SOT observatory, considered optimum by the SOT Facility Definition Team (FDT), consists of the following major components:

- The SOT telescope (described above).
- A UV spectrograph, covering at least $1200 < \lambda < 1825$ Å and $2775 < \lambda < 2825$ Å.
- A tuneable, universal filter and magnetograph covering 4000-11,000Å.
- A visible light spectrograph, covering $3900 < \lambda < 7000$ Å (the proposed Fraunhofer Institute PETRA would serve well).

- From three to five other solar instruments of a "PI class", operating in both rotate-in and swing-in cannisters.
- An XUV facility-class telescope and spectrograph, such as the European designed GRIST and the instruments proposed in a previous section in this document, covering the range $100 < \lambda < 1250$ Å. The SOT truss would provide support and coarse pointing.
- A soft X-ray facility, such as designed by the XUV/Soft X-ray FDT (and as proposed in a previous section), covering approximately $2 < \lambda < 100$ Å.

7.3 Platform Requirements

- Size of SOT: 7.3 m x 3.8 m
- Weight of Full-Up SOT: 6600 kg
- Orbit:- Full Sun (polar is ideal) at 450 km
- Stabilization: 1 arc sec over 15 min (PMA will help here)
- Orientation: Solar pointing
- Data - Telemetry: Film Storage up to 100,000 frames. 50 Mbs data downlink with 10^{-6} error rate desired (optimum).
- Maintenance/Checkout: 6 mo. to 1 yr.; should be nominal
- Environment: Avoid 10-100 Hz vibration across gimbal; avoid H_2O and hydrocarbon contaminants.
- Power: 2000 watts continuous; peak not significantly greater
- Operations: Ground control identical to Spacelab POCC.

CHAPTER VI

SPACE PLASMA PHYSICS PANEL

Panel Chairman:	John Winckler, University of Minnesota
Panel Members:	Jim L. Burch, Southwest Research Institute, Texas R. G. Johnson, Lockheed George Paulikas, Aerospace Corporation Erwin Schmerling, NASA Headquarters W. L. Taylor, TRW
Panel Liasion (MSFC):	Rick Chappell

1. INTRODUCTION

1.1 Science Objectives

One of the major results of the space age has been to give us our present picture of the solar-terrestrial system. Space measurements have demonstrated how the outer layers of the sun evolve and give rise to the interplanetary solar wind. Furthermore, they have shown how this solar wind interacts with the terrestrial dipole field to produce the earth's magnetosphere and in like manner the magnetospheres of other magnetized planets. One of the early breakthroughs was the discovery of the radiation belts followed by the delineation of the bow shock, the magnetopause and the tail structure. The age-old problem of the origin of the aurora, the cause of magnetic storms, the origin of the radiation belts and particle bombardment of the upper atmosphere with all its effects on communication, and weather, and in general, the coupling of appreciable amounts of energy from the sun to the earth's atmosphere have to be understood in terms of this new picture of the earth's environment.

For the most part, the sun-earth system just described is a vast and complex series of cosmic plasma interactions - that is, interactions produced by ionized or electrically charged gases, in some cases very hot, entrained in magnetic force fields. Solar-terrestrial plasmas illustrate in many respects cosmic plasmas as they exist throughout the universe. It is a readily accessible laboratory for investigating not only terrestrial, but also cosmic problems.

The "Colgate Report" (see bibliography) describes the study of solar system plasmas as "an important branch of science, concerned with problems of true intellectual significance that may be studied effectively in space and whose importance extends to laboratory physics as well as to large scale astrophysics." The report identifies "six general abstract problems, vital to further understanding of space plasmas, that have already received considerable theoretical attention and have important implications beyond the study of solar-system plasmas. These are: (1) magnetic-field reconnection, (2) the interaction of turbulence with magnetic fields, (3) the behavior of large-scale flows of plasma and their interaction with each other and with magnetic and gravitational fields, (4) acceleration of energetic particles, (5) particle confinement and transport, and (6) collisionless shocks.

Of these problems perhaps the only one that has hitherto been addressed by the space research program in a reasonably systematic way is the last, and it is precisely the collisionless shock problem on which space science has had the greatest impact. The other topics, especially (1) and (5), are clearly of key importance to controlled fusion research, while all six are of considerable astrophysical interest" (from pp. 4-5).

The report further identifies a number of broad categories of problems critical to further studies of the magnetosphere, as shown schematically in Figure 1.1 of the report reproduced here.

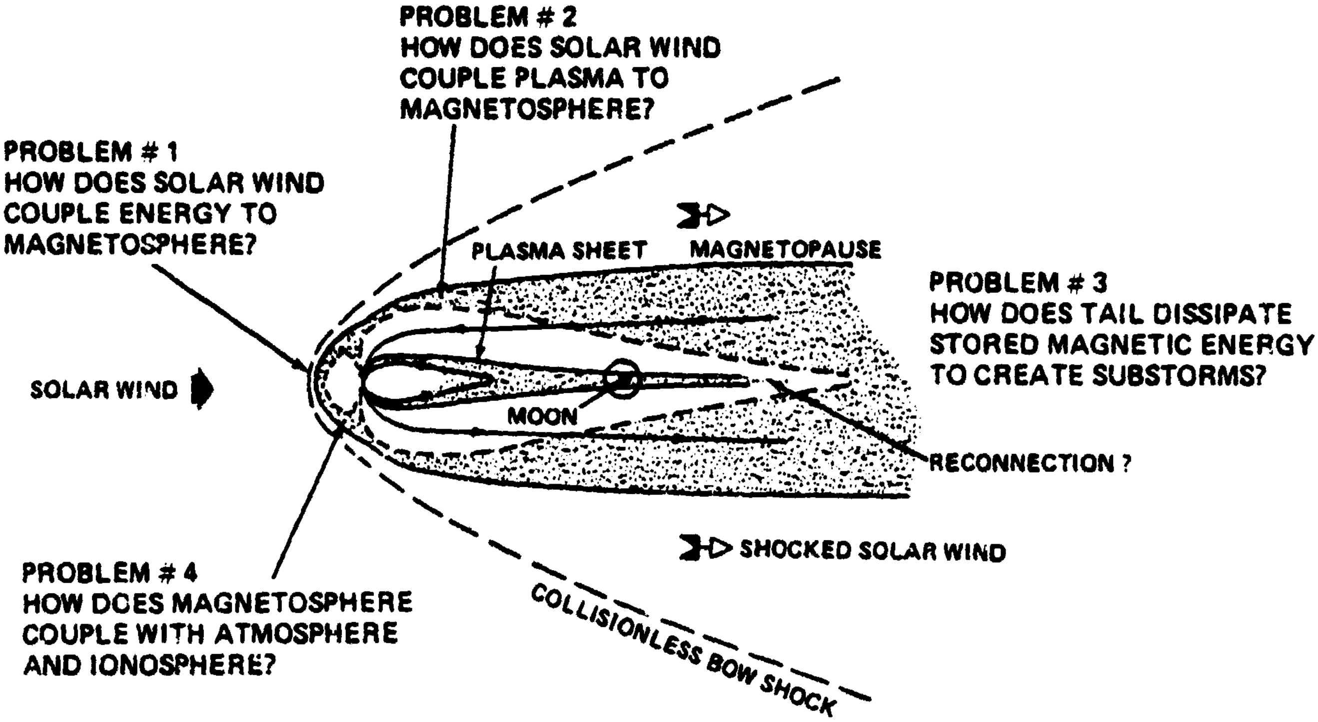

Figure 1.1. Critical problems of magnetospheric physics.

One of the most important and at the same time one of the most complex links in the solar-terrestrial chain is the coupling between the magnetosphere and the atmosphere (see Figure 1.1, Problem #4). It is very possible that this coupling provides the "trigger" to release the energy stored in the tail current and field systems, and this coupling thus is also a part of Problem #3 (Figure 1.1). The entry, transport and acceleration of solar plasma into the magnetosphere are processes of major importance and are included in Problem #3 (Figure 1.1). In the following we will suggest experiments which are addressed to the solution of these broad categories, and to the six fundamental topics identified by the Colgate Report, and for which the Space Science Platform is the best, and in most cases the only means of implementation.

1.2 Flight Missions for Space Plasma Physics

The elegant picture of the magnetosphere which we now have, has been derived from data from a large number of special purpose free-flyers, mostly of modest size. Some of the problems stated in Figure 1.1, such as numbers 1 and 2, can still be attacked effectively by such missions, of which a significant number are at present either operational, or approved for flight. A list of NASA missions in these categories follows in Table 1.1. Space plasmas are also under study on various Application or DOD missions but these are principally aimed at evaluating the effects of the environment on various systems and are not listed here.

Table 1.1

MISSION	STATUS
Atmosphere Explorers C & E	Operational
International Sun-Earth Explorers 1, 2 & 3	Operational
Solar Maximum Mission	Launch 1979
Dynamics Explorers A & B	Launch 1981
Solar Mesosphere Explorer	Launch 1981
Solar Polar Mission	Launch 1983
San Marco D	Approved
Active Magnetospheric Plasma Tracer Explorer	Tentatively Approved

Space plasma instrumentation is included in three early Shuttle missions, namely OFT-4 (launch 79), Spacelab 1 (1980) and Spacelab 2 (1981). These investigations are of a preliminary type, and the severe restrictions of early Shuttle missions limits their ability to give definitive solutions to the problems mentioned above.

Advances in science are often tied to advances in technology. The ability to orbit large and heavy instruments for long duration flights makes possible a whole new class of active experiments which require large power sources and large structures, as well as a new class of passive observing devices of very large aperture and high resolution.

The advent of the Space Shuttle has naturally led to many studies of its use for space science. For example, during the "AMPS" study in space plasmas, a very detailed examination was made of how to use the Shuttle-Spacelab system itself as a research base. As in other disciplines, the problems which surfaced were many and severe. Despite the large inherent capability of Shuttle, the power and weight for individual instruments is either completely inadequate or disappointingly low. The limited flight duration of Sortie missions and the severe problems of time-lining during Sortie flights does not permit even minimum global or temporal coverage for a large variety of experiments.

The fact that the Shuttle exterior is covered with insulating tiles makes it difficult to operate large particle accelerators on-board. Wave and plasma diagnostics are difficult because of EMI and other contaminations. The deployment of large extensidles which can not be retracted or released is, of course, impossible.

For large instruments, these difficulties would seem to be overcome by the SSP concept, which supplies the essentials: power, weight, size, duration, control and data capability.

1.3 Categories of Investigations

The space plasma investigations may be conveniently classed as "active," which includes both the injection of tracers and major perturbations of the environment, or as "passive" in which the natural environment is studied in detail to identify cause and effect relationship. In a third category many investigations may be coordinated so that all the inputs and effects in the large solar terrestrial system may be studied together. We will now proceed to discuss a number of typical space plasma physics investigations designed to address the objectives in the Colgate Report and which could be implemented by means of the SSP. These are to be considered as typical examples; many others could be added.

2. TYPICAL EXPERIMENTS FOR SPACE SCIENCES PLATFORM

2.1 Active Experiments

2.1.1 Plasma Wave Injection Facility. A large number of space plasma physics investigations could profitably be carried out using a Space Science Platform (SSP). Most, if not all of the active experiments identified by the atmospheres, magnetospheres and plasmas-in-space (AMPS) studies as important and possible with Spacelab can be easily accomplished on an SSP and in most instances done more effectively. Other investigations are only possible with an SSP, since it has greatly increased resources. A Plasma Wave Injection Facility (PWIF) would be an essential component of the SSP scientific instrumentation. The PWIF would allow the techniques of experimental plasma physics to be used to determine the validity of the theoretical plasma physics models presently being applied to the magnetosphere and ionosphere and to distinguish between rival hypotheses.

Investigations with a PWIF will attack experimentally a number of the six general problems that were identified by the Colgate Committee (Report, 1978) as vital to the understanding of space plasmas. Aspects of the following problem will be better understood after a comprehensive program of PWIF investigations:

- Interaction of turbulence with magnetic fields
- Acceleration of energetic particles
- Particle confinement and transport
- Collisionless shocks

Descriptions of a few of the important investigations that could be carried out with a PWIF on an SSP follow:

Wave-Particle Interactions. There is evidence that power line radiation, primarily at harmonics of the world's 50/60 Hz power grids in the kHz range, affects the electron population and produces spontaneous wave generation in the radiation zones. Ground transmitters in the VLF range also stimulate emissions and affect electrons. A PWIF on an SSP would be many times more effective in studying these wave-particle interactions than are ground transmitters. In addition, a PWIF operating in the few kHz range and at the proper power level should produce significent temporary reductions in the trapped electron population. Initial PWIF wave-particle interaction studies can be carried out on early Spacelab flights. These first experiments will confirm that wave-particle interactions are indeed occurring and might be able to measure the precipitated particle fluxes. However, much larger powers than available from Spacelab are likely to be required to significantly reduce the particle population. Initial SSP experiments would determine the required power level. Later higher power experiments would deplete the radiation zone on field lines near the SSP for the study of subsequent refilling. Energetic particle detectors with high pitch angle resolution ($\sim 1^{o}$) will be required to determine the precipitation efficiency of the experiments. After the process is well understood and reproducible, practical use could be made of a PWIF to drain the radiation zones whenever a sensitive cargo of humans, electronics or solar cells was to pass through the zones. Table 1.1 gives SSP requirements for wave-particle interaction studies.

Magnetic Pulsations. Magnetic pulsations are wave-like variations in the earth's magnetic field with periods of seconds or longer. They have been observed on the ground and on high altitude satellites. Theories of magnetic pulsation and propagation are highly complex since the free-space "wavelengths" of the pulsations are the same order as the size of the magnetosphere. As a result of this size comparability, magnetic pulsations appear to be resonances, or standing waves on geomagnetic field lines produced by propagating Alfven mode disturbances.

Field line resonances, excited by some external mechanism that successfully transfers energy through the magnetopause are detected as Pc 2, 3, 4, or 5 on the ground, or by satellites in the distant magnetosphere. The mechanism is thought to be an imposition of large amplitude bow shock pulsations on the magnetopause, governed by interplanetary magnetic field (IMF) orientation; a Kelvin-Helmholtz instability at the magnetopause, governed by solar wind velocity and other factors and stimulated by any available perturbation; a direct pass-through of upstream waves (from the bow shock), also governed by IMF orientation; or any combination of these.

Those waves which are resonant or nearly resonant in the magnetosphere cavity undergo minimum damping as they fill the magnetosphere. By generating artificial Pc 3, 4 and 5 waves with the PWIF and observing them elsewhere in the magnetosphere, the resonant magnetosphere theory can be investigated and quantified and the acciracu of resonant frequency predictions evaluated. Observations on (or near) field lines connected to the PWIF will also determine the damping or growth of propagating pulsation waves. A practical benefit of this investigation may be the ability to measure solar wind parameters accurately from ground magnetic pulsation observations.

In order for pulsations to be recorded on the earth they must encounter and penetrate the ionosphere and the conducting ground. Until recently the conventional wisdom stated that the polarization as measured on the ground was nearly the same as that above the ionosphere. However, recent theoretical calculations have shown that these polarizations may differ by as much as 90°. If true, this will have profound effects on pulsation theory. Artificial pulsation generation well above the ionosphere and detection and polarization determination on the ground would permit definitive evaluation of the rotation theory.

A related investigation is one which tests the applicability of adiabatic particle motion theory to the motion of highly energetic ions (~ 100 MeV/nucleon) in the South Atlantic Anomaly. This experiment is described in detail in the inner magnetosphere energetic particle dynamics section.

To carry out these investigations in the magnetic pulsation frequency range requires a source of the waves and pulsation receivers at other locations. The frequency range is commonly referred to as ULF and is a very difficult range in which to excite plasma waves. The primary obstacle is the difficulty of coupling the electrical energy into waves. Efficient direct coupling requires an antenna nearly as long as a wavelength. Large structures available on an SSP will help increase direct radiation efficiency.

Two indirect methods of exciting ULF waves are also possible. One method is to transmit two VLF waves, closely space in frequency which might interact nonlinearly, giving rise to ULF waves at the difference frequency. The second method is to transmit VLF waves, modulated at ULF. The VLF waves should interact with electrons near the equator, precipitating some into the ionosphere. The precipitating electrons will act as a long antenna, and will radiate some ULF energy. The high power available to a ULF transmitter on an SSP will allow a large electrical power to be delivered to the antenna. The requirements on an SSP to support a ULF transmitter/antenna system are given in Table 2.1.

Plasma Instabilities. Plasmas with non-Maxwellian velocity distributions are generally unstable to plasma wave growth. Theories to describe these instabilities abound, both in the linear and non-linear regimes. These theories should be tested in the unique plasma conditions of the ionosphere, namely, in a plasma with a Debye length very much smaller than the container. To obtain a non-Maxwellian plasma a second plasma component with a different velocity distribution must be added to the ambient plasma. This can be done with an electron accelerator. To provide a theoretically unstable total distribution the accelerating voltage need only be a few volts ($\lesssim$ 100 V) in the ionosphere. The beam current must be high enough, however, to produce a beam density which is at least a few percent of the ambient density and spread over a significant area, certainly as large as an electron gyroradius, perhaps as large as a few wavelengths. Wave growth will occur in the dual component plasma when the distribution is unstable and when a perturbing wave is present. Random fluctuations can act as the seed for wave growth, but in this case, a wave supplied by the PWIF will grow to measurable amplitudes faster.

The most unstable modes are generally short wavelength electrostatic waves. Early Spacelab flights should discover how to preferentially excite electrostatic modes. By launching these waves into the dual component plasma, wave growth will occur. A subsatellite on the same field line with plasma wave detectors will be able to measure the waves and thus the growth rates. These growth rates are predicted by theory and depend on the plasma distribution function, which can be measured with plasma analyzers (RPA's, ESA's) on the subsatellite. A subsatellite with capabilities of the Spacelab 2 PDP would be more than adequate for making these measurements. Subsatellite characteristics are described elsewhere in this report.

Atmospheric Gravity Waves. Atmospheric gravity waves are believed to play a role in the energy transfer to and within the mesosphere and thermosphere. Two major sources have been identified, the troposphere and the auroral zones. Tropospheric gravity waves propagate upwards and dissipate in the mesosphere and thermosphere. It is estimated, for example, that 10% of the energy deposition in the upper mesosphere/lower thermosphere comes from atmospheric gravity waves. Those waves arising in the auroral zone propagate horizontally toward the equator. Again they are believed to be an effective means for the transport of auroral energy, but no definitive studies have been made.

Atmospheric gravity waves couple to the ionosphere and manifest themselves as Traveling Ionospheric Disturbances (TID's). TID's in turn can easily be observed by techniques designed to determine ionospheric electron densities. The properties of gravity waves are largely unknown (for example, their speed of propagation has been estimated with a spread of more than an order of magnitude) due largely to the fact that most observations have been made from the ground from one or a small number of locations. An SSP moving much faster than the group velocity of the gravity wave will be able to provide more comprehensive data on gravity waves than before possible. A topside sounder on the SSP with directional sounding will allow a three dimensional map of gravity waves to be constructed as the SSP passes over a TID. One way to accomplish the directionality required is to utilize the doppler shift of the received signal which depends on the angle between the received sounder pulse and the velocity of the SSP. Another more straight-forward technique is to utilize antennas with directionality. The SSP will be the first space vehicle with the capability to erect the large structures required for an antenna with the necessary directionality.

It might also be possible to use an incoherent scatter radar from low earth orbit; however, high powers and a large antenna are required. For a 7 km spatial resolution at an orbital altitude of 250 km a peak transmitter power-antenna area product of $\sim 4 \times 10^{11}$ m^2 W is required to measure a density of 10^4 ele/cm^3 at 120 km with an accuracy of 10% operating near 50 MHz. The antenna diameter is 100 m, minimum. A minimum size antenna requires $\sim 10^7$ MW peak power or about 250 kw input power.

Magnetospheric Low Energy Electron Densities. The dynamics of the total cold electron population of the inner ($r \lesssim 6.6\ R_e$) magnetosphere has been studied for many years. However, the measurements have all been at a single point, along a line or a few points and/or lines. The ability to monitor constantly the electron distribution in the inner magnetosphere would allow great advances in the physics of the inner magnetosphere. These distributions will give fundamental information on filling processes in the inner and outer plasmasphere. Also, the radar observation of changing plasmapause location will reflect changing convection electric fields in the magnetosphere, a valuable tool in determining magnetospheric dynamics.

However, the technical problems are formidable but may be soluble with an advanced SSP. A bistatic incoherent scatter radar with a transmitter at geosynchronous orbit and receiver at Jicamarca might be possible. For ~ 0.1 Re spatial resolution and an integration time of one hour, the transmitter-antenna would need a peak power-area product of ~ 10^{13} m^2 -W with a minimum antenna diameter (or dimension) of 500 meters operating near 50 MHz. Densities above ~10 cm^{-3} would be measurable. A one kilometer diameter dish would need a peak transmitter power of 3 x 10^5 watts or about 100 kw input power. If the electrons and the resulting return were partially coherent, say by being ordered by electrostatic waves, the received signal would be higher. Requirements on the SSP for this investigation are listed in Table 2.1.

2.1.2 The Particle Beam Injection Experiment. Next to a solar flare, the magnetospheric substorm (or auroral substorm) is the most spectacular display of plasma dynamics which can be studied in great detail. The substorm releases important quantities of energy into the atmosphere from the more distant magnetosphere in the form of Joule heat, molecular dissociation (and reconnection) X-rays, visible, U.V. and I.R. radiations, plasma and EM waves and magnetic pulsations. Cause and effect, particularly the "triggering" mechanisms are difficult to identify because like many cosmic plasma processes, the system is highly interactive.

Active perturbation experiments can break into the natural feedback loop and seperate cause and effect. We now suggest an experiment in which a large amount of energy is injected into the 100 km-level ionospheric region prior to the natural sub-storm onset, by means of a powerful electron acceleratior on SSP. Energetic electrons of 10-40 KeV energy may be the best way to accomplish this, and in fact nature may use this method as the more energetic auroral electrons ionize the E-region. This ionization provides a path for Hall and Pederson currents, and releases the magneto-tail energy by discharging the cross-tail current through the ionosphere. We envision an experiment carried by SSP consisting of a large area current generator formed of sets of parallel conducting surfaces arrayed perpendicular to the B-field, with areas of 10^4 m^2. Electron currents of 10 amperes at up to 40 KV are driven from SSP orbit downward to create significant E-layer ionization near the 100 km level. With this power density and current density (1 ma/m^2) a bright visual aurora would be produced. Under proper magnetospheric conditions a localized electrojet may be formed and a localized auroral deposition event may occur. The role of particle ionization as a substorm "trigger" could be tested and the energy release studied. The field-aligned currents produced by such a device would be studied for wave emission and beam-plasma effects, the production of vertical (or field-aligned) potential differences, the upward acceleration of ions, etc., in other words many of the detailed substorm processes. The global and temporal coverage offered by the orbital SSP would permit

Table 2.1

Parameter	Investigation		
	Wave-Particle Interactions	Magnetic Pulsations	Inner Magnetosphere Cold Electron/ Dynamics
Orbit (alt, incl)	250-500 km, 55°	>2000 km or Geosynch 50-60°	Geosynchronous
Stabilization	NR (no requirement)	NR	NR
Orientation	knowledge to 1°	same	same
Data rate (one)	≤ 200 kbs	≤ 100 kbs	≤ 5 Mbs
On board storage	(only to store data for non-realtime communication periods)		
Maintenance	None required except to repair failures		same
Checkout (on orbit)	None	Only for geosynchronous	Yes
Environmental sensitivity	Pressure ≤ 10^{-5} torr - Strict EMI requirements	Pressure ≤ 10^{-6} torr	Pressure ≤ 10^{-6}
Power	25 kw (500 kw later) average		3MW peak (2% duty cycle)
Operations	Manned interaction desirable in real-time - on board or on ground. Shuttle tended or free flying ok		free flying
Weight	1000's of kG	1000's of kG	100's of kG
Size (volume +)	10's of m^3	10's of m^3	1-10 m^3
Antenna sizes	100's of m long	1 km long	≥ 500 m diameter dish
Diagnostics on SSP	high pitch angle resolution particle detector	None	None
on subsatellite	0-30 kHz plasma wave receiver	ULF magnetometer	None
on ground	plasma wave receivers	ULF magnetometer	Receiving location

the investigation of a wide range of magnetospheric and ionospheric conditions over a wide latitude (and height) range as well.

Requirements for this experiment are as follows:

(1) An on-board voltage source of 400 KW peak power for pulse durations of a few seconds with a 10% duty cycle.

(2) Acceleration or current-drive electrodes-deployed as 100 x 100 meter conducting sheets or screens. [Note: The form and deployment of the large accelerating (or current drive) screens must be studied in detail. A size such as 100 x 100 m illustrates the problem!]

(3) Various local plasma diagnostics on the SSP. Energetic particle detectors.

(4) Remote sensing equipment: optical imagers and photometers on SSP, magnetometer and wave detectors on a subsatellite.

(5) Coordinated ground-based or aircraft observations under the SSP orbit.

(6) High-latitude orbit - 56° would reach the auroral zone frequently at given local time, if at least 6 months SSP duration were available.

(7) Weight-difficult to estimate. In total, including diagnostics, many tons.

(8) Stabilization - magnetic orientation for certain periods $\pm 1^{\circ}$.

(9) Data - T.V. bandwidth plus 200 KBS digital data. Imaging devices are the pacers here. Onboard recording and/or TDRSS.

(10) Operations: This type of experiment with its well-defined geometry is a good candidate for ground control.

(11) Maintenance - Checkout-in principle, quite simple. Requires deploying large structures. The accelerator power drive is a major component and would have to be returned to earth for overhaul.

2.1.3 Chemical Release Experiments for Studies of the Entry, Transport and Acceleration of Magnetospheric Plasma. Plasma enters the magnetosphere from the solar wind and from the ionosphere. In the case of ionospheric plasma, the entry is probably controlled by magnetic field-aligned pressure gradients and by the localized occurrence of field-aligned electric fields. At the magnetopause turbulence, magnetic neutral points and magnetic merging may all play important roles, although the question of entry processes of solar wind plasma is still very much an open one. Once inside the magnetosphere, plasma is transported and accelerated by electric fields and by spatial and temporal variations of magnetic fields.

Investigations of these plasma entry, transport and acceleration phenomena have included the direct plasma and field measurements of programs such as ISEE (International Sun-Earth Explorer) and the measurement of electric fields by tracking artificial ion clouds. A Space Science Platform (SSP) in low-altitude earth orbit can contribute substantially to studies of these phenomena by providing the capability to conduct long-term experiments involving the injection of plasma clouds and particle beams into the magnetosphere and subsequent observations of the transport and acceleration which they experience. For the sake of brevity, attention is focused here on the class of experiments using gas releases.

Recent Results and Planned Missions. Since the late 1960's, gases released in the earth's ionosphere and magnetosphere have been used as tracers of the motions of ions and neutral gases. The released gases have generally been alkali metals (Li, Ba, Sr, etc.) which have low ionization potentials and hence are easily ionized by sunlight. Subsequent to their ionization the gases, which are released either isotropically (thermite releases) or are projected along magnetic field lines (shaped-charge releases), are governed in their motion by the electric and magnetic fields they encounter. These ionized-gas clouds are made visible by resonant-fluorescent scattering of sunlight allowing their subsequent motion to be tracked by optical means. Tracking therefore, can provide measurements of the large-scale electric and magnetic feilds that surround the earth. These measurements also determine the paths of natural plasmas, which follow the same paths as the injected ions.

Experiments already conducted have provided measurements of the time-development of large-scale ionospheric and magnetospheric electric fields, have detected for the first time the existence of electric fields with components along magnetic field lines (parallel electric fields), and have been used to map the configuration of magnetic field lines. The approved spacecraft mission AMPTE (Active Magnetospheric Plasma Tracer Explorer) will attempt to trace the entry of solar-wind plasma into and through the magnetosphere by releasing lithium clouds in the distant magnetosphere and solar wind and detecting the ions directly at various locations within the magnetosphere. This experiment will have to be repeated a number of times under different conditions of solar activity and for various orientations of the interplanetary magnetic field.

A comprehensive series of magnetospheric chemical release experiments is now under study in the Spacelab multi-user instrument program. CRM's (Chemical Release Modules) are planned to be carried to low orbit by the shuttle and boosted into various near and distant earth orbits by the Solid Spinning Upper Stage (SSUS). Loaded with approximately 100 gas-release cannisters of various types, each CRM will have a lifetime of a year or more during which releases can be commanded at desired locations and times. Observations of the releases will be made from the ground, from sounding rockets, from airplanes, or from Spacelab.

Space Science Platform. The Space Science Platform (SSP) would provide an ideal observing station for chemical release experiments. The advantages provided by the SSP include the following: (1) optical observations can be made from above the atmosphere, thereby avoiding the scattered light which restricts ground observations to those times when the atmosphere is dark and the gas cloud is sunlight; (2) large high-sensitivity optical imagers can be employed; (3) observations can be under the real-time control of scientists who are either on board the platform or in specially-equipped ground-based control centers; (4) continuous opportunities exist for the conduct of gas-release experiments, allowing the quick-reaction study of transient phenomena such as solar flares, coronal holes and magnetospheric substorms. Although items (1)-(3) above can be achieved to some degree with Spacelab, the continuous and long-term opportunities provided by an SSP for the conduct of such experiments is a key advantage, allowing the investigation of these phenomena under various conditions within the solar-terrestrial system.

<u>Scientific Objectives of an Example Experiment.</u> An example of a chemical release experiment is the study of plasma transport and acceleration in and above the aurora. The objectives of this experiment are to investigate the auroral electron acceleration mechanism and its role in populating the magnetosphere with ionospheric ions. Direct measurements of electric fields and electron and positive-ion fluxes on auroral field lines have been interpreted in terms of parallel electric fields at altitudes of 100 to 800 km. Equipotential contours in a magnetic meridian as sketched in Figure 2.1 are thought to exist above the aurora. However, this picture is based on direct measurements by particle detectors and electric-field probes aboard polar-orbiting satellites, which can only provide one-dimensional scans through the region. This experiment would probe the structure of these auroral electric fields in detail by injecting tracer ions and tracking their motions.

<u>Experiment Description</u>. The experiment would utilize a CRM flying at an altitude between 500 and a few thousand kilometers and leading the SSP by several minutes. A trail of barium or other suitable gas would be released by the CRM over a distance of a few hundred kilometers and above an auroral arc. If a thermite release is used the orbital velocity of the CRM will result in Ba^+ energies of approximately 40eV, and an upward flow will result from the magnetic mirror force. Somewhat higher upward velocities could be attained with a trail of shaped-charge releases. In either case the ions would move upward and into the acceleration region. Eastward and westward flow velocities $\bar{V} = \frac{\bar{E} \times \bar{B}}{B^2}$ will be superimposed upon the field-aligned velocities in the regions north and south of the aurora. These convective flows should decrease toward the center of the acceleration region where the ions also encounter strong field-aligned electric fields. Observations of the details of the Ba^+ flows using optical imagers mounted aboard the SSP will result in a map of the true equipotential contours.

Due to time variations, local-time variations, and a great variety of magnetospheric conditions which can exist, numerous experiments of this type must be performed.

<u>Requirements on the SSP</u>. Instruments needed on the SSP are listed as follows:

(1) A Chemical Release Module of the type now under study in the Spacelab Multiuser Instrument Program with SUSS propulsion unit, to be launched from a shuttle.

(2) An imaging system similar to the Spacelab I Low-Light-Level TV with pointing system capable of 0.01° stability, scanning rates of 20°/minute, and unobstructed viewing over 2Π steradians (upward hemisphere).

(3) Orbit: Altitude above 250 km and magnetic latitudes above 65° (57° inclination orbit satisfactory, polar orbit preferred).

(4) Data: Real-time imagery data (4.2 MHz TV) needed in SSP or on ground.

(5) Power: Same as Spacelab I LLLTV.

(6) Weight/Volume: Same as Spacelab I LLLTV.

(7) Operations: Real-time pointing of imager is required under the control of on-board or ground-based scientist who has access to images in real-time.

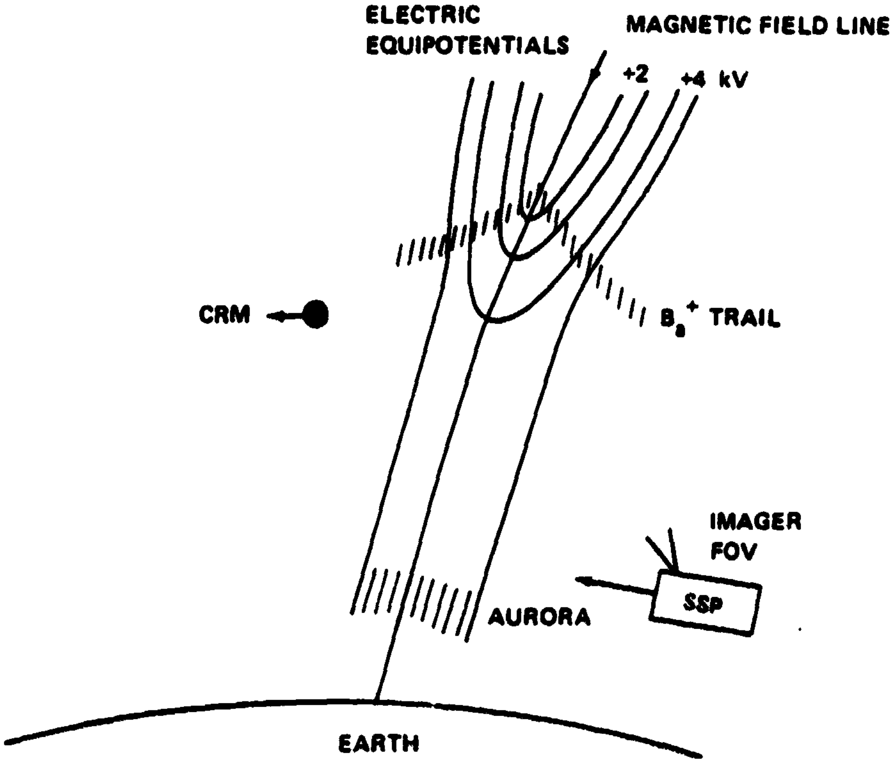

Figure 2.1

2.2 New Passive Observations of the Natural Environment

2.2.1 Radiation Belt Dynamics.

The lower fringes of the earth's radiation belts have been the subject of intensive study since the beginning of the space age. Indeed, the discovery of trapped energetic radiation at low altitudes was the premier scientific achievement made possible by satellite technology. Although a great deal of information is available about radiation belt dynamics, the details of many of the processes which couple the magnetosphere to the ionosphere and neutral atmosphere, and which occur in the region between 100 and 1000 kilometers are still not well understood. The capability of the space science platform to carry into orbit large, power consuming experiments and operate these for long periods of time opens new horizons in the study of radiation belt dynamics and will make possible a better understanding of the exchange of matter and energy between the magnetosphere, ionosphere and atmosphere system. An observational program, incorporating new types of passive observation that are well integrated with the program of active experiments described elsewhere in this report, promises to close many of the gaps in our understanding of radiation belt dynamics as well as providing, for example, baseline information on the presence of minor species of ions in the radiation belts could be obtained with very high sensitivity (not now available) against which the possible polluting effects of massive use of ion propulsion transport or chemical release can be assessed.

Typical experimental programs which would benefit from the integrated (weight, power, duration) capabilities of the space science platform are described below.

(1) The energetic proton population which the space science platform will encounter while traversing the South Atlantic Anomoly represents the most energetic (~ 100 MeV) and long lived (~ 10's of years) component of the near earth radiation. High-accuracy, high time resolution measurements of the distribution function of this population have never been carried out because of limitations or experiment size. Such a study may shed light on the upper limits of adiabatic motion in our magnetosphere as well as the perturbing effects of natural or man made (see Section 2.1.1 on lasma wave injection) electromagnetic radiation. Present theory, never experimentally verified, holds that energetic protons are scattered by waves with ultra-low frequencies. Experimental verification of this theory would close one of the remaining gaps in our understanding of the origin and loss of proton radiation in the inner zone. Tests of the theory of adiabatic motion on a time scale not accessible to laboratory devices, may provide insight into fundamentals of charged particle orbit theory as well as contributions to understanding trapped particle behavior in laboratory plasma devices.

(2) It is known that precipitation of energetic particles from the radiation belts provides one of the sources of ionization of the middle and low latitude ionosphere. This precipitation is one of the signs

of trapped radiation belt particles. The level of this precipitation varies in a complex manner in response to magnetic activity and is also dependent on geographic longitude because of the offset of the earth's magnetic field. Measurement of the magnetosphere-ionosphere-atmosphere interactions at low and middle latitudes have been difficult because of the combination of weight, flight duration and size limitations of the instruments that could be carried into orbit. The capabilities of the SSP promise to overcome these limitations and make possible high accuracy studies of magnetosphere-ionosphere-atmosphere interactions at low and middle latitudes. Together with data from comprehensive high altitude magnetospheric research programs such as OPEN, an explanation of the cause and effect relationships between magnetospheric disturbances and low latitude effects would then be within reach.

(3) The distribution of species in the trapped radiation has been established in a very preliminary way using instrumentation severely constrained by spacecraft facilities. We know, for example, that significant fluxes of He^{++}, He^{+} and O^{+} may be found in some regions of the radiation belts. On the other hand, there is virtually no information on the possible presence of minor species (or even information on many of the major species) in many regions of the near earth magnetosphere. It is known that the ionosphere supplies some fraction of the magnetospheric particle population by acceleration of particles out of the ionosphere at high latitudes. One could thus infer that not only ionospheric species but also meteoritic materials (Fe, Na) might well be ingested by the magnetosphere in this manner. Species - specific studies of plasma transport, acceleration and loss processes separating charge and mass are an extremely powerful tool in space plasma physics. The capabilities of the SSP will make possible such studies, with immediate contributions to an improved understanding of magnetospheric dynamics and magnetosphere-ionosphere coupling processes. This measurement program carried out in coordination with the active experiments described elsewhere in this report and carried out over a spectrum of solar and magnetic (and meteoritic!) activity will provide an accurate baseline of the minor constituent population in the magnetosphere against which possible man-made perturbations can be judged.

Instrument Descriptions

Energetic Ion Detector. Measure ions (protons → iron) with energies > 100 keV/nucleon using a detector system with a geometrical factor of approximately 10-100 cm^2 sr. The instrument will be mounted on a scan platform which will be controlled either automatically or in closed loop mode following either the magnetic field direction or instantaneous count rate in the South Atlantic Anomoly region.

Precipitating Particle Detector. This instrument will detect electrons and (light) ions with energies less than 200 keV using electrostatic aperture defining and aperture sweeping techniques. The instrument will have a geometric factor of approximately 50 cm^2 sr and will gather data on a global scale, with particular emphasis on low and middle latitudes.

Minor Constituent Detector. This instrument detects ions in the energy range at 10 keV to 100 keV, concentrating on ions heavier than Helium and capable of detecting mercury ions. This instrument is intended to make a comprehensive survey of the energetic ion population in the lower magnetosphere against which the effects of ion propulsion systems may be assessed.

Platform Requirements. Platform requirements are as given in the Table below.

Table 2.2

	Energetic Particle Detector	Precipitating Particle Detector	Minor Constituents Detector
Orbit	Inclination 40° 100-1000 km	Inclination 60°-90° 100-1000 km	Inclination 90° 100-1000 km
Stabilization	3-axis earth oriented acceptable for SSP, experiments to be mounted on individual scan platforms which scan with respect to local magnetic field.	3-axis earth oriented acceptable for SSP, experiments to be mounted on individual platforms which scan with respect to local magnetic field.	3-axis earth oriented acceptable for SSP, experiments to be mounted on individual platforms which scan with respect to local magnetic field.
Data			
•Storage	Require 100% coverage in South Atlantic and conjugate regions.	Require 100% coverage each orbit	Require 100% coverage each orbit.
•Rate	4kb	16kb	16kb
Maintenance/Checkout	Replace/repair entire instrument	Replace/repair entire instrument	Replace/repair entire instrument
Environment			
•Vibration	-	-	-
•Contamination	-	Clean	Clean
Power	100 W	75 W	75W
Operations			
•Ground	Checkout only	Checkout only	Checkout only
•Shuttle Attached	Checkout only	Checkout only	Checkout only
Weight	100 kg	200 kg	200 kg
Duration of experiment	1 year + reflight	1 year + reflight	1 year + reflight

2.2.2 Hot Plasma Entry, Acceleration and Transport Studies. Recently, large fluxes of energetic (keV) H^+, O^+, and He^+ ions of ionospheric origin have been observed entering and trapped in the earth's magnetosphere. The large fluxes of H^+ ions with keV energies entering the magnetosphere from the ionosphere cannot generally be distinguished from the H^+ ions which enter the magnetosphere from the solar wind. Thus, investigations of the transport and acceleration of the solar wind ions which have entered the magnetosphere, and in some cases even solar wind entry studies, must be pursued by measuring the minor ion species (He^{++}, O^{6+}, etc.) which are not common in the ionosphere.

Existing spacecraft observations on hot plasma entry, acceleration and transport processes are extremely limited. For example, solar wind entry into the magnetosphere near the equatorial plane on the dayside is being investigated with an ion mass spectrometer aboard the ISEE-1 spacecraft, in which the minor species of the solar wind are used to identify unambiguously the origin of the plasma in the entry region as well as in regions deeper within the magnetosphere. Although important new results are being obtained, there are major limitations to the solar wind entry and transport observations imposed by the ISEE spacecraft orbit. First, it appears that the dayside equatorial region is not a major entry region for the solar wind. Second, the infrequent sampling of a given region (3-day orbit), the high radiation backgrounds within the magnetosphere, and the small geometric factor of the instrument, severely limit the investigation of the transport of solar wind ions within the magnetosphere.

Energetic (0.5 - 16 KeV) plasma composition measurements at low altitudes have shown that the H^+ ions in the outer magnetosphere ($L \gtrsim 5$) were nearly always undergoing rapid pitch angle diffusion as evidenced by isotropic pitch angle distributions of the downward-going ions. Similarily, wheneever He^{++} and O^+ ion fluxes were intense enough to be observed, rapid pitch angle diffusion at high L-shells was also found. Although the He^{++} observations were very infrequent due to the low sensitivity and relatively low fluxes of He^{++} ions, the more frequently observed O^+ ions support the conclusion that rapid pitch angle diffusion is a common characteristic for ions with masses from 1 to 16 AMU at L-values greater than about 5.

These observations have important consequences for studies of the entry, acceleration, and transport of the hot plasma ions, since rapid pitch angle diffusion can provide at low altitudes a sample of the ion fluxes from the vast regions of the outer magnetosphere. The fluxes of the minor ion species are not intense enough to form a visible image of the outer magnetosphere on the atmosphere analogous to that produced by the auroral electrons. However, they can be directly measured on each revolution (about 100 minutes) of low altitude spacecraft at high latitudes. Such data on the temporal changes in the energy, L-shell, and local time distributions of the minor ion species from the solar wind could provide information on the entry, acceleration and transport of the ions for various conditions of the magnetosphere and the impinging solar wind. Similar information would also be obtained for ions identified to be of ionospheric origin.

A relatively large weight, power and volume instrument, which could be accommodated by the Space Science Platform, would be required to provide the necessary high sensitivity for the minor ion species measurements.

Additional platform requirements are given below:

Table 2.3

Orbit: 70-90° Inclination
> 600 km altitude

Stabilization: ± 1°

Look Direction: 45° to zenith with ± 45° field of view
in one plane, and ± 10° in other plane.

Data: Storage; 30-90° latitude
Rate; 10 kbs

Maintenance/Checkout: Nominal

Environment: Vibration; not important on orbit
Contamination; ISEE-class control

Power: 100 watts

Weight: 100 kg

Size: 1 m x 1 m x 0.5 m

Duration of Experiment: 1 year plus reflight

2.3 A Coordinated Approach to Investigations of the Solar Terrestrial System

The study and understanding of the solar-terrestrial environment is becoming a major focal point of space research. This interest has been spawned by man's need to understand the processes which dominate the physical surroundings in which he lives with particular attention given to global environmental protection and to weather and climate prediction. Recent studies which show the close correlation of changes in the Sun's output with variations in the Earth's climate have added particular impetus to this area of research. These correlations have been found to exist both for the short term, more subtle solar magnetic cycles and for the longer term, hundred-year periods of significant solar activity change. It is clear that the successful study of this broad region of space will require the unified and coordinated effort of scientists throughout the solar, magnetospheric and atmospheric disciplines. The move toward such a unification has already begun and could be enhanced through the coordinated use of the space science platform. The platform's substantial capabilities for the support and stabilization of comprehensive clusters of solar-terrestrial instruments will permit simultaneous, event-oriented observation within the sun-earth system to be accomplished.

Within the coupled sun-solar wind-magnetosphere-atmosphere chain, magnetosphere/atmosphere coupling is a fundamental link. The other links in this coupling sequence are addressed in the solar and atmospheric sections of this report. Studies of this magnetosphere/atmosphere link involve the measurement of energy transfer from the magnetosphere to the atmosphere and its subsequent effects on atmospheric composition and dynamics. This energy transfer can take place through direct energetic particle precipitation from magnetosphere to atmosphere and through Joule heating processes involving the interaction of the ions and neutral gases in the upper atmosphere. In both instances, the requisite observations involve the simultaneous measurement of the energy input processes such as PCA events, auroral processes, or ion drifts and the resulting dynamic and chemical atmospheric response down through the different layers of the atmosphere-thermosphere, mesosphere, stratosphere and even troposphere where our weather systems are formed. These observations are comprehensive in nature and require independently-pointed clusters of magnetospheric and atmospheric instruments of both the direct measurement and remote sensing variety.

It is not appropriate in this document to delineate the long list of specific experiments that are envisioned in the magnetosphere-ionosphere-atmosphere area. However, it is instructive to describe a couple of example investigations which illustrate the coordinated use of a comprehensive grouping of magnetospheric and atmospheric instruments.

2.3.1 A.I.M. Coupling Through Ion-Neutral Interactions. One such investigation is in the area of energy transfer from the magnetosphere to the ionosphere through Joule heating effects caused by the interaction of ions and neutrals in the upper atmosphere. The objective of the investigation would be to measure both the ion drift that is produced by magnetospheric electric fields and the resulting neutral gas drifts or winds caused by the interaction between the ions and neutrals. This interaction is quite significant in the auroral region. A typical experiment might involve the use of a series of barium releases from a free-flying chemical release module that is above and ahead of the space science platform. These releases would be spread along the CRM orbit across the auroral oval. Their drift following release would be a visual indicator of the convection electric field pattern.

The drifts of the ion clouds would be observed using an imaging system on the Space Science Platform (SSP). At the same time, atmospheric instruments would image the auroral patterns and through interferometric techniques would measure doppler shifted emissions from the atmosphere below the releases. The doppler information would then be used to derive the wind fields which give the dynamic response of the atmosphere to the magnetospheric-induced changes. In addition to the winds themselves, the comprehensive cluster of atmospheric instruments would record any induced changes in temperature and composition that propagate down through the atmosphere. Although it is possible to perform such a limited version of this experiment on a shuttle sortie mode flight, the key to its success will lie in its repetition during a variety of magnetospheric conditions that have been controlled by solar changes. Such changes can be expected to occur over many different periods of time including substorms (hours), magnetic storms (days) and Solar rotation (months). Observations spread over these longer periods are desirable to ensure the understanding of flare-induced and perhaps every solar cycle effects. In this example, the space science platform is essential for both the long duration operation and the contamination free operation of independently gimballed clusters of instrumentation.

2.3.2 An Approach to Solar Influences on Weather and Climate. A second and more exploratory example investigation would be the search for possible physical mechanisms which link changes in the magnetic sector structure of the solar wind to changes in the dynamics of the lower atmosphere; in particular, to the vorticity area index of circulation patterns in the troposphere. Such correlations have been carefully demonstrated satistically but the physics of why the connection exists is still unclear. In this exploratory series of experiments the solar, magnetospheric and atmospheric instrumentation on the platform would be employed. Using soft X-ray or EUV imaging techniques, the solar disk would be monitored for the presence of coronal holes which are known to be associated with the solar wind magnetic sector structure. Following the appearance of a coronal hole and its rotation across the solar disk, a satellite such as ISEE-C would measure the sector boundary change sweeping across the magnetosphere. Instruments on the Space Science Platform would then measure the response of the magnetosphere, ionosphere and atmosphere. Imaging systems would record changes in the auroral oval dynamics. Barium releases or perhaps even platform-borne incoherent scatter radar facilities could be used to measure the convection-induced velocity field changes in the ionosphere. At the same time, atmospheric remote sensing instruments would observe a continuing variety of atmospheric dynamic parameters from thermospheric winds to tropospheric circulation patterns with the objective of uncovering the essential physical links. Such an investigation would continue over many days since the lower atmospheric response is known to take place slowly compared to the magnetospheric convective changes. Since this investigation is exploratory, it is somewhat speculative in nature and the detailed steps of its implementation cannot be fully specified. It is, however, the comprehensive nature of the instrumentation that can be carried on the Space Science Platform which allows the necessary operational flexibility to conduct such exploratory and fundamentally important studies. As in the previous example, long duration, global coverage and large independently gimballed instrument cluster operations are essential serivces provided by the Space Science Platform.

These two examples are not unique. With the Space Science Platform, scientists can work toward the establishment of a complete Solar Terrestrial Observatory platform which keys its operation to events which are initiated by solar changes and whose effects are then spread throughout the magnetosphere, ionosphere and atmosphere. The ability to respond to these events through the coordinated observation of all of these regions is an essential service which will result from the Space Science Platform implementation.

Requirements concerning this phase of the Space Science Platform are as follows.

(1) Orbit: Maximum latitude coverage (prefer Polar) together with optimal solar viewing.

(2) Orientation: Simultaneous viewing of the Sun, Earth (Nadir and Limb) and magnetic field line scanning by a number of different instruments without shadowing or plasma wake interference.

(3) Data: 100's of megabits to accommodate imaging systems.

(4) Environment: Low particle and EMI contamination.

(5) Power: 10's of kilowatts.

(6) Operations: Ground-based and/or manned activation of alert modes for certain conditions.

(7) Spatial extent: Sufficient separation of experiments to preclude mutal contamination or restricted viewing.

3. THE EXTENSION OF SPACE PLATFORM EXPERIMENTS TO GEOSYNCHRONOUS ORBIT

In the space plasma physics discipline, almost all of the experiments that are envisioned for low earth orbit find new and in many cases enhanced significance at geosynchronous orbit. This stems from the basic fact that geosynchronous orbit is in the "heart" of the magnetosphere and intersects a variety of different plasma conditions that are not accessible at low altitudes, for example, the geosynchronous plasma environment can at times be dominated by the hot, kilo-electron volt plasma of the ring current and plasma sheet and at times can be influenced most strongly by the cold, electron volt plasmaspheric plasma. These variable plasma conditions allow new classes of wave/plasma, beam/plasma and plasma injection studies to be carried out.

In the beam plasma category, electron and ion beams can be injected from geosynchronous orbit to trace out magnetic field lines during different levels of magnetospheric disturbance. These experiments will give fundamentally new information on the coupling of processes between the ionosphere and the magnetosphere.

For the wave injection experiments, enhanced coupling between waves and particles can be expected for many resonance interactions when the injection takes place at the equator near geosynchronous orbit. Direct injection into the outer portions of the radiation belts can probe pitch angle diffusion processes thought to be occurring naturally in the magnetosphere as mentioned above. The bistatic radar investigations for determining electron densities are made possible through the availability of a geosynchronous platform.

In the gas release category, ambient plasma conditons can be significantly perturbed through geosynchronous injections. For example, processes controlling the interaction between the ring current and the plasmasphere can be studied directly through the injection of a cold plasma and the observation of its influence on the hot ring current particles.

Magnetosphere/atmosphere studies will be enhanced by the new perspective of geosynchronous orbit. The energetic plasma of the magnetosphere can be measured directly while its effects in the high latitude atmosphere can be imaged on a hemispheric scale. It is apparent therefore that both active injection and coordinated passive observations will be well suited for future geosynchronous editions of the Space Science Platform.

4. GENERAL REQUIREMENTS FOR THE SSP FOR EFFECTIVE PLASMA RESEARCH

The Space Science Platform has been presented to the working group at an early stage of its conceptual development, and thus there is a very good opportunity for the science requirements to influence its design. Although the requirements for each of our typical experiments have been detailed in the appropriate sections above, it seems useful to summarize the general characteristics which we think this system should have to maximize its usefulness. The characteristics are:

(1) Minimum flight duration of one year to ensure the proper coverage of solar conditions, magnetospheric configuration, etc.

(2) Orbital coverage including significant portion of the auroral zone. A 56° orbit is acceptable for many studies. A polar orbit is very desirable.

(3) Nominal Shuttle altitude ranges are assumed (up to 500 km). The future transition to synchronous orbit is an exciting and important possibility.

(4) The SSP must avoid extensive nonconducting exterior surfaces.

(5) The power system should be capable of high peak power on a low duty cycle. For example, the 25 KW average mentioned for the power module should be capable of 400 KW peaks.

(6) Power beams and solar arrays should be designed to minimize the SSP magnetic dipole moment.

(7) It is important to insure that the SSP is free of significant sources of electromagnetic interference. Precautions such as the use of a single-point ground and the operation of all voltage-converter oscillators at a single frequency (e.g., 25 kHz) will be necessary to achieve acceptable EMI levels. The document entitled "AMPS Subsatellite Facility Plan," which is available through the Shuttle Spacelab Payloads Project Office at NASA/GSFC, presents details of electromagnetic compatibility requirements similar to those needed for the SSP.

(8) Gyro control of aspect should be used rather than gas jets. Every precaution should be used to preserve a clean molecular environment, avoid outgassing, etc.

(9) Data processing, storage and transmission should be such as to provide global coverage (e.g., > 90%), using for example TDRSS or sufficient data storage on board.

(10) A number of the space plasma physics investigations proposed for the Space Science Platform will require subsatellites. Some of the experiments require remote measurements of the effects of source systems such as wave injectors and particle accelerators on the ambient plasma medium. Still others require passive observations at locations well removed from the nominal trajectory of the SSP.

Two general types of subsatellites will be required: (1) a tethered subsatellite which can be deployed to altitudes between 100 and 150 km where the coupling between plasma phenomena and the neutral atmosphere is strongest; and (2) a maneuverable subsatellite which can be positioned at specified locations up to altitudes of a few thousand kilometers. Both of these two types of subsatellites would be docked at the SSP when not in use. When in use they would be tracked by, and would transmit data back to the Space Science Platform. Descriptions of the tethered subsatellite deployment system are given in the document, "Proceedings of the Workshop on Uses of a Tethered Subsatellite System." Maneuverable subsatellites of the type required for the SSP are described in the document entitled "AMPS Subsatellite Facility Plan," which is available through the Shuttle Spacelab Payloads Project Office at NASA/GSFC.

5. A BIBLIOGRAPHY OF SPACE PLASMA PHYSICS SOURCES

The ideas developed in the Space Plasma Physics Panel report have their roots in a series of working group, workshop, facility definition team and National Academy of Sciences committee reports. This section is meant to highlight the work of our predecessors and to indicate how this has influenced the thoughts that we have presented herein.

The basic goals of research in Space Plasma Physics can be found in several reports. Of specific interest have been the following:

(1) Space Plasma Physics - The study of Solar-System Plasma, Volume 1, Reports of the Study Committee and Advocacy Panels, Space Science Board, National Academy of Sciences, Washington, D. C., 1978.

(2) Global Problems in Magnetospheric Plasma Physics and Prospects for their Solution - Juan G. Roederer, Space Science Reviews, 21, 23-70, 1977.

(3) On the significance of Magnetospheric Research for Progress in Astrophysics, C. G. Falthammer, S. I. Akasofu, H. Alfven , H. Alfven, Royal Institute of Technology Report, April 1978.

The implementation of these goals and their integration into the broader goals of studies of the solar-terrestrial system are discussed in the following reports:

(1) Scientific Objectives of the Atmospheres, Magnetospheres and Plasmas in Space Project, Marshall Space Flight Center Report, July 1975.

(1a) The Solar Terrestrial Observation as a Major Module of a Space Station - An Advocacy Document, NASA/Marshall Space Flight Center Report, September 1976.

(2) NASA Workshop on Solar-Terrestrial Studies from a Manned Space Station, February 1977, NASA Conference Paper CP-2074.

(3) NASA Guntersville Workshop on Solar-Terrestrial Studies, NASA Workshop conducted at the Guntersville State Park, Guntersville, Alabama, October 1977.

(4) Report of the Wave Injection Facility Definition Team, TRW Contract Report, May 1978.

(5) AMPS Subsatellite Facility Plan, Goddard Space Flight Center Report, March 1978.

(6) Chemical Release Module, Goddard Space Flight Center Report, March 1978.

(7) The Solar Terrestrial Observatory as a Major Module of a Space Station, C. R. Chappell, Advances in the Astronautical Sciences, Vol. 35, 1977.

(8) The Solar Terrestrial Observatory, C. R. Chappell, AIAA 16th Aerospace Sciences Meeting, Huntsville, Alabama, January 1978.

(9) Origin of Plasmas in the Earth's Neighborhood, Goddard Space Flight Center Report, May 1978.

(10) Upper Atmosphere Research Satellites - GSFC Report, 1978.

(11) NASA Workshop on the Uses of a Tethered Satellite System, Marshall Space Flight Center Report, May 1978.

In the area of information on the space systems necessary to accomplish these solar-terrestrial objectives, the reader is directed toward the following reports:

(1) Statement of Mr. William G. Huber, Manager of the Power Module Task Team, for the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U. S. House of Representatives, February 1978.

(2) Space Science Platform - Concepts and Approaches, Material presented at the Space Science Platform Workshop, Joe Wheeler State Park, Alabama, August 1978.

In this bibliography therefore can be found the desires, the capabilities and hopefully the realities of future solar terrestrial research.

CHAPTER VII

ATMOSPHERIC SCIENCES PANEL

Panel Chairman: Rex McGill, Utah State University

Panel Members: Bob Hudson, GSFC
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1. SUMMARY

The atmospheric sciences panel feels that the future need for a vehicle like the Space Science Platform in the late 1980's is well established. The atmospheric sciences, after the results of currently planned free flyers and shuttle missions, will require a great deal of further research. The plans for a series of Upper Atmosphere Research Satellites is a natural follow-on from these programs. It is expected that by the time the UARS missions are completed, the principle thrust of atmospheric sciences will be Solar Terrestial effects. These will require large, probably dedicated observational programs.

The SSP is viewed as a viable candidate for an appropriate observatory which would encompass portions of programs from atmospheric sciences, space plasma physics and solar physics.

The observatory will require large amounts of power, reasonable stabilization and probably a set of "daughter" free satellites and "puppy dog" tethered systems. The atmospheric science panel encourages NASA to further explore the possibilities inherent in this vehicle.

2. SCIENTIFIC NEEDS

The composition and dynamical behavior of the earth's atmosphere is the result of a continual interplay between solar radiation, atmospheric photochemistry, thermal radiative emission, turbulent diffusion and motions. The balance between these processes leads to the distinctive characteristics identifying the troposphere, stratosphere, thermosphere, etc. The need to understand these complex interactions arises from three sources: firstly, the ability of man to inadvertently modify his own environment; secondly, the possible role of the upper atmosphere in weather and climate; thirdly, the application of the resulting information to the study of the other solar planets.

The thermosphere and troposphere are, at present, the best studied regions of the atmosphere, having been explored with both satellite and ground based platforms. In the thermosphere the recent emphasis has been on studies of processes, e.g., the A.E. and D.E. satellite series are being specifically flown to study thermospheric photochemistry and dynamics, respectively. The stratosphere and mesosphere have received less attention, although the NIMBUS G, and SME payloads, and instruments such as ATMOS and CLIR on AMPS, will provide some critical data. Recognizing the critical need for further research, OSS has proposed the UARS program of satellite measurements and theoretical analyses to study the interaction between chemistry, radiation, and dynamics in the stratosphere and mesosphere. The first mission is planned for the early 2980's, with a follow-on mission 12 months later.

Studies of the basic processes within atmospheric regions does not necessarily enable one to follow complex solar-terrestrial relationships, as these involve understanding the complete path of which solar energy is transported and modified. The transfer of this energy does not occur by electromagnetic radiation alone, but also by means of charged particles, electric fields and currents, and neutral winds. Some of the local coupling in the thermosphere between the neutral and charged constituents of the atmosphere will be investigated on the D. E. spacecraft, but a full investigation of the complete solar terrestrial coupling will require a much larger complement of instruments making both in-situ and remote measurements of all the atmospheric regions simultaneously.

Space Shuttle, in its Spacelab mode, could only carry partial complement of instruments, because of power limitations. In addition, the duration of its flights limits the extent of the studies. The Space Science Platform opens up a new capability to perform long duration missions with the large instrument complements required. The response of the atmosphere to periodic and sporadic events (e.g., solar flares, PCA events, volcanic eruptions) requires continuous monitoring and thus leads naturally to an observatory concept for the overall payload. The ability of the Space Science Platform to serve as a base for this observatory payload and to provide the necessary flexibility for future development, makes the platform a valuable tool in the study of atmospheric physics from space.

3. ATMOSPHERIC SCIENCE INVESTIGATIONS WITHOUT SPACE SCIENCE PLATFORM

A thorough understanding of the normal condition of the atmosphere and its response to solar variation and other external perturbations will not spring from any particular set of observations. It must be developed gradually as individual and coordinated observations fill in the details of the large picture and new questions are posed. At some stage the comprehensive measurement capability of large, long duration observing systems such as the space platform becomes necessary. In the process of reaching that point, many instruments will be developed, many observations made, and many questions answered. It is important that these earlier steps be exploited fully so that progress may be made most rapidly and economically.

For many investigations in atmospheric science, the use of spacecraft is not desired. The ability of satellites to obtain global data coverage is unique, but earth based measurements and rockets, balloons, and aircraft will continue to be useful expecially exploratory measurements and, for these questions which require very detailed measurements at one location. An example of such a study is the determination of the photochemical balance between the many stable species and radicals existing at one point in the stratosphere in order to check the parameters included in chemical models.

A large body of meteorological data as well as significant data base of stratospheric temperatures and ozone distributions has been obtained through meteorological satellites, particularly the Nimbus series, including Nimbus G to be launched in September 1978. The individual instruments on Nimbus G are limited, in particular the infrared radiometers have a moderately short operational lifetime as they require cryogenic cooling of detectors. The Stratosphere-Mesosphere Explorer will be a satellite dedicated to the study of the middle atmosphere. Using infrared and ultraviolet techniques it will study ozone and its response to solar UV variability.

The Space Shuttle will provide a large increase in the capability for space observations. In the sortie mode, large single instruments or clusters of smaller instruments may be carried. The principal limitations are the fairly short duration of the missions, the limited power available, and the contaminated environment. Numerous new instruments and techniques will be developed for operation in this mode as described in AMPS studies. Investigations include observation of the atmosphere, chemical releases, or plasma modifications. Cryogenic instruments will alllow high sensitivity measurements of atmospheric consituents. The short flight duration will preclude measurements of dynamical effects with some time scales and will make the probability of observing the atmospheric response to a major solar event small.

The Upper Atmospheric Research Satellite is planned to study the atmosphere in the 10-120 km range. It is designed to study interaction between the chemical, dynamical, and energetic processes. It will carry a complement of remote sensing instruments, including radiometers and spectromenters for analyzing the chemical and physical state of the atmosphere. It will include solar UV irradiance monitors as well as the atmospheric instruments. It will be an evolutionary program, with different instruments flown on subsequent missions. UARS will be a moderate sized satellite and will be used for larger term but less intensive (i.e., more specialized instruments with lower data rates) investigations than the shuttle sortie missions.

These investigations will provide information for understanding the chemistry of the middle atmosphere and its interaction with dynamics and variability in the solar radiative input. Thorough studies of the response of the atmosphere to solar transient events will require coordinated studies of the plasma environment, as well as the solar inputs and its interaction with the upper atmosphere. Such studies require larger complements of instruments and coordinated measurements than a free flyer such as UARS can provide.

The availability of a space science platform will not eliminate the need for conventional satellites or shuttle sortie missions. The sortie mission still has an important role for the development of new instruments or measurement concepts before deployment on the SSP or other platforms, for measurements of limited duration, or for which manned intervention is desirable. Small free-flying satellites willbe used where orbits are required which are not available for the SSP and when a daughter satellite remote from the SSP is needed. They are also useful for carrying instruments which are extremely sensitive to contamination or interference by other instruments or components on the platform.

4. TYPICAL PAYLOADS FOR PLATFORMS

4.1 Scientific Rationale

As discussed in the preceding sections it is believed that by the mid 1980's our knowledge of the atmosphere will have reached a stage at which further significant progress will require studies of the earth-sun system as a whole. The emphasis will be on simultaneous measurements of parameters which will allow the flow of energy to be traced from the sun through the interplanetary medium and magnetosphere into the atmosphere. Instruments will be required which can measure effects of this energy over an altitude range extending from the troposphere to the thermosphere. Such a requirement demands a large cluster of instruments to achieve an understanding of the atmosphere on a global scale. Measurements will be made over temporal scales which allow adequate coverage to define the spatial, diurnal, seasonal and solar cyclic variations involved.

To achieve these objectives measurements will be required of the energy influx to the atmosphere as well as the response of the atmosphere to this influx over a large range in altitude; i.e., measurements of atmospheric composition, temperature, motion and radiation field. Instrumentation capable of making such measurements largely exists or will exist in the near future as a result of programs such as UARS, Shuttle/SL and AMPS.

Future requirements, therefore, point to a cluster of large facility-type instruemnts with consequential requirements for power, space and maneuverability. Such a facility might truly be regarded as an Atmospheric Science Observatory. The concept of an evolving Space Science Platform provides a rational and satisfactory answer to these requirements.

Over the past decade numerous studies have been carried out to determine the optimum combination of atmospheric instrumentation for flight on the Space Shuttle system, and for the Upper Atmosphere Research Satellite Program. The Space Platform will allow us to combine these into a more elaborate payload incorporating large telescopes, an extensive complement of pointing controls, large and more directional radio antennas, better cryogenic systems and high power lidar transmitters, with the possibility of ultimately adding some form of incoherent-scatter radar to the observatory. It is also expected that several of the instruments designed primarily for magnetospheric studies will play an important role in resolving several of the problem oriented objectives of the Atmospheric Sciences.

4.2 Observatory Description

The proposed observatory would be capable of making measurements of the parameters listed below, which ideally would be integrated with relevant data taken by other ground-based or spaceborne instruments operational at that time. The multi-parameter data base (See Table 1 for details) would include measurements of: the solar EUV and UV flux, radiometers and interferometers from which densities, temperatures and winds may be deduced. These measurements will be supplemented by microwave limb soundings. It is likely that a Fabry Perot interferomenter will also be available in the visible range to provide data primarily on thermospheric and stratospheric winds. The lidar promises to be a valuable tool for exploring both the stratosphere and thermosphere. The performance levels will depend on the power output that can be achieved and the altitude of the orbit.

Several magnetospheric instruments that will also play an important correlative role in the Atmospheric Sciences Program include, for example, the electron gun which would be used to excite several atomic and molecular processes relevant to atmospheric chemistry. The chemical release-module would provide valuable information on motions of ions and neutral constituents in the thermosphere, allowing the component of electric field perpendicular to the magnetic field to be determined.

Tethered satellites and subsatellite clusters could significantly contribute to studies of solar terrestrial relations. Tethered satellites could be used to obtain in-situ atmospheric measurements at altitudes near the turbopause while simultaneous, complimentary and coordinated measurements are being made from the SSP. In this way global vertical variations in atmospheric phenomena could be observed, such as gravity wave characteristics, and turbopause altitude variations. Reflecting elements and optical instruments could be placed on maneuverable subsatellites and tethered satellites for use with the lidar and other radiation sources in the SSP to make possible long path length measurements through the atmosphere. By controlling the subsatellite orbit and the separation from the SSP, the atmosphere may be studies in different altitude regions including the stratosphere. A mass spectrometer could be placed in the SSP and the subsatellite for study of the horizontal propagation characteristics of gravity waves. Instruments which monitor the morphology and dynamics of the aurora, such as the low light level photometric imaging experiment being developed for Spacelabl, would provide valuable information on the high latitude global energy input and dynamics of energetic particle precipitation. With such a complement of instruments it is expected that it will be possible to make in-depth studies of the solar terrestrial coupled systems, and quantitatively assess the significance of man-made effects on the environment as well as possible sun weather relationships.

An example of a type of study which can be uniquely done by a large collection of observing instruments such as would be available in the observatory mode of the SSP is an attempt to trace the effects of large perturbations due to solar proton events. In these events incoming particles produce off nitrogen and odd hydrogen which results in the production of radicals such as OH and NO. The high altitude ozone has been observed to decrease in one such event. An opportunity to follow most of the relevant processes during and after such an event would be most useful in interpreting the mechanisms by which weather may be affected by solar activity. Measurements of interest include: particle fluxes and their ionization profiles from appropriate emissions, e.g., 3914 A; NO from emissions at 5.2 m; OH densities by LIDAR or resonance fluorescence; O/N_2 ratio above the region to enable inference of low altitude heat inputs; thermospheric winds by in-situ measurements of neutrals and ions; mesospheric winds by doppler shift measurements; temperature by rotational temperature measurements of $O_2('\Delta)$, $O_2(\Sigma)$ and OH; O, O_3 by measurements of OH, $O_2('\Delta)$, O('D) and a variety of other emissions where possible. These measurements, coupled with long term, intensive monitoring of O_3 density profiles and radiative temperature measurements of H_2O, O_3 and CO_2 would enable one to make the checks on solar weather interactions which cannot be equaled by any other proposed platform or set of platforms. Such measurements should logically be coupled with measurements of electric fields, magnetic fields, particle spectra, ionization densities and neutral winds as a function of altitude. These, coupled with solar observations and magnetosphere information from other spacecraft should yield an unparalleled opportunity for the study of sun-earth relationships.

One important coupling of the solar variability with the terrestrial atmosphere is the effect of changes in the solar irradiance in the middle UV on the chemistry and dynamics of the middle atmosphere. Radiation at these wavelengths (1500-3000 A) is primarily responsible for both production and destruction of ozone and for the energy which drives the stratospheric circulation. It has long been known that the ozone quantity is anti-correlated with the solar cycle and there are indications that the solar middle ultraviolet is positively correlated with activity. However, the details of the mechanisms and all of the ramifications of these mechanisms, including feedbacks, have not been established.

Studies of this problem will require very accurate measurements of solar spectral irradiance, global quantities of ozone and associated chemical species, and atmospheric temperatures and motion (geostrophic winds). The two important time scales are the 28-day period of solar rotation and the 11-year solar cycle. Much of the effort of SME and UARS will be directed toward this problem, but the SSP atmospheric observatory, with its larger complement of instruments and long duration, plus the possibility of periodic recalibration, can contribute importantly, expecially to the understanding of the solar cycle variation.

TABLE 4.1

SPECTROSCOPIC INSTRUMENT COMPLEMENT

Instrument	Measurement
EUV/UV Solar Spectrometer	Solar Flux
UV/VIS Airglow Spectrometer	NO, O_2, N_2, O, N_2^+, O^+
UV/VIS Imaging Photometer	Spatial Distributions
Doppler Interferometer	Winds, Temp
I.R. Filter Radiometer	O_3, T, NO_2, HNO_3, CH_4, N_2O
Modulated Gas Cell Radiometer	H_2O, NO, T, Winds, CO, CH_4, N_2O
I.R. Occultation Radiometer	HO, HF, CF_2Cl_2
Cryogenic Limb Interferometer	CO, HNO_3, NO, NO_2, CF_2, O_2, $CFCl_3$ ClO, CH_4, N_2O, O_3
Far I.R. Spectrometer	OH, CH_3Cl, HF, $ClONO_2$, H_2O_2, N_2O_3, O
Microwave Limb Scanner	Winds, O_3, ClO, OH
Lidar	H_2O, O_3, NO, Na, Winds, CO_2, OH
I.R. Airglow Spectrometer	O_2', OH, CO_2, NO, CO, NO^+

TABLE 4.2

CORRELATIVE MEASUREMENTS

Measurement	Remarks
Electric Fields	Several Techniques
Particle Flux	Several Techniques
Magnetic Field	Several Techniques
Local Composition	Subsatellite
Local Temperature	Subsatellite
Local Winds	Subsatellite
Local Ion Drifts	Subsatellite
Ionized Component	Incoherent Scatter

5. SPACE PLATFORM REQUIREMENTS FOR ATMOSPHERIC SCIENCE

Orbit: It would be desirable to have at least two orbiting vehicles. One orbiter at 28 (or lower) inclination would concentrate on diurnal fluctuations in the atmosphere. A second orbiter at 70 inclination would concentrate on sensing of meridional effects, and particularly particle influences on the polar cusps and auroral regions. If only one is flown, the 70 inclination should be emphasized since this inclination optimises the latitude coverage.

The orbital altitude should be in the range from 300 to 500 km. The lower altitudes could introduce problems of contamination from the station-keeping boosters, but would aid the signal to noise of some of the instruments. Circular orbits are satisfactory for most of the experimental objectives.

Stabilization: The instruments located on a common platform should be oriented in a mode in which the platform normal is oriented towards nadir and is held at this attitude to within a few degrees. It is required that the instruments have knowledge of their aspect in inertial space to various degrees. The table below summarizes the requirements for aspect knowledge as a function of sensing type. It is understood that some instruments such as the occultation measurements require steering or tracking to higher degrees of accuracy but that these requirements would be met by the instrument itself (or cluster where commality exists).

Observation	Altitude Knowledge	Platform Rate Stability
Nadir Emissions	3°	$.1^{\circ}$/sec
Limb Emissions	$.03^{\circ}$ (1 KM)	$.003^{\circ}$/sec
Limb "Winds"	$.008^{\circ}$ (1m/sec)	$.008^{\circ}$/sec
Occultation	$.02^{\circ}$	$.002^{\circ}$/sec
Insitu	$.3^{\circ}$	N/A

NOTE: Platform accelerations should be $.1^{\circ}/sec^{2}$; when this level is exceeded by the platform, knowledge must be made available to investigators to validate data.

Orientation: Remote sensing experiments for atmospheric information require primarily limb viewing, spacecraft-radar viewing, and also off nadir sensing, e.g., viewing natural and artificial aurora (along B). Generally, the hemisphere centered about nadir should be available for various remote sensing instruments and the platform to which these instruments are fixed should be so oriented.

It would be advantageous to be altitude stabilized about the local vertical so that occultation instruments and limb instruments could be placed for optimum viewing so as not to interfere with nadir pointing instruments.

Data Handling: All data telemented (no film or recovery data).

- On-board storage for TDRSS non-coverage periods only.
- Data all digital
  4 channels 15 MHz
  15 channels 1 MHz
  15 channels 1 KHz

Maintenance/Checkout:

- Service/recalibrate/replace on a periodic basis
- Done in a pallet/module level

Environment:

- Particulate and gas environment most constraining to cryogenic infrared instruments - critical to the point of abandoning those instruments in the complement
- Insitu measurements probably would best be done on a free flyer

Power:

- Passive instrumentation, typical 150 watts/instrument at 15 instruments per pallet, 2 pallets, 4-5 Kw total average
- Active instrumentation - Lidar 3-6 Kw

Acceleration instrumentation (3 Kw peak at 10% time)
Cyrogenic module requires power to regenerate cryogenic ~ 1 Kw

Operations:

- POCC type operation, would be engineer manned at non-shuttle attended periods and investigator manned during shuttle tending

CHAPTER VIII

LIFE SCIENCES PANEL

Panel Chairman:	Calvin Ward, Rice University
Panel Members:	Louis Avioli, Jewish Hospital of St. Louis
	Joseph Brady, John Hopkins University
	Corale Brierley, New Mexico Institute of Mining and Technology
	Allan Brown, University of Pennsylvania
	Peter Chevalier, Mayo Clinic
	Thomas Coleman, University of Mississippi
	Rufus Hessberg, NASA Headquarters
	Richard Johnson, ARC
	Xavier Musacchia, University of Louisville
	Stuart Nachtwey, JSC
	A. H. Smith, University of California at Davis
	Jack Spurlock, Georgia Tech. University
Panel Liasion (MSFC):	John Hilchey

1. BROAD SCIENTIFIC NEEDS OF SPACE LIFE SCIENCES IN THE 1980's

Expansion into space will inevitably involve the human organism whether for functional tasks or as a result of the innate desire to explore, understand, and eventually occupy these frontiers. That mankind will go into space is no longer questioned; instead, it is when, how far and for how long?

The overwhelmingly unique characteristic of space that must be reckoned with is that of weightlessness and its complex influence on biological mechanisms. The effects of gravity upon living systems have a long history of consideration. Galileo (in his "Discourses," 1638) compared structural differences between animals of different size, and attributed them to be a response to Earth-gravity. He also noted that very similar changes were incorporated by architects into various structures, and this led to the statement of the Principle of Similitude. Galileo also invented the telescope, establishing modern astronomy -- so most of the concerns of modern space science have a common, as well as ancient origin. Unfortunately, further development of gravitational biology was hampered by an inability to alter the gravity-environment, which is only now becoming a feasibility. So it seems reasonable that an extra effort be extended to space life sciences to offset the centuries of impeded progress.

The understanding of these mechanisms of gravitational effects is a fundamental scientific endeavor independent of questions of human health. However, if humans are to work productively in space, and eventually master this environment, the means must be available to understand the complex interactions of gravitational force with living systems. Without denigrating the importance of the Space Sciences Platform as a research tool uniquely suited for basic researches in several biological areas, we must emphasize that crucially important practical questions focus on the ability of man, animals and plants to cope with hypogravity either by adaptation or by provision of artificial gravity. A major purpose of the Platform will be to explore these issues and to search for acceptable g-levels in a space environment provisioned for these studies. Specifically, the issue is to understand biological processes in zero g and to investigate the mechanisms in the domain of zero to one g which is unavailable on Earth.

We must study and test the biological organism, especially the human and his subsystems, for life and work in space over extended periods at minimum costs, both physiological and fiscal. It is logical and timely to explore these issues in the forthcoming era where transportation into space will be routine and large facilities such as the Space Platform will be available for research.

A coherent gravitational biology — integrating the effects of weightlessness, sub-gravity, Earth-gravity and greater fields — will have many important influences upon all biological science. The constancy of Earth gravity has constrained biological science to a single gravitational niche. Understanding the effects of the dynamic property of the environment will not only greatly expand our concepts, but it may well have very important applications in medicine and agriculture.

Since 1957 when the Soviets successfully launched Sputnik I, man has collected and accumulated a vast amount of biological data with emphasis on the effect of zero g space flight on the astronauts, as well as the response of a variety of biological specimens to this environmental perturbation. Presently, it has been established that man can perform pre-designated tasks, at least adequately, for up to 90 days in a weightless environment. Although the limiting conditions for a range of behavioral interactions have yet to be adequately defined, observed responses to the zero g environment indicate significant alterations in a number of biological homeostatic control mechanisms (see Skylab Medical Report):

(1) Cephalad redistribution of body fluids.
(2) Progressive loss of muscle mass and body nitrogen stores.
(3) Loss of skeletal mass with increases in urinary calcium which were not only in the range seen in terrestrial subjects with recurrent renal calculi, but also inappropriate for the circulating blood calcium levels.
(4) A tendency toward hypokalemia with associated elevations in renin and aldosterone, but paradoxial increases in sodium excretion.
(5) Intestinal malabsorption of calcium.
(6) Increases in circulating cortisol, testosterone, catecholamines, thyroid stimulating hormone, parathyroid hormone and thyroid hormone.
(7) Anemia, and blood volume contraction, with associated changes in red blood cell size and shape.
(8) Transient alterations in vestibular function.
(9) Decreases in circulating glucose and insulin.

The aforementioned alterations notwithstanding, the astronauts were capable of performing well and tolerated exercise testing well; and since these changes reverted to near-normal subsequent to the Skylab mission, they have either been ignored or considered inconsequential. This Panel is, however, concerned that the astronauts were at the threshold of irreversible biological damage. Hence, we recommend that more detailed analysis of these acquired alterations in cardiac, hematological, renal, electrolyte, and hormonal imbalances be made if, in fact, plans for zero g activity are anticipated for periods extending beyond 80 to 90 days.

Until more complete sets of data are available for analysis, the accumulated evidence could be consistent with the following sequellae:

(1) Cardiac failure with associated disturbances in cardiac conduction.
(2) Intrarenal calcification (nephrocalcinosis) and kidney stone formation (nephrolithiasis).
(3) Enhanced risk of skeletal fractures.
(4) Gradual decrease in work/energy thresholds and fatigue syndrome.
(5) Inappropriate fuel for glucose production and/or end organ resistance to gluconeogenic factors.

(6) Acquired disturbances in renal tubular reclamation of minerals (i.e., Na^+ and Ca^{++}).

(7) Decreased sexual potency and activity.

It is reasonable to expect that if well conceived, scientifically-based experiments are performed in Space Shuttle flights, the etiology and pathogenesis of biological changes which occur early in flight will be elucidated. Although this, in turn, will offer some insight into those abnormalities which obtain and persist beyond 14 days, it should be followed by similarly well-designed but long-term studies. Since further Skylab missions are presently "off the books", a Space Platform environment is deemed essential to these follow-up studies. Most specifically, we assume that Space Shuttle experiments in man will emphasize: venous pressure recordings; measurement of cardiopulmonary dimensions, blood hormones and their circadian rythms, and urine composition and output; analysis of eighth nerve-vestibular control mechanisms (the latter in appropriate laboratory models); and characterization of antidiuretic hormone-aldosterone-renin-water excretion-sodium excretion relationships. It is also assumed that human subjects in these experiments will be scientifically motivated observer-technical personnel (i.e., payload specialists).

Specifically, these payload specialists would be required to function in a technical capacity during studies designed to evaluate the effects of short-term as well as prolonged (> 80 days) exposure to weightlessness on a variety of biological phenomena. In addition, these same payload specialists would also serve as human subjects for experiments designed to study man's biological and behavioral responses to short- and long-term exposure to zero g.

The design for subsequent experiments utilizing the Space Platform should obviously be guided by the results obtained in the 10 to 14 day Space Shuttle studies. In addition, to follow these initial short-term studies under conditions of extended exposure (i.e., > 80 days), an integrated experiment model is essential. By this we mean that an organism's survival in space cannot be predicted from studies of individual components. Such predictions require studies of the intact organism per se, as well as its interactions with other organisms and with the environment. This integrated approach will, by definition, require a behavioral methodology for integrating the performance of payload specialists, their health status, and the interpersonal requirements of a habitable social environment. This concept requires a specially configured facility for the analysis of the behavioral aspects of this study.

Gravity has been called the common denominator in all terrestrial life phenomena. Life on our planet evolved under a 1 g field. In addition to the obvious ways in which organisms are adapted to that field intensity, there may well be more subtle dependencies on gravity that escape our attention because we lack a sufficient body of data on organisms at gravity levels other than unit g. Now we are in a period of increasing experimentation with organisms exposed to g-forces greater or less than normal; already such research has indicated changes within adaptable physiological limits as well as some pathophysiological responses. Both for practical considerations, and also for increasing our basic understanding of how gravity is important to organisms, many kinds of ground-based and space experiments are called for. Tests on animals and those on plants will be considered collectively and separately in later sections of this paper. Animals, and in some cases plants, will be used to satisfy basic research objectives, but they will also serve as models for elucidating the physiological and behavioral responses of man to hypogravity.

It is quite reasonable to assume that future manned space missions, beyond the era of Space Shuttle, will involve teams of many human participants working and living in space for extensive periods of time. For practical logistical reasons it is highly probable, for longer duration missions, that dependence upon non-regenerative life support systems (i.e., total resupply from the Earth) will be prohibitively costly. Indeed, partially or nearly completely closed life support systems will eventually be required to sustain the food, water and breathable atmosphere supplies for these more sophisticated space habitats. Realistically, these requirements will probably be met through development of progressively more closed systems over a number of years, with some capabilities having longer development lead-times than others.

The broad categories of life-support functions for which closure sub-systems can be considered are food supply, revitalization of atmosphere, water supply and waste processing. Physicochemical and biological processes must be studied, evaluated, and compared to select the best combinations to satisfy closure requirements. In the specific case of food supply, requirements will have to be met exclusively by biological (e.g., plant and animal culture) techniques until chemical synthesis of food becomes a viable alternative.

Therefore, the broad scientific needs in the area of life support systems technology, in the 1980's, will be to understand through sequentially designed investigations the following:

(1) Evaluation of the effects of the space environment (principally weightlesness and radiation) on the dynamics of candidate biological and physiocochemical processes.

(2) Development of life support sub-systems that can reliably perform the various regenerative functions under conditions realistic for a space habitat (including definition of the minimum gravitational force required for proper function of particular sub-system candidates).

(3) Development of techniques to couple and integrate the various sub-systems in a stable, safe, and efficient manner (including monitoring and control features).

Each of these investigative areas can be further subdivided into research needs that can be satisfied by one of three facility modes:

(1) Earth-based facilities (no specific need for conducting these experiments under conditions of weightlesness).

(2) Shuttle Attached Payloads (limitations of the Shuttle configuration, services, and mission duration are not too restrictive).

(3) Space Science Platform (requires conditions of weightlessness and duration exceeding the capabilities of Shuttle Attached Payloads).

The life sciences community recognizes that the radiations of space may represent one of the factors most seriously limiting long duration space residence of man and his life supporting organisms. The radiation problem permeates the entire life sciences program and is common to all the required experiments ranging from human health to basic investigations on graviperception. Space experiments to date suggest that synergism exists between the effects of weightlessness and radiation. Hence, radiation exposure should be measured and monitored for all experiments performed. However, to date, natural radiation doses received, due to relatively short flight durations, have not posed a health problem or affected the results of space life sciences experiments. This suggests that near-term radiation studies should be conducted primarily in ground-based facilities where more controlled radiation doses can be obtained. Further space radiation experiments will require radiation-intensive orbits, very long duration flights, or preferably, on-board radiation sources. Specific radiation studies will not be suggested in this report because those most required in the near future can be performed in earth laboratories.

The Life Sciences Panel views the whole problem of life in space as one having many interrelated parts, perhaps even as a jigsaw puzzle where all pieces are needed to understand the whole. On one end of the problem spectrum is our concern for the human health problems identified to date and at the other, the basic reactions of animals, plants and even cells to the weightless environment. Hence, we consider the appropriate space life sciences program to be one which produces generalizable knowledge, most of which will be useful in the near or far term in achieving the applied objective of space habitation. This integrated approach to life sciences research is illustrated in Figure 2.1. We also look forward to the possible use of the knowledge gained in the space life sciences program for earth-based biomedical and agricultural applications. The integrated life sciences program presented should yield the information required to satisfy all of the stated objectives.

2. SPACE LIFE SCIENCES NEEDS SATISFIED BY SHUTTLE ATTACHED PAYLOADS

The Shuttle/Spacelab facility will serve adequately for the performance of a variety of life sciences experiments which can be accomplished at intermediate g levels (10^{-2} to 10^{-3}) during relatively short exposures (7 to 14 days) to the space environment. An integrated life sciences program as presented will make extensive use of the Shuttle as an optimum test facility for selected experiments. The program will also employ the STS for development and test of equipment and protocols for experiments requiring much longer time periods and/or lower g levels (10^{-4} or lower). We view the life sciences program as an evolutionary one which eventually will require experimental facilities in orbit for

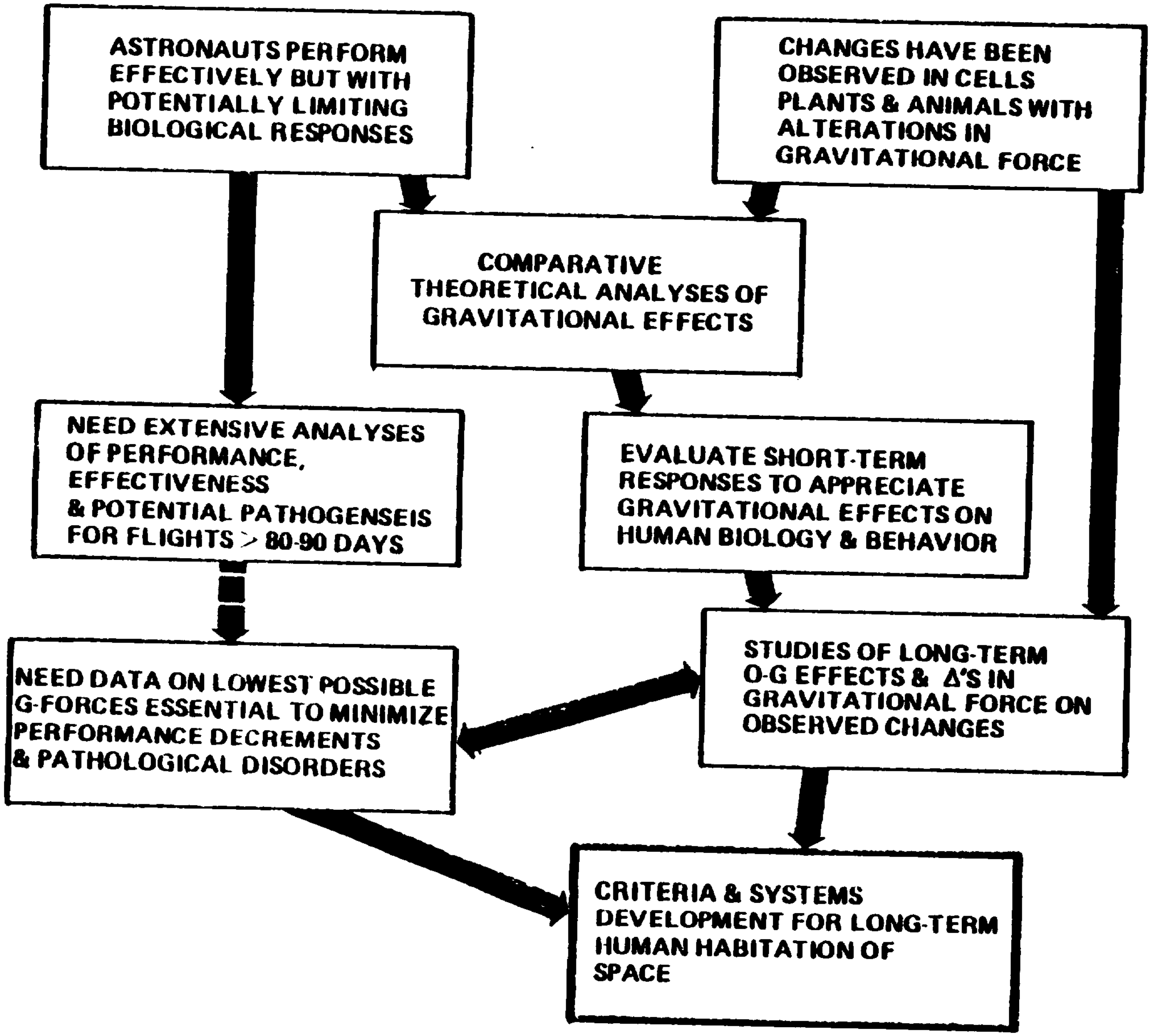


FIGURE 2.1 INTEGRATED APPROACH TO LIFE SCIENCES SPACE RESEARCH

three years and perhaps longer. In the interim, the Space Sciences Platform is considered the next logical facility to provide the flight durations and low g forces required to develop the knowledge necessary to assure man's health and performance during long duration residence in space. Human and animal experiments developed for Spacelab will lead to more extensive programs utilizing the SSP. Where possible, Spacelab equipment should be interfaceable with Platform configurations. Plant and lower organism experiments, both for basic science investigations and to support development of regenerative life support systems, will be started on Spacelab and logically evolve to require the SSP system for successful completion. Table 2.2 illustrates the evolutionary (Shuttle to SSP) nature of the space life sciences program.

3. TYPICAL EXPERIMENTS REQUIRING SPACE SCIENCE PLATFORMS

3.1 Biomedical Experiments with Humans and Animal Models

The prime objective of experiments planned for the Space Science Platform should be to determine the minimal environmental requirements for prolonged survival in space. Specifically, it must be determined:

(1) If g fields, which could be realistically implemented with the Space Platform, reverse the deleterious effects of zero g on bone loss and progressive increases in urinary calcium concentration and excretion rates. These experiments will 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 in prolonged exposure to decreased gravitational forces. Specific areas of investigation might include analysis of bone strength as a function of time of exposure to weightlessness, pharmacological or other interventions that slow bone resorption, the measurement of calcium precipitation, and design of interventions that prevent such precipitation.

(2) Are early signs of cardiovascular deterioration progressive, and if so, to what degree are they irreversible? Preliminary observations in humans indicate 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. In this regard, experiments can be designed for various species; however, bipeds, in particular, in experiments to date, indicate that these cardiovascular, hemodynamic, and hematopoietic alterations are limited to those species which normally assume the upright posture. Specific protocols would identify interventions, particularly increases in accelerative forces, which would alter central blood volume, myocardial muscle mass, spatial distribution of pulmonary blood flow and ventilation, and myocardial contractility as determinants of cardiovascular status. Specific areas of investigation might include assessment of the magnitude of long-term cardiopulmonary congestion and the final disposition of early cephalic fluid shifts; the design of interventions that maintain red cell and plasma volume; detailed assessment

TABLE 2.2. EVOLUTIONARY NATURE OF THE SPACE LIFE SCIENCES PROGRAM

	Metabolism	Energy	Skeletal	Muscle	Nutrition	Cardiovascular (Hemodynamics)	Fluid Shift	Electrolytes	Endocrinology	Hormones	Enzymes	Minerals	Life Cycle	Reproduction	Embryogenesis	Growth	Development	Genetics	Circadian Shifts	Geotropism	Response	Circumnutation	Phototropism	Morphology	Epinasty	Gravimorphology	Thigmomorphology	G-sensors	Behavior
Man		S/P	P	P	P	S/P	S/P	S/P		S/P	S/P	S/P							P									S/P	S/P
Animals																													
Mouse		S/P	S/P	S/P	S/P	S/P	S/P	S/P		S/P	S/P	S/P	P	S/P	S/P	S/P	S/P	P	S/P		S/P							S/P	S/P
Hamster		S/P	S/P	S/P	S/P	S/P	S/P	S/P		S/P	S/P	S/P	P	S/P	S/P	P	P	P	S/P		S/P							S/P	S/P
Quail		S/P	S/P	S/P	S/P	S/P	S/P	S/P		S/P	S/P	S/P	P	S/P	S/P	P	P	P	S/P		S/P							S/P	S/P
Rat		S/P	S/P	S/P	S/P	S/P	S/P	S/P		S/P	S/P	S/P	P	S/P	S/P	P	P	P	S/P		S/P							S/P	S/P
Rabbit		S/P	S/P	S/P	S/P	S/P	S/P	S/P		S/P	S/P	S/P	P	S/P	P	P	P	P	S/P		S/P							S/P	S/P
Fowl		S/P	S/P	S/P	S/P	S/P	S/P	S/P		S/P	S/P	S/P	P	S/P	S/P	P	P	P	S/P		S/P							S/P	S/P
Dog		S/P	S/P	S/P	S/P	S/P	S/P	S/P		S/P	S/P	S/P	P	P	P	P	P	P	S/P		S/P							S/P	S/P
Monkey		S/P	S/P	S/P	S/P	S/P		S/P		S/P	S/P	S/P	P	P	P	P	P	P	S/P		S/P							S/P	S/P
Plants		S/P			S/P						S/P	S/P	P	S/P	S/P	S/P	S/P	S/P	S/P		S/P	S/P	S/P		S/P	P	P	P	
Invertebrates		S/P		S/P	S/P			S/P		S/P	S/P		P	S/P	S/P	S/P	S/P	S/P	S/P		S/P	S/P						S/P	S/P
Microorganisms		S/P			S/P						S/P		S/P	S/P				S/P	S/P		S/P							S	
Regenerative Life Support					S/P							S/P	P						P		S/P		P		P				P

LEGEND

S - Shuttle only

P - Platform only

S/P - Shuttle followed by Platform

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.

(3) Whether decreases in skeletal muscle mass will adversely affect work performance in space and whether these changes are reversible by small increases in artificial g-forces or by other interventions. Most specifically for these protocols, continual monitoring of animal models is deemed essential in order to minimize the effect of malnutrition on muscle mass. The use of animal models will allow highly focused histological and biochemical experimental protocols with emphasis on: morphological analysis of muscle specimens (including electron microscopy); whole-body in-vitro nitrogen balance studies; and chemical analyses of contractile proteins and metabolic substrates. In man, and other species, nitrogen balance protocols would be coupled to measurements of urinary 3-methyl histidine, the latter reflecting muscle catabolic processes. Specific areas of investigation include: long-term optimization of exercise strategies to minimize muscle loss; interventions to specifically maintain antigravity muscles during periods of disuse; and evaluation of the role of substrates, metabolites, and humoral factors on the maintenance of muscle mass and function.

These three specific areas of investigation highlight a broad spectrum of problems that must be dealt with if man is to live and work in space. Additonal concerns necessarily involve radiation exposure, reproduction, and many other factors not delineated here. It is important to emphasize that there is little difference between experimental facilities designed to facilitate habitation of space, to advance terrestrial medicine and to further our understanding of basic biological principles.

To understand the integrated cellular response to prolonged weightlessness requires a study of complex biological phenomena. Therefore, if advances are to be made, experiments should not be limited to human subjects. They will necessarily include studies in a variety of animal and plant species whose selection is dictated both by the nature of the scientific query and the fact that man would be an inappropriate subject due to the contraints imposed by experimentation limits with human volunteers.

Table 3.1 illustrates the types of biochemical and physiological studies needed which would benefit from, or would require, a Space Sciences Platform.

3.2 Behavioral Experiments With Humans and Animal Models. One of the primary objectives of experiments planned for the SSP should be the investigation of behavioral adaptations to fractional gravitational force environments in order to determine optimal conditions for long-term extraterrestrial habitation. Specifically, it must be determined:

(1) How a range of g fields which could be realistically implemented with the SSP (e.g. 0, 0.2, 0.5, and 1.0) affect performance levels over extended time periods. These experiments would be carried out with

TABLE 3.1. REQUIREMENTS FOR HUMAN AND ANIMAL RESEARCH AND SPACE SCIENCE PLATFORM

	Subject		Human Observer	Human Intervention	Samples				Bacteriology/ Cultures	Non-Invasive			Drugs Pharacological Agents Diets	Special Invasive Procedures
	Man	Animals			Blood	Urine	Fecal	Tissue		Imaging	Cardiovascular Function	Respiratory Function		
Nutrition/Digestion	Yes	Yes	No	Yes(A)	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No
Disease/Contagion/ Therapy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Muscle/Work Tolerance	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No
Bone Metabolism	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No
Heart and Myocardium	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Hematology	Yes	Yes	No	Yes	Yes	No	No	No	Yes	No	Yes	Yes	Yes	No
Peripheral Hemodynamics and Control	Yes	Yes	No	Yes	Yes	No	No	?	No	Yes	Yes	No	Yes	Yes
Pulmonary Function/ GaS Exchange	Yes	No	No	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	?
Vestibular Function/ Orientation	Yes	Yes(?)	Yes	Yes	No	No	No	Yes(A)	No	?	No	No	Yes	?
Behavior/Human Interaction	Yes	?	Yes	No	No	No	No	No	No	No	No	No	Yes	No
Mental Capacity/ Reflexes	Yes	Yes	Yes	Yes	No	No	No	Yes(A)	No	Yes(A)	No	No	Yes	?(A)
Renal/Electrolytes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes
Humoral Balance/ Endocrine	Yes	Yes	?	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes
Reproduction/ Sexuality	?	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	No	Yes	No
Cellular Integrity/ Cytoplasmic Chemistry	?	Yes	No	Yes	Yes	No	No	Yes	?	No	No	No	Yes	?

both human subjects and animals using a variety of learned (e.g. classical and instrumental conditioning techniques) and unlearned (e.g. activity level measures) behavioral assessment procedures. In addition, technologically advanced psychophysical methodologies would be employed to determine changes in levels of sensory-motor function. The validity, reliability, sensitivity, and comparability of such performance assessment procedures have been convincingly demonstrated in behavioral pharmacology and behavioral physiology laboratories over the last decade.

(2) How the basic behavioral assessment procedures and other life sciences studies can be integrated within the frame work of a comprehensive programed environment concept approach to a dedicated habitability module which could be realistically implemented with the SSP configuration. In addition to the standardized learned and unlearned performance evaluation and psychophysical assessment procedures, these experiments would explore the application of a total and continuous "life space" program within the context of an integrated work and habitability model. This approach would provide for objective measurement and quantification of individual and social adjustment patterns (e.g. frequency and duration of social episodes, social distance measures, etc.) which have been developed in recent ground-based studies with small human groups under confined micro-society conditions.

3.3 Gravitational Physiology Studies On Animals. Broadly based experiments in space are needed to uncover the overall effect of protracted weightlessness upon vegetative functions of animals. Experience with chronically accelerated animals indicate that hyper-g effects are progressive. Assuming the same for protracted weightlessness, maximally useful results would require tests of up to 120 days in space for experiments on individual animals. Multi-generation studies would be proportionally longer.

Gravity and body size interact strongly. Experiments are needed on groups of animals representing a considerable range of mass, and comparisons should be made between quadrupeds and bipeds, as well as between birds and mammals (the two types of homeotherms). For example: mouse (0.03 kg), hamster and coturnix (0.11 kg), rat (0.30 kg), rabbit and chicken (2-4 kg), and dog and monkey (10 kg) represent the range of specimens needed. Results will establish scale factors in gravitational physiology of homeotherms necessary for relating results of animal experiments to humans.

Experiments are needed at several g-levels. In addition to those at 1 g, there should be studies at 1.5 g and 2.0 g on centrifuges on Earth, at 0.2 g, 0.5 g, and 1.0 g on centrifuges in space, and the all important control, nominal "zero g". Typical observations and measurements to be made in hypogravity include:

(1) Body mass determinations and nutritional balances at weekly intervals.

(2) Urinary concentrations of creatine, creatinine, HO-proline, and 3-M-Histidine.

(3) Respiratory metabolism, heart rate and body temperature as indicators of circadian rhythms.

(4) On animals sacrificed at intervals: Hematology, plasma composition, and bone histology.

(5) Fluid and electrolyte shifts to reveal redistribution of body fluid to the thoracic and head regions as occurs in animals and humans.

After space flight, the remaining animals will be returned to the 1 g laboratory for intensive study of deadaptive and/or readaptive changes.

These measurements of progressive changes under weightlessness or at different levels of hypogravity ($0 < g < 1$) need not be done on all animals simultaneously. Changes induced by weightlessness would indicate perturbations of processes or organismic components that probably could be identified specifically. Subsequent experiments would follow-up such leads and allow investigators to evaluate and understand the mechanisms responsible for the adaptive and important pathological effects.

Basic questions on the role of gravity in evolution and physiology could be answered by animal experimentation (e.g. $\bar{g}$ effects on the complete life cycle of one or more typical homeotherm species, viz. sperm and egg production, fertilization, embryogenesis, birth, rearing of neonates (maternal and litter behavior), growth and development, and reproduction).

Mechanisms involved in early physiological responses to weightlessness can be assessed by utilizing short-term (7 to 14 day) Shuttle-Spacelab flights, but chronic exposure responses also will require the long-term (120 days or more) exposure that would be possible on a Space Platform. See Table 3.2 for illustration of proposed animal studies, most of which will serve to model expected effects in man. Animal studies will help overcome most of the invasive and replication problems encountered using man as the test subject.

3.4 Gravitational Biology Studies On Plants. For plant organisms, gravity is among the more significant environmental factors that condition form and function. The most interesting research to be done on plants in space will not examine weightlessness as a stress that could be harmful. Since plants are structurally over-built, deleterious effects generally occur only at g-levels far above what a land animal of comparable mass can tolerate. Instead, gravity is considered by many biologists as a nonstressful source of environmental information to the plant.

Studies of plant reactions to environmental g-signals will be of two kinds: (1) exploratory observations to determine whether particular functions or features of the plant are at all dependent on a g-force, and (2) experiments to describe, over a range of g-levels, specific organismic properties found to be g-dependent. Broad questions representative of those that can be answered by exposing test plants to unusual g-forces include:

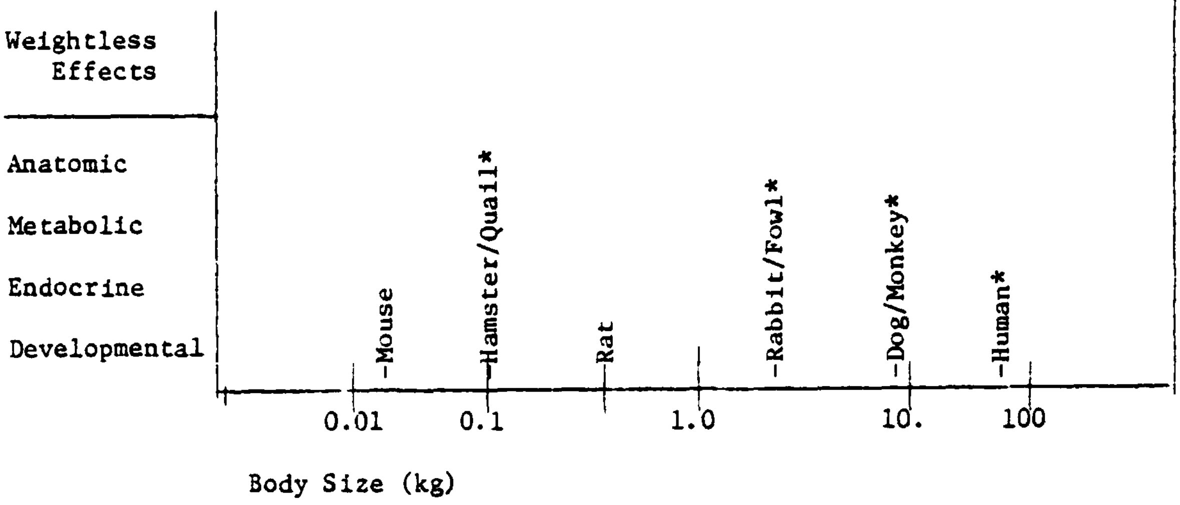
(1) How do plants detect the g-force and by what mechanism(s) do their bioaccelerometers operate?

(2) Do plants require gravity as an orienting force during embryogenesis or at any later stage of development?

(3) How are the common nastic responses to gravity, such as hyponasty of lateral organs, related to the intensity of the gravitational

TABLE 3.2. EXAMPLE ANIMAL STUDIES FOR FLIGHT PROGRAMS

	Shuttle Short Term (7-14 days)	Space Platform Long Term (120 days)
Scaling Effects	-	+
Life Cycle (Reproduction, etc.)	-	+
Skeleto-Muscle Metabolism	+	+
Nutritional Metabolism	+	+
Water Metabolism (fluid Shifts) Electrolyte Balance	+	+
Body Composition	+	+
Hematology	+	+



SCALING EFFECTS PROJECT

*Biped

stimulus?

(4) How does the application of a g-force prevent the anomalies in plant cell division that were observed in experiments in weightlessness by both U.S. and Soviet investigators?

(5) How are the gravitropic responses of plants brought about?

(6) Do the nearly ubiquitous circumnutations of plant organs (roots, branches, tendrils, hypocotyls, etc.) depend on gravity, or is the driving stimulus quite endogenous?

(7) Does the release of a plant from gravity produce a phase shift of its circadian rhythm as was reported from experiments with simulated hypogravity?

(8) What are the kinetics of a typical phototropic response uncontaminated by geotropism?

(9) How does the g-force influence the activity of certain plant enzyme systems that were altered in tests with simulated hypogravity?

To find answers to these and other questions, experimenters must be able to alter g-levels both upward and downward from unit g. Hypergravity tests are being done on centrifuges on Earth, but the hypogravity studies can be done only in space. The research must be conducted in several different kinds of space facilities because the experiment requirements vary considerably with respect to: (1) the g-force limit above which the experimental objective would be compromised, (2) the duration of the experiment, (3) the need for "hands-on" manipulation during the progress of the experiment, (4) the volume, and perhaps in some cases, the mass of the equipment, and (5) the peak and average power requirements.

Table 3.3 shows most of the kinds of plant experiments that we now believe would be appropriate for space missions. In the top part of the Table are tests that can be done using Shuttle Attached Payloads. The remainder of Table 3.3 shows tests that cannot be accomplished by that means, but which require a Space Platform.

Two examples will be given of plant experiments that will require a Space Platform with capability greater than that of a Shuttle Attached Payload.

(1) What is the threshold for g-force detection by a plant? This measurement was attempted on earth using clinostats for hypogravity simulation. The possible inadequacy of the simulation was recognized by the investigators, but the tests were done before space vehicles became practically available for botanical research. Initial results indicated that the bioaccelerometers were sensitive to as little as 10^{-7}g. That fantastic sensitivity measurement was distrusted, and the apparatus was redesigned to reduce, as much as possible, low level vibrational inputs. The tests were then repeated and the limit was found to be about 10^{-3}g. In spite of the

TABLE 3.3. PROBLEM AREAS IN PLANT BIOLOGY THAT REQUIRE EXPERIMENTS IN SPACE

Problem Area	Days	g-Force Limit	Minimal Vibration Required	In-Flight Centrifuge Essential	High Power Req.	Needs Space Platform
Geotropic Response	1-5	$5x10^{-2}$	-	Yes	-	No
Mutation	1-5	$5x10^{-2}$	-	Yes	-	No
Circadian Phase Shift	10-14	$1x10^{-3}$	-	Yes	-	No
Photropic Response	2-10	$1x10^{-3}$	-	No	-	No
Hyponasty	1-5	$5x10^{-2}$	-	Yes	-	No
Enzyme System Activity	10-14	$5x10^{-2}$	-	Yes?	-	No
g-Sensor Mechanism	1-5	$1x10^{-2}$	-	Yes	-	No
g-Sensor Mechanism	1-5	$1x10^{-4}$	Yes	Yes	-	Yes
Gravimorphogenesis	30-90	$1x10^{-4}$	Yes	No	Yes	Yes
Mitotic Abnormality	1-5	$1x10^{-4}$	Yes	Yes?	-	Yes
Thigmomorphogenesis	10-14	$1x10^{-4}$	Yes	No	-	Yes
Thigmomorphogenesis	30-90	$1x10^{-4}$	Yes	No	Yes	Yes

experimenters' caution, the different values obtained warn us that we cannot be sure the hypogravity simulation method is valid. Obviously the measurements should be made under real, not simulated hypogravity. When the sensitivity threshold is measured in space, the results should be unambiguous, but tests will require a Space Platform on which the "background" g-level will be no greater than 10^{-4} g. We are not confident that a Shuttle Attached Payload could achieve this with crew members' activities and other sources of accelerations to contend with.

(2) To answer the question, "How does gravity determine the course of plant morphological development?", it will be necessary to grow a population of plants which experience no detectable g-signals through at least one complete life cycle. The minimum duration will be about 4 weeks which exceeds what Spacelab can accommodate. Moreover, if, as has been suggested, a g-pulse can determine whether or not a particular developmental sequence will ensue, the test environment must not include even brief episodes of g-force applications above a threshold now estimated to be no higher than 10^{-3} g. The Shuttle Attached Spacelab cannot meet this requirement.

It seems evident that for some important experiments on animals and on plants the Space Platform, if it is appropriately designed, could be uniquely useful for basic research in biology.

3.5 Development of Regenerative Life Support Systems. Many of the physico-chemical and biological components for regenerative life support systems will require testing in the Space Shuttle or Shuttle Attached Payloads, including Spacelab and possibly tethered spacecraft. Utilizing the Shuttle and Spacelab, the spatial requirements, energy needs, and mission demands can be ascertained for the physico-chemical methods of: (1) potable water treatment by thermal and membrane (reverse osmosis) regenerative processes; and (2) thermal and chemical oxidative technology for solid waste management. Conventional anaerobic / aerobic bacterial digestion and biological oxidation pond treatment systems for regeneration of potable water and solid waste treatment have not been examined in hypogravity environments. Although the micro-organisms involved may not be affected by the influences of low-gravity, the processes of microbial/substrate interaction may be influenced by this environment. Therefore they should be subjected to subscale testing in the hypogravity environment provided by the Shuttle Attached Payloads. For photosynthetic processes to be considered for possible utilization for atmosphere regeneration, illumination requirements for optimum operation must be satisfied. Space Shuttle and its attached payloads can provide the necessary conditions for tests using solar and filtered-solar illumination. This spacecraft also allows for generation of artificial lighting for necessary control experiments or demonstration of the need for totally artificial illumination. Biological gas regenerative mechanisms involve the complexities of photo-oxidative processes. These studies are also amenable to the use of the Shuttle. To date, mostly static cultures have been tested in space, and it is essential to examine active photosynthetic organisms in the low-gravitational and otherwise stressful conditions of the space environment.

The photo-oxidative process is multifaceted since, in addition to oxygen regeneration, it does produce food as a by-product, thus yielding a net water balance, an integration of the nitrogen cycle, mineralization through nutrient exchange, and recovery of carbon and oxygen from metabolic CO_2. Each facet can be considered an identifiable component of the overall system, and each must be tested phenomenologically in the Shuttle program to ascertain its applicability toward eventual incorporation into an ecologically balanced, integrated life support system.

An evolutionary series of typical studies, experiments, and tests of regenerative life support system processes and components would be based on early use of Shuttle payload flight capability followed by subsystem and system tests on the Space Sciences Platform.

- Component processes for potable water production, waste management, atmospheric regeneration and food production may be found, after Shuttle-based substage testing, to require specific and rigid conditions for acceptable performance. These requirements may include filtration of natural non-terrestrial illumination, or a specific requirement for artificial lighting. Perhaps optimum performance of the biological system may necessitate the induction of a pseudo-gravitational field of some magnitude, i.e., 0.2, 0.5, or 1 g. The Space Science Platform could ideally match the anticipated spatial requirements of multiple experimental modes for illumination optimization and/or gravity simulation (i.e., centrifuging).

- Closure of the regenerative life support system entails utilization of crop plants for food production. Considerable effort in selection of food plants, adaption of plants to the specialized space environment, and optimization of species for high performance in productivity and food value is essential. The criteria for plant longevity, stability in a stress environment, optimum growth, normal development and maximum productivity, must be established by testing in the rigors of the actual space environment. To establish these criteria, selected plants must be subjected to long-duration exposure to weightlessness through complete life cycles, and input-output data similar to that illustrated in Table 3.4 must be obtained. By virtue of this requirement such experimentation needs the long-term space exposure that can be provided by the Space Science Platform program. Also obvious to obtaining maximum food plant productivity is development of plants which have spent several generations in space (hypogravity, illumination, etc.) and have adapted to the new environment. This necessitates multi-generation production of plants, a time consuming process. Such experimentation will require orbital stay times offered by the Space Science Platform.

- Ideally it is desirable, when designing a life support system for long-term space habitation for man, to consider materially closed regenerative systems. An important consideration in this matter is the possibility of providing a fully operable nitrogen cycle (as is conventional on Earth), ranging from bacterial fixation of atmospheric nitrogen to ammonification, and nitrification. Selected processes and systems could provide space habitats with mechanisms for food production, atmosphere regeneration, and natural mineralization that are less energy-intensive than physicochemical schemes for the same purpose. Demonstration that a complete cycle is operable in the artificial circumstances of the extraterrestrial environment can be provided only by the long-term experimentation in space that would be possible on the Space Science Platform.

TABLE 3.4. INPUT-OUTPUT ESTIMATES FOR PLANTS IN THE TERRESTRIAL ENVIRONMENT

Plant Species	Value	Total Biomass $g/m^2/day$	Harvest Index %**	Consumable Biomass $g/m^2/day$	Time to Maturity days	Area of Illumin. m^2/g	Volume for Growth m^3/g
Corn	Average	2.55 - 3.56	27	0.84 - 1.92	70	.0056	.0140
	Good	5.82 - 8.89	33	0.96 - 2.40	70	.0016	.0040
	Projected	*	47	*	70(5x/yr)	*	*
Bean	Average	0.55	29	0.16	100		
	Good	0.63	32	0.20	100		
	Projected	*	36	*	100		
Tomato	Average	1.63 - 3.61	80	1.45 - 2.89	65	.0095	.0238
	Good	5.81 - 6.46	89	3.45 - 5.17	65	.0024	.0060
	Projected	*	89	*	65(5.5X/yr)	*	*
Lettuce	Average	3.53	100	3.53	40	.0071	.0021
	Good	5.88	100	5.88	40	.0043	.0013
	Projected	*	100	*	40(9X/yr)	*	*
Kale	Average	1.34	100	1.34	60	.0124	.0124
	Good	2.02	100	2.02	60	.0082	.0082
	Projected	*	100	*	60(6X/yr)	*	*
Potato	Average	2.26 - 4.53	55	1.49 - 1.87	90	.0049	.0074
	Good	2.71 - 5.44	66	2.99	90	.0020	.0030
	Projected	*	66	*	90(4X/yr)	*	*
Chlorella	Average	16 - 18	100				
	Good	25 - 43/12 hrs	100				
	Projected,a	240/12 hrs	100				
	Projected,b	720/12 hrs	100				

* Without changing $g/m^2/day$, or Harvest Index %, projected yields in a closed, continuous-cropping system would be increased by factors as indicated in "Time to Maturity" data.

** Harvest index is the percentage of the aerial dry weight of a plant that provides useful food material.

To obtain highest performance, long-term space study is essential to ascertain and manipulate a variety of parameters including: acceptable nitrogen fixing plant species; bacterial species involved in pertinent aspects of nitrogen cycling; and an appropriate medium for integration of the cycle. It will be necessary to obtain input-output data with appropriate parameters for microbial species similar to that required for plants (again see Table 3.4). The latter point must be carefully considered since soil or soil-substitutes (such as are used in hydroponics) must be exhaustively studied for relative merits and tradeoffs. The time frames of such studies are so long as to be considered experiments that can only be conducted on a Space Science Platform, not on Shuttle Attached Payloads.

The consideration of food crop production in space necessitates attention to scaling problems. Although many aspects of plant reactivity to space can be studied in short-term (14 days) space flights, long-term space flights, i.e., the Space Science Platform, are necessary for determination of food-crop productivity, mission demand for food production, and scaling requirements for food production in space habitats. Provision of food for space habitats requires extensive investigation to optimize its integration, since this component is undoubtedly the single most complex factor in closure of the regenerative life support system.

An alternative technique for food-crop production involves the use of non-solid substrates, i.e., hydroponics. Whether a solid substrate (soil) or a liquid medium is employed will depend largely on requirements for plant growth in hypogravity. However, utilization of liquids in space presents unique problems, and successful management of some regenerative processes, such as the nitrogen cycle, may depend on providing appropriate solid/liquid interfaces. The area of fixed-film bioreactors, such as the use of microorganisms attached to solid substrates (as it applies to mineralization), requires thorough investigation in space.

Use of liquid media also necessitates consideration of gas exchange, or mass transfer of gas through a liquid medium. It is known that in hypogravity situations, bubbles in liquids behave differently than they do in 1g. Liquids would, in fact, remain more saturated since gas-bubble dissipation through buoyancy is not operational. This may possibly provide more optimum conditions for development of aerobic microbial populations. Such conditions may, indeed, be optimum for mineralization aspects. This enhanced gaseous mass-transfer approach may also be applied favorably to aerobic treatment of waste products and single cell protein production where maximum productivity could be obtained in minimum volumes. Scaling of such processes is required. These aspects all demand exhaustive investigation in space where long-term experimentation in hypogravity is possible. The Space Science Platform meets all essential criteria for these types of investigations, including long-term experimentation periods and spatial requirements for larger-scale apparatus.

The facility modes that will be required to support the various categories of life support systems research are summarized in Figure 3.1.

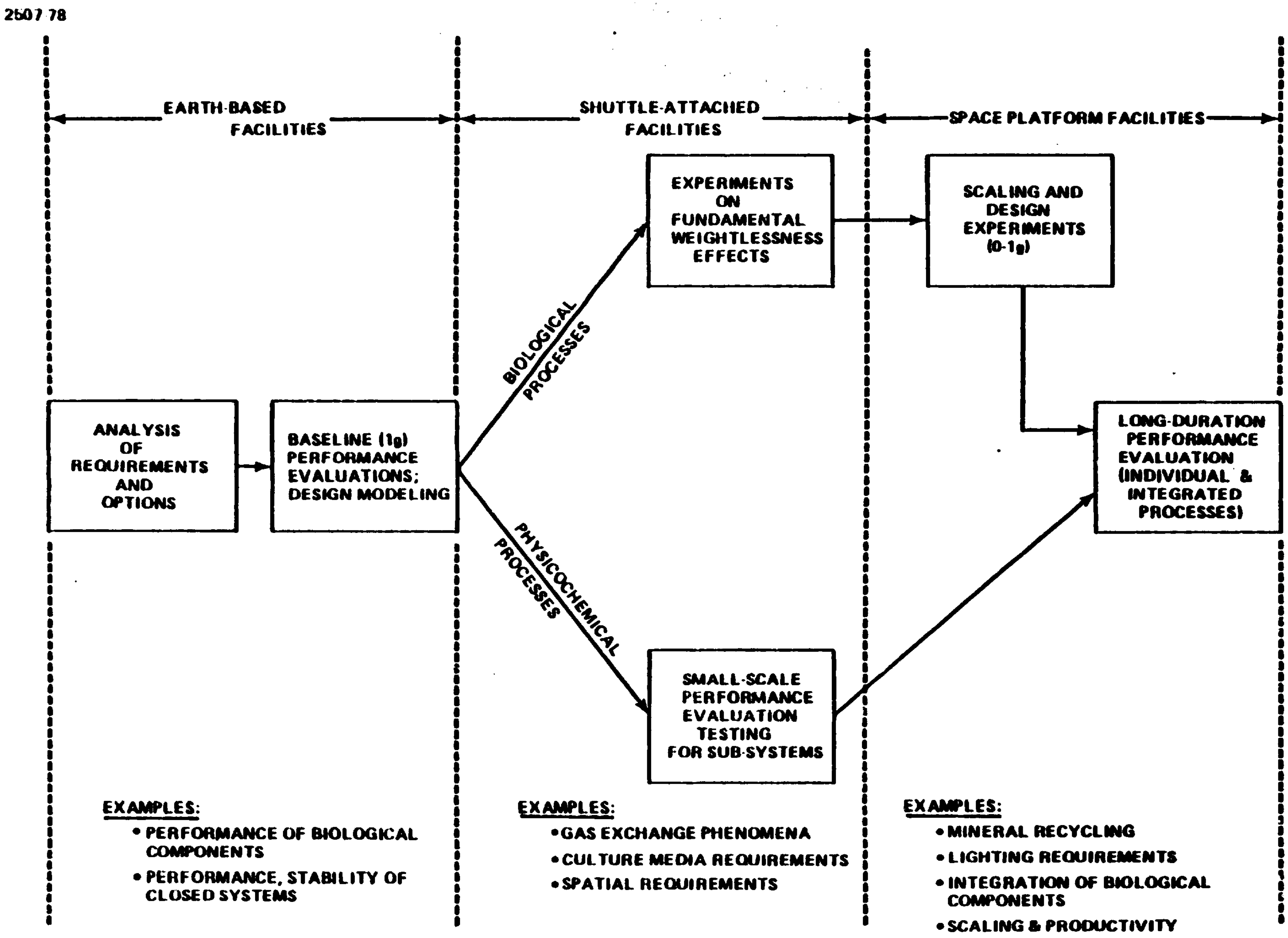


FIGURE 3.1

TIME-PHASED DEVELOPMENT OF REGENERATIVE LIFE SUPPORT SYSTEMS

4. PLATFORM REQUIREMENTS

The requirements for the life sciences aspects of the Space Science Platform focus primarily on extension of capabilities limited in Spacelab, namely longer duration, and increases in laboratory volume, power, and weight. The important feature which may go beyond Spacelab in significant ways is the provision of controlling gravitational and pseudo-gravitational forces in the range of 10^{-6} to 1 g. An important new feature beyond current STS capabilities is the provision of ample crew habitability features so that humans can not only work efficiently in space, but be adequate subjects for controlled biomedical and behavioral testing. For design purposes and comparison with other SSP concepts, first order platform characteristics are:

(1) Orbit: Nominal, avoiding high-radiation orbits, with the special exception of radiation studies where access to high radiation orbits might be desired.

(2) Acceleration: It is necessary to have platforms of low disturbance (less than 10^{-4}g).

(3) Orientation: There are no specific orientation requirements as a whole. For certain plant studies, maximum sun viewing will be required.

(4) Data and Telemetry: Spacelab-like capabilities will suffice for life sciences SSP activities (data rates of 50 to 1000 K bits/sec with the additional provision of downlink video).

(5) Maintenance and Checkout: Hands-on experimentation is fundamental to life sciences activities. Specimen and equipment handling will be performed routinely.

(6) Environment and Contamination: There are some unique contamination avoidance requirements imposed by life sciences (e.g. ethylene). Exposure to extraneous electromagnetic fields, ion beams, etc. should also be avoided.

(7) Environment and Vibration: Less than about 10^{-3} g is necessary for some experiments.

(8) Power: Initially about 25-50 Kw of user-available power would be required for experimentation (exclusive of any habitability or other environmental control requirements).

(9) Operations: Ground, STS, and SSP operations would be logical extensions of those envisioned for Spacelab (see (13) below).

(10) Duration: 3 to 12 month orbit-stay-times are required with growth capability to 2 to 3 years.

(11) Crew size: 6 to 12 persons would be typical for life sciences SSP. They would also serve as experimental subjects.

(12) Thermal Rejection: The ability to dissipate the full electrical loads should be routinely available. For illuminated photosynthesis experiments, using sunlight, thermal rejection capabilities above the electrical load level will be required.

(13) Shuttle Supply/Expendibles: Shuttle visitation, expendibles resupply, and crew rotation are all expected for SSP operations. Long duration tests on specimens may be conducted over experiment durations exceeding the safe stay time for human crew members, requiring crew changeout for continuous operation.

(14) Habitability Features: To assure that adequate physiological and behavioral studies can be made on the human subject/crew members, it is necessary that crew quarters be designed and provisioned with adequate volume

and ammenities so that crowding and other stressful environments do not occur. In the most far-ranging concepts for life sciences SSP, it will be desirable to operate habitability modules at partial-g levels which might be obtainable by rotation of the entire module on a tether about a large radius.

(15) Centrifuge(s): See Section 5 below.

(16) Illumination: As mentioned above, certain photosynthetic experiments will require illumination by natural/or filtered sunlight.

(17) Automation: Life sciences investigations generally do not lend themselves to automation.

(18) Contamination Avoidance: Since inhabited modules imply venting and dumping of gases, and since other, non-life science investigations may be extremely contamination sensitive, it may be necessary to emphasize contaminent tanks, filters, traps, baffles, and other contamination avoidance systems.

5. CENTRIFUGE CHARACTERISTICS AND REQUIREMENTS OF SPECIAL SIGNIFICANCE TO THE LIFE SCIENCES

For plant, animal and human studies, provision of centrifugal forces will be required in the nominal zero g through 1.0 g range. To achieve these forces without scientific compromise, gravity gradients within the test specimen should be less than 5%, thus dictating the centrifuge size as a function of the specimen height. Since many studies of gravitational effects are anticipated over a range of force levels and specimen size, several centrifuges of differing size may be required, ranging in radius from several tenths of a meter to several tens of meters.

Only chronically maintained g-levels need be furnished; rapid accelerations or declerations such as might simulate rocket launch or atmospheric reentry profiles would not be of interest. Thus, only low torque operations would be required.

For small plants and animals a centrifuge 0.2 to 2.0 m in radius would be optimal, and experimental centrifuges in this size range can be (and are) used in Spacelab. A 1.8 m subject would be accelerated at 0.5 g with a g-gradient of 5% on a centrifuge with a 35 m radius. Nothing larger would be required.

For some sets of experiments it may be advantageous to employ an alternative to a centrifuge to produce a hypogravity condition. The experiment payload could be lowered from the Space Platform on a tether some tens of km in length. The maximal g-force (from atmospheric drag) that could be achieved in this way would be limited to about 0.1 g. For a minority of biological studies in hypogravity this might be even more useful than the centrifugation method because at the end of the tether vibrational isolation would be excellent, and the low g-levels could be determined with excellent precision. For most hypogravity experiments there would be no advantage, however.

6. QUESTIONS ABOUT THE SSP CONCEPT THAT REQUIRE EARLY RESOLUTION

(1) Less than 10^{-4} and preferably 10^{-5} g is required for some life sciences experiments. Will the SSP provide micro-g, or must the life sciences assume the responsibility for facilities for maintenance of micro g?

(2) Will it be feasible to build a multiple pressurized module SSP for life sciences with 25 to 50 KW of power for experimental purposes over and above power needed for crew habitability, etc.?

(3) What mechanism will NASA use to insure that facilities (SSP) developed will be in response to the stated needs and objectives of the life sciences rather than, as has been usually the case in the past, the reverse where life sciences is asked what they can do with an existing facility?

(4) Does NASA prefer multidisciplinary SSP ventures for particular orbits or should life sciences plan dedicated missions?

(5) What is the current NASA projection for the growth of man's habitation of space (e.g., fabrication and maintenance of the Space Power Systems)?

APPENDIX A

SPACE SCIENCE PLATFORM WORKSHOP

JOE WHEELER STATE PARK RESORT

AUGUST 21-25, 1978

Sponsored by University of Alabama in Huntsville
In Cooperation With:

NASA Office of Space Science
and
George C. Marshall Space Flight Center

AGENDA

Monday, August 21

8:30 - 9:00	Coffee and Doughnuts	
9:00 - 9:30	Welcome and Introduction	A. Timothy R. O'Dell J. Hoomani
9:30	OSS Program Review	
	Astrophysics	J. Rosendahl
	Solar/Terrestrial	D. Bohlin
10:45	Coffee Break	
	Life Sciences	R. Hessberg
	Lunar/Planetary	W. Brunk
11:30 - 12:00	STS Future Plans	R. Freitag
12:00 - 1:00	Lunch	
1:00 - 1:30	Space Platform Needs	C. Lundquist
1:30	Space Platform Characteristics	F. Digesu
3:00	Coffee Break	
3:00	Meeting of Chairman and Liaison Personnel	R. O'Dell
4:00	Panel Meetings	
6:00 - 8:00	UAH Reception	

Tuesday, August 22

8:00 - 9:00	Coffee and Doughnuts
9:00 -	Panel Work Sessions
10:45	Coffee Break
11:00 - 12:00	Panel Work Sessions and Open Discussion
12:00 - 1:00	Lunch
1:00	Panel Work Sessions
3:30	Coffee Break
4:00	Panel Work Sessions

Wednesday, August 23

8:30	Coffee and Doughnuts
9:00	Panel Work Sessions
10:45	Coffee Break
11:00	Panel Work Sessions
12:00	Lunch
1:00	Panel Work Sessions
3:30	Coffee Break
4:00	Panel Work Sessions
6:00 - 8:00	Barbecue at Pavilion No. 3

Thursday, August 24

8:30	Coffee and Doughnuts
9:00	Panel Progress Reports and Open Discussion
10:45	Coffee Break
11:00	Panel Work Sessions
12:00	Lunch
1:00	Panel Work Sessions
3:30	Coffee Break
4:00	Panel Work Sessions

Friday, August 25

8:30	Coffee and Doughnuts
9:00	Presentation of Final Reports

Astrophysics Panel	A. Walker
Solar Physics Panel	R. Moore
Astronomy Panel	W. Moos
Space Plasma Physics Panel	J. Winckler
Life Sciences Panel	C. Ward
Atmospheric Science Panel	R. McGill
Lunar and Planetary Panel	W. Baum
Summary Remarks	A. Timothy C. R. O'Dell

ADJOURN

OSS SPACE SCIENCE PLATFORM WORKSHOP

Co-Chairpersons:

Dr. A. F. Timothy
Dr. C. R. O'Dell

PANELS

Astrophysics

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Robert Howard, Hale Observatories
Stuart Jordan, GSFC
Ron Moore, Cal Tech, Chairman
Neil Sheeley, NRL
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H. W. Moos, John Hopkins University, Chairman
Nancy Roman, NASA Headquarters
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W. L. Taylor, TRW
John Winckler, University of Minnesota, Chairman

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Joseph V. Brady, Johns Hopkins University
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Allan H. Brown, University of Pennsylvania
Peter A. Chevalier, Mayo Clinic
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R. Hessberg, NASA Headquarters
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Xavier J. Musacchia, University of Louisville
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Jack M. Spurlock, Georgia Institute of Technology
Calvin H. Ward, Rice University, Chairman

Atmospheric Sciences

Bob Hudson, GSFC
Bill Mankin, NCAR
Rex McGill, Utah State University, Chairman
George Newton, NASA Headquarters
Doug Torr, University of Michigan

Lunar and Planetary Sciences

William Baum, Lowell Observatory, Chairman
William Brunk, NASA Headquarters
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Michael Klein, JPL
Harold P. Larson, University of Arizona

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Alan Gary, MSFC
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Gary Swenson, MSFC
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APPENDIX B

SPACE SCIENCE PLATFORM CONCEPTS AND APPROACHES PREPARED BY PROGRAM DEVELOPMENT, MSFC

On the following pages, possible concept approaches for a Space Science Space Platform are offered as examples of schemes which can be explored in structuring the carrier accommodations for experiment programs.

No specific design is intended. Rather, possible approaches toward providing a wide range of platform amenities for scientific investigations from space are illustrated along with indications of versatility for experiment support.

NASA
National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center Alabama 35812

SPACE SCIENCE PLATFORM
CONCEPTS AND APPROACHES

OFFICE OF SPACE SCIENCES
SPACE SCIENCE PLATFORM WORKSHOP
JOE WHEELER STATE PARK RESORT, ALA.
AUGUST 21, 1978

MSFC - Form 454-1 (Rev. October 1976)

1288-78

CONCEPT OBJECTIVES

- PLATFORM PROVIDES ORBITAL MOUNTING BASE, POWER, POINTING, COMMUNICATION AND DATA MGT. THERMAL SUPPORT, TIMING AND ATTITUDE REFERENCE
- FLEXIBILITY IN APPROACH
  - INITIAL SIZE AND GROWTH ABILITY
  - ADAPTABLE TO VARIOUS ORBIT ALTITUDE / INCLINATIONS
  - RESPONSIVE TO MULTI DISCIPLINES SCIENCE NEEDS / REQUIREMENTS
  - ACCOMMODATION OF MANY EQUIPMENT (INSTRUMENT) TYPES
  - ACCOMMODATION OF SINGLE OR MULTIPLE INSTRUMENT GROUPS / SIZES
  - ABILITY TO ADD / DELETE INSTRUMENTS OR INSTRUMENT GROUPS
  - POINTING AND ORIENTATION FLEXIBILITY
- UTILIZATION OF PLANNED ORBITAL AND SUPPORT SYSTEM WHERE BENEFICIAL (I.E. 25kW P.M., MMS HARDWARE, PALLETS, IPS, MMU OR TELEOPERATOR, ETC.)

SPACE SCIENCE PLATFORM DISCUSSION TOPICS

APPROACHES TO RESOURCE PROVISIONS

CONCEPT BUILDING ELEMENTS

CONCEPT APPROACHES

- PALLETS/PRESSURE MODULE
- NEW GROUND BUILT STRUCTURE
- ORBIT BUILT LARGE STRUCTURE

ORBIT KEEPING

POINTING ANALYSIS/CONSIDERATIONS

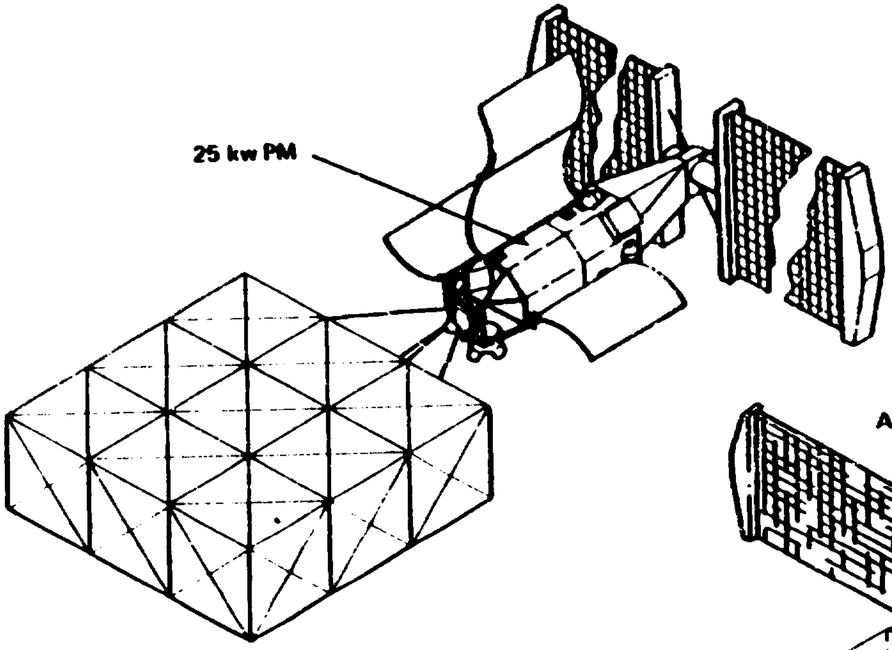
SUBSYSTEMS SUMMARY

TDRSS OVERVIEW

SUMMARY

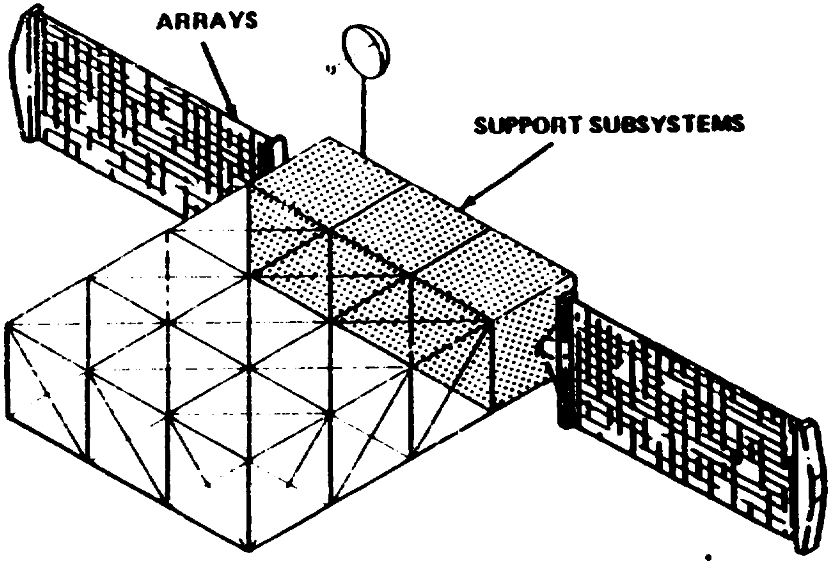
PD614-78C

ALTERNATE APPROACHES TO BASIC RESOURCE PROVISION



UTILIZATION OF FREE FLYING POWER MODULE

OPTIONS:
-CENTRALIZED RESOURCES
VS.
-DECENTRALIZED RESOURCES



INTEGRAL SUPPORT SYSTEM

2246-78

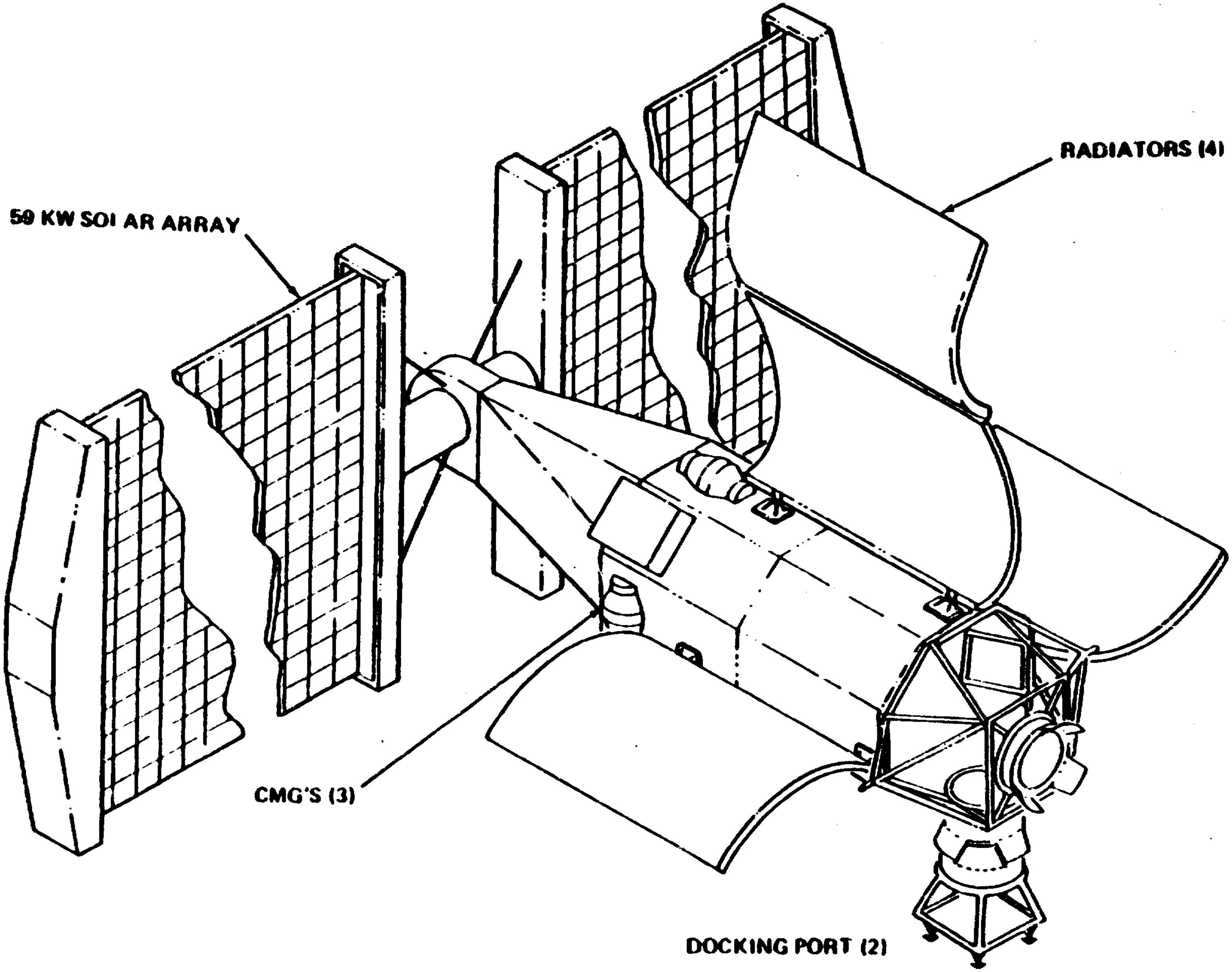
CENTRALIZED VERSUS DECENTRALIZED RESOURCE PROVISIONS

SHOULD PLATFORM BE "BIG BROTHER" OR SHOULD RESOURCES BE DECENTALIZED DOWN TO SOME LEVEL (EXPERIMENT OR EXPERIMENT GROUP.)

FOR EXAMPLE

RESOURCE	CENTRAL	DECENTRAL
POWER	CENTRAL SOURCE DISTRIBUTION NETWORK	LOCALIZED VOLTAGE REGULATION AND A.C.
HEAT REJECTION	FLUID LOOPS CENTRAL RADIATORS	EXPERIMENT PASSIVE COOLING WITH FINS/PAINT/HEAT PIPE
CRYOGENIC COOLING	CENTRAL CRYO DISTRIBUTION (PERHAPS CLOSED LOOP)	EXPERIMENT PECULIAR H_e DEWARS
DATA PROCESSING AND HANDLING	CENTRAL FACILITY FOR EXPERIMENT CONTROL, SEQUENCING, DATA PROCESSING, STORAGE	DECENTRALIZED EXPERIMENT MINI PROCESSORS CENTRAL HOUSEKEEPING DATA, "TRAFFIC COP," AND EXPERIMENT SUPPORT FUNCTIONS PRECISION TIME REFERENCE (VIZ: 10^{-14} H MAZER SOURCE) EPHEMERIS INFORMATION AS FUNCTION OF TIME

BASELINE POWER MODULE



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POWER MODULE
FREE FLYER SUPPORT CAPABILITY

	RESOURCES AVAILABLE TO PAYLOADS
POWER	25 KW ORBITAL AVERAGE / SOLAR ARRAY/BATTERIES
THERMAL CONTROL	12 - 14 KW_T/FOUR RADIATORS WITH FLUID SYSTEMS
STABILIZATION AND CONTROL	3 CONTROL MOMENT GYROS/THREE AXIS STABILIZATION SYSTEM
COMMUNICATIONS	4 KBPS DOWNLINK OMNI ANTENNA > UP TO 2 MBS WITH DISH ANTENNA UP TO 50 MBS WITH K_u BAND SYSTEM
DATA MANAGEMENT	65 KBPS DATA BUS CAPACITY / NSSC I COMPUTER
STRUCTURE	ORBITER COMPATIBLE DOCKING MECHANISM TWO DOCKING PORTS
LIFETIME	5 YEARS (WITH ORBITAL MAINTENANCE)

SPACE SCIENCE PLATFORM
DISCUSSION TOPICS

APPROACHES TO
RESOURCE PROVISIONS

CONCEPT BUILDING ELEMENTS ⇦

CONCEPT APPROACHES
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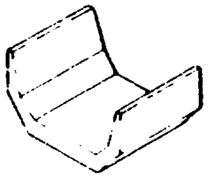
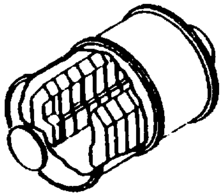
SPACE SCIENCE PLATFORM

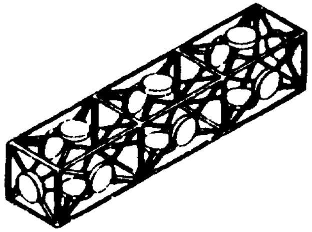
PLATFORM BUILDUP ELEMENTS AND INSTRUMENT CARRIERS



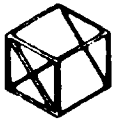
PALLET



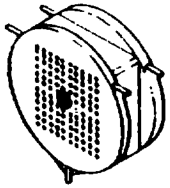
PRESSURE MODULE



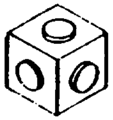
PLATFORM CORE



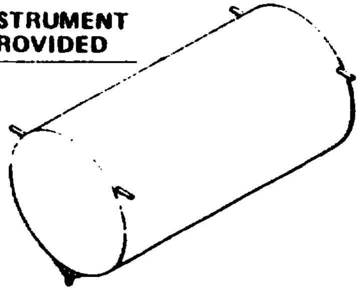
CUBE



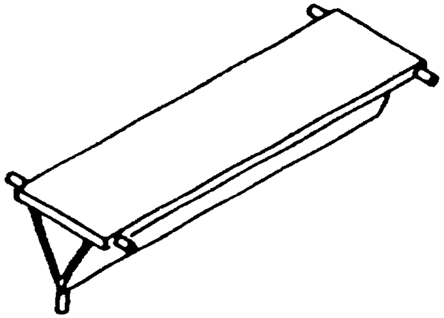
DISC



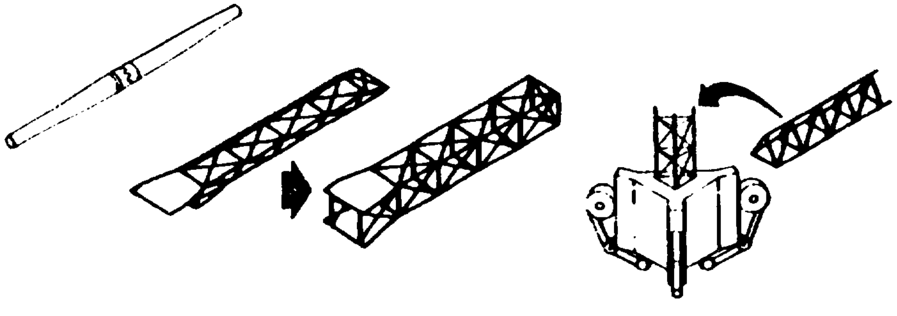
DOCKING ADAPTER



INSTRUMENT PROVIDED



LAUNCH PLATFORM

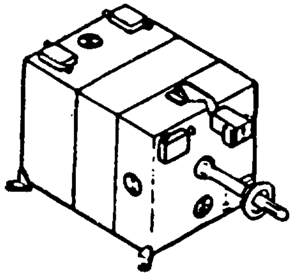


ERECTABLE MEMBERS

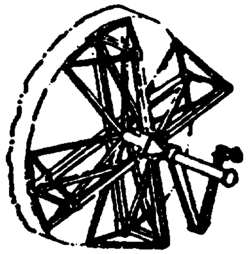
1287-78

SPACE SCIENCE PLATFORM

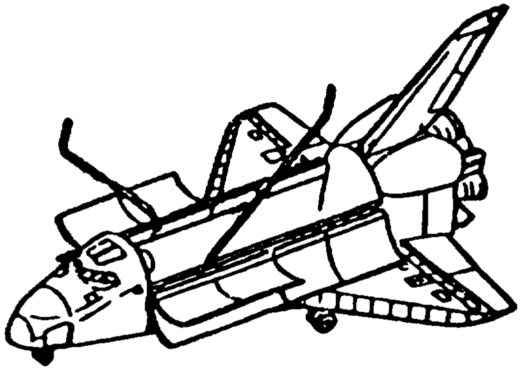
POTENTIAL OPERATIONAL SUPPORT ELEMENTS



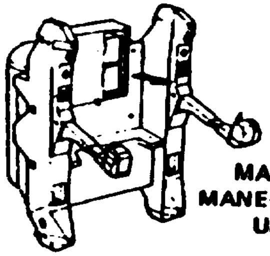
FREE FLYING
TELEOPERATOR (CORE)



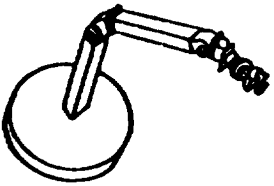
S/C SERVICER/EXCHANGER
SYSTEM



SPACE SHUTTLE



MANNED
MANEUVERING
UNIT



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SPACE SCIENCE PLATFORM DISCUSSION TOPICS

APPROACHES TO RESOURCE PROVISIONS

CONCEPT BUILDING ELEMENTS

CONCEPT APPROACHES

- **PALLETS/PRESSURE MODULE** ⇦
- **NEW GROUND BUILT STRUCTURE**
- **ORBIT BUILT LARGE STRUCTURE**

ORBIT KEEPING

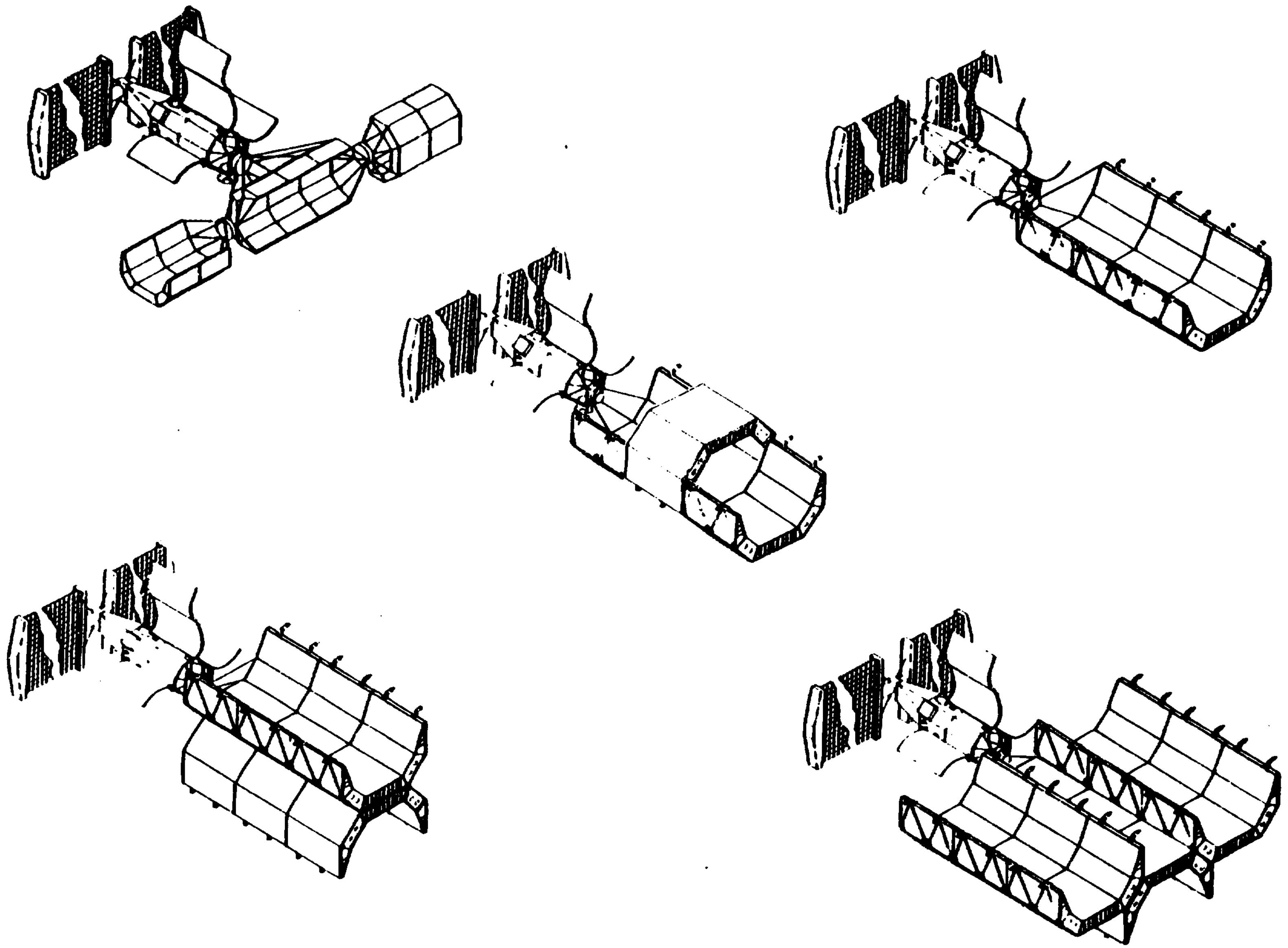
POINTING ANALYSIS/CONSIDERATIONS

SUBSYSTEMS SUMMARY

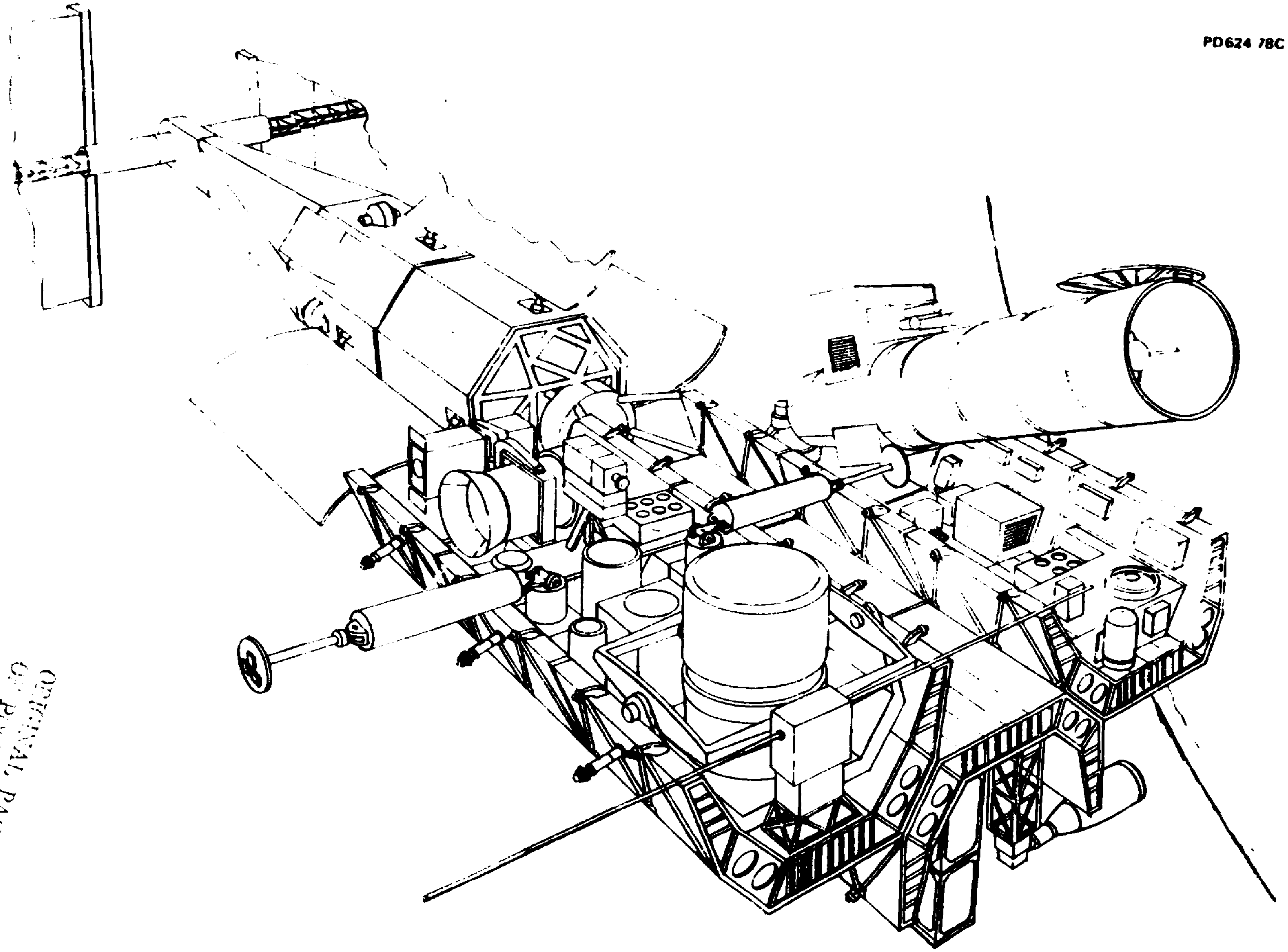
TDRSS OVERVIEW

SUMMARY

INITIAL PLATFORM CONCEPT APPROACHES - PALLET UTILIZATION

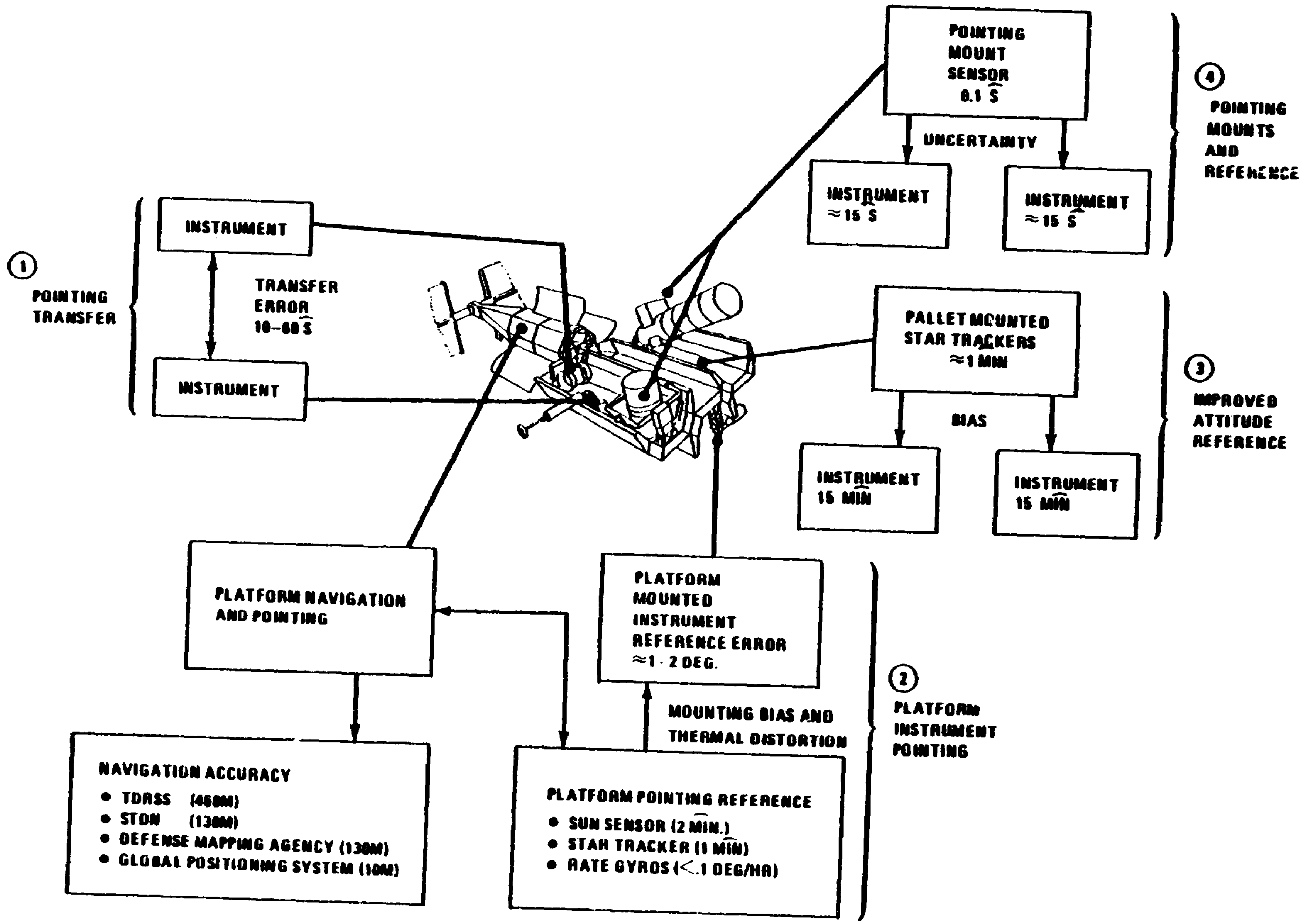


PD624 78C



2233-78

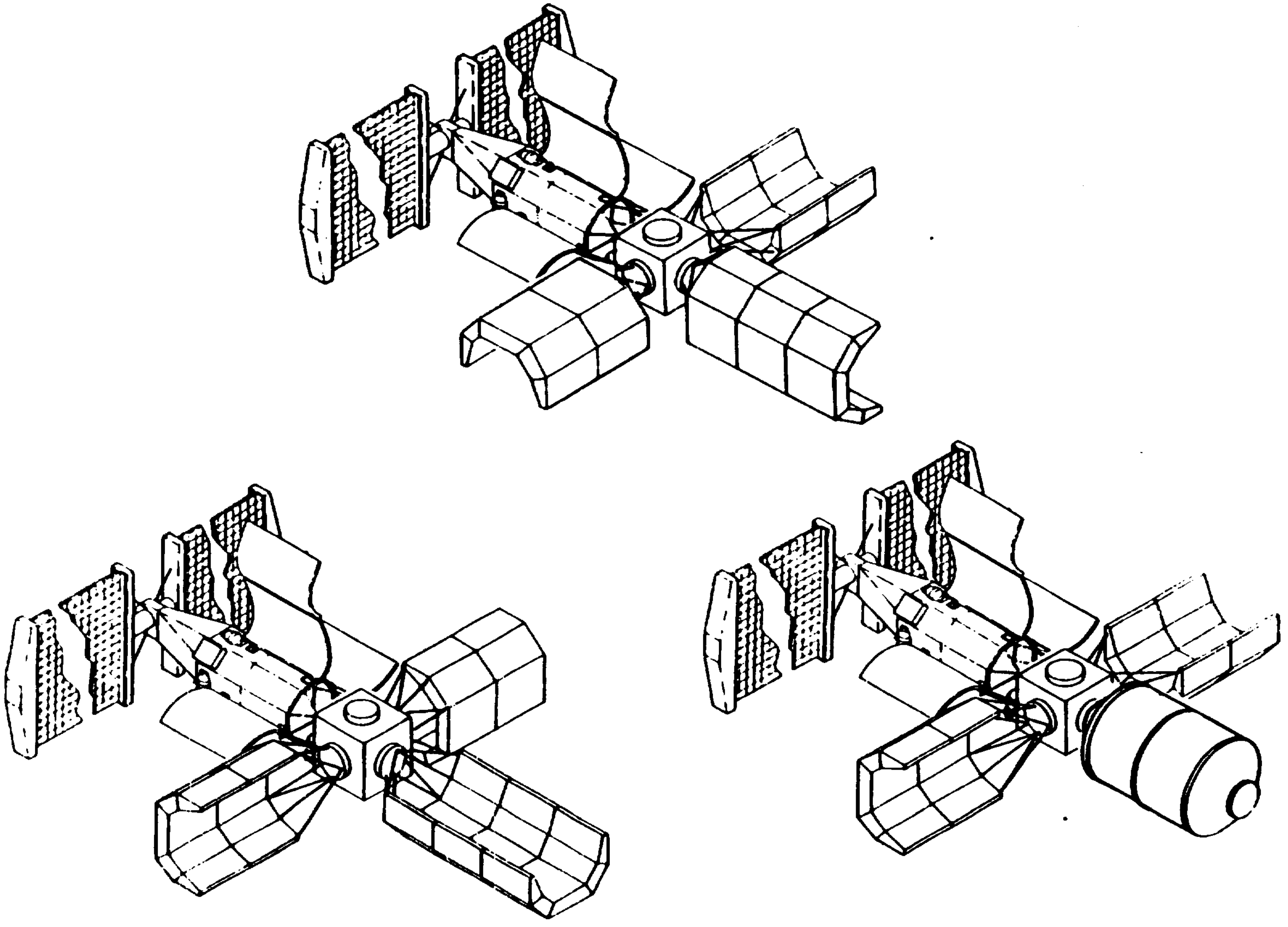
TYPICAL POINTING REFERENCE SERVICES



SPACE SCIENCE PLATFORM

PD715-78C

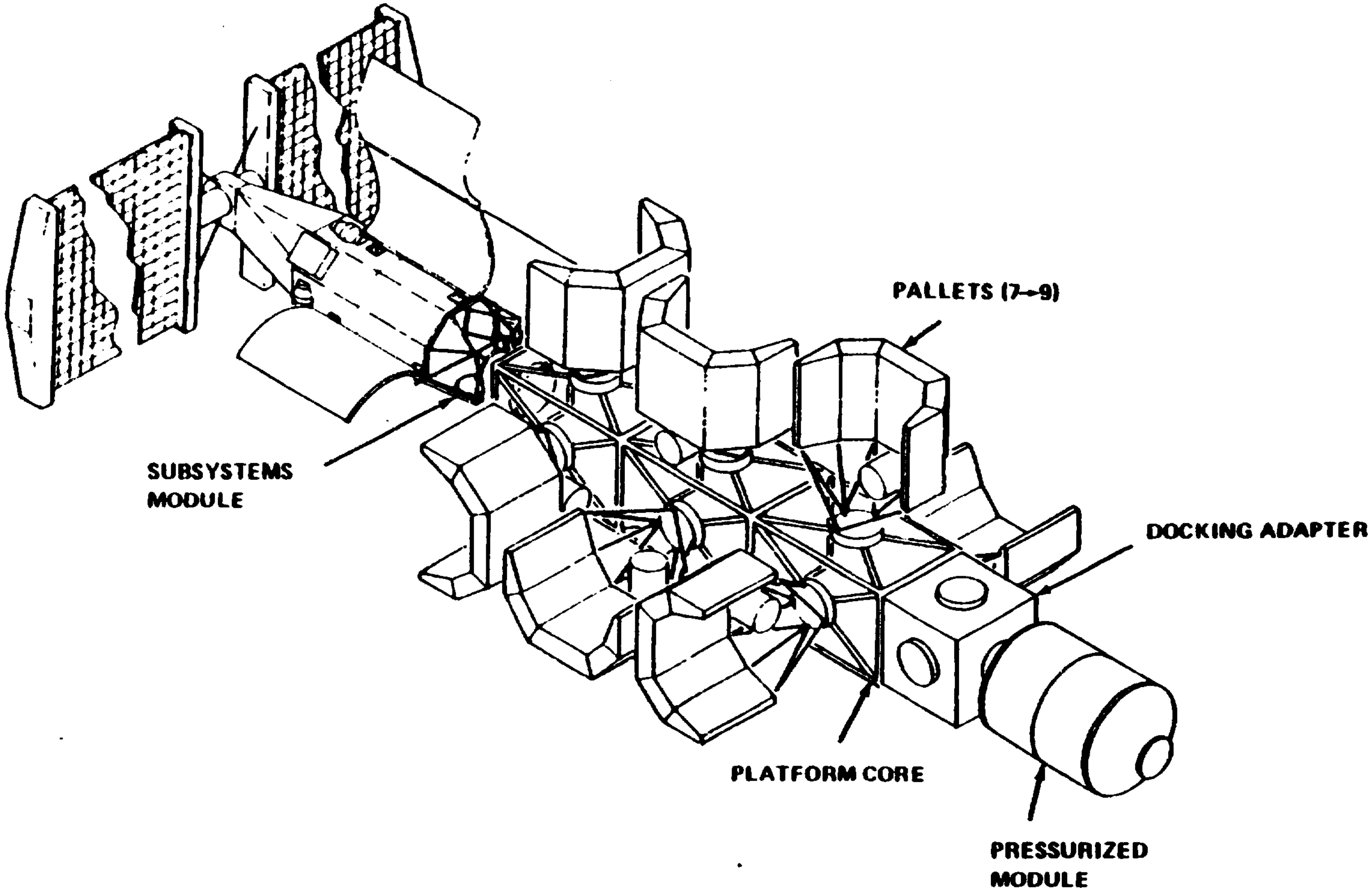
CONCEPT UTILIZING PALLET
TRAIN AND DOCKING ADAPTER



SPACE SCIENCE PLATFORM

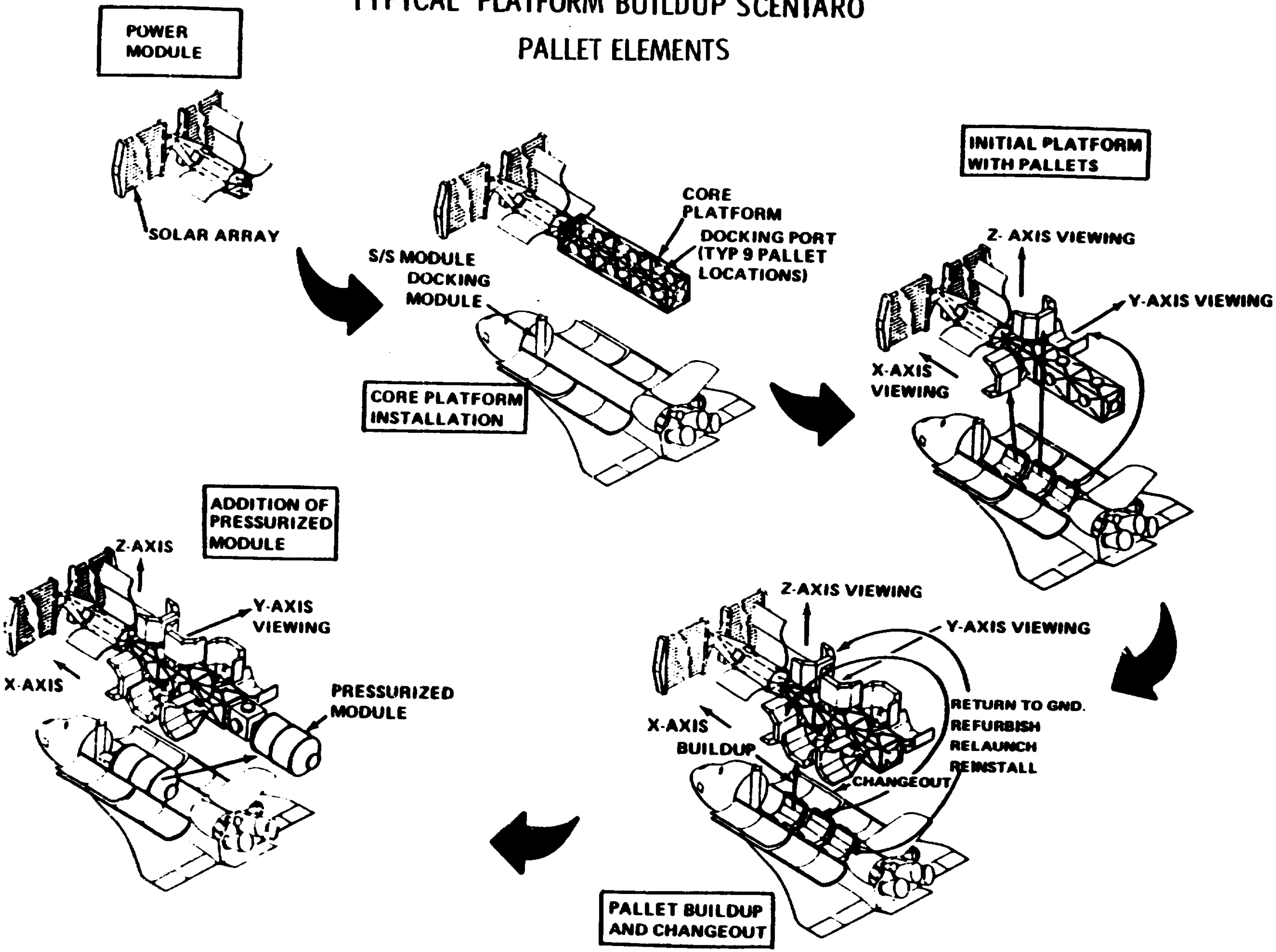
SINGLE PALLET ELEMENTS AND PLATFORM CORE

PD736-78C



SPACE SCIENCE PLATFORM
TYPICAL PLATFORM BUILDUP SCENIARO
PALLET ELEMENTS

PD728-7



SPACE SCIENCE PLATFORM
CONTAMINATION ISSUES

- o CLEANLINESS
  - ATTITUDE CONTROL EFFECTORS
    - o RCS/CMG's/MAGNETIC TORQUERS/G.G. MOMENTUM DUMP
  - MOLECULAR DEPOSITS
    - o SHIELD SOURCE (NO DIRECT MOLECULAR PATH)
    - o MEASURE AMOUNTS - CALIBRATE/CLEAN
  - PARTICLES
    - o SHIELD SENSITIVE DETECTORS
    - o MONITOR - FLAG DANGEROUS LEVELS
- o ELECTROMAGNETIC COMPATIBILITY

FIELDS	CONTROL
MAGNETIC FIELDS	PARTS SELECTION
RELAYS	MAGNETIC MATERIALS CONTROL
TRANSFORMERS	CONTROLLED WIRE ROUTING
MAGNETIC MATERIAL	SINGLE POINT GROUND
BATTERIES	SHIELDING
ELECTRIC FIELDS	GROUNDING, BONDING, SHIELDING
TRANSMITTERS	SYNCHRONIZATION
POWER PROCESSORS	WIRING CONTROL
SOLAR ARRAY	BLACK BOX EMISSION CONTROL
WIRING	FILTERING
PUMPS	FREQUENCY CONTROL

SPACE SCIENCE PLATFORM
DISCUSSION TOPICS

APPROACHES TO RESOURCE PROVISIONS

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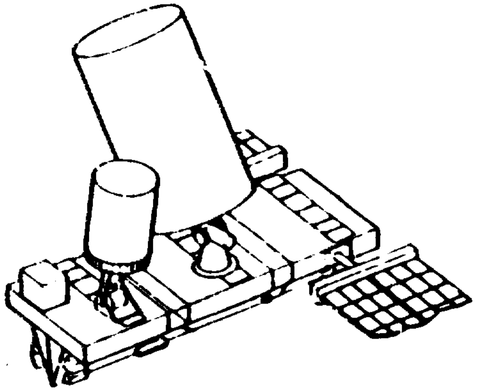
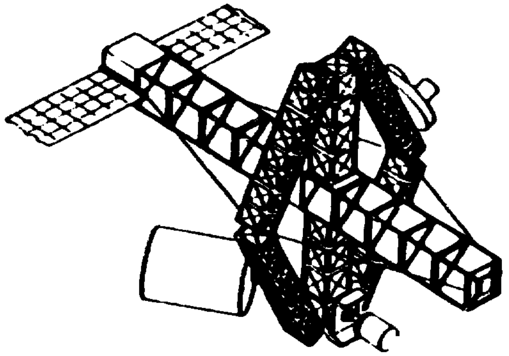
SPACE SCIENCE PLATFORM

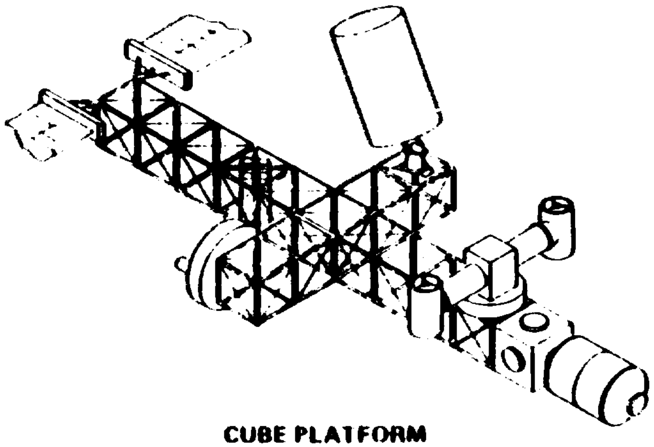
REPRESENTATIVE PLATFORMS UTILIZING GROUND BUILT STRUCTURE



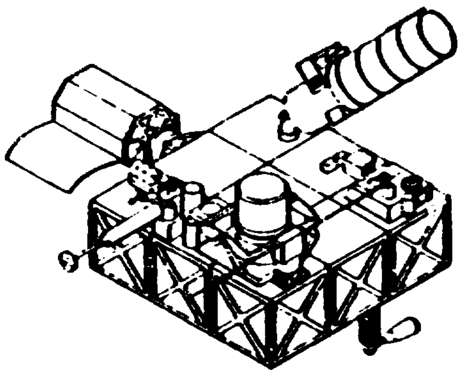
"T" PLATFORM



CUBE WITH DEPLOYABLE STRUCTURE



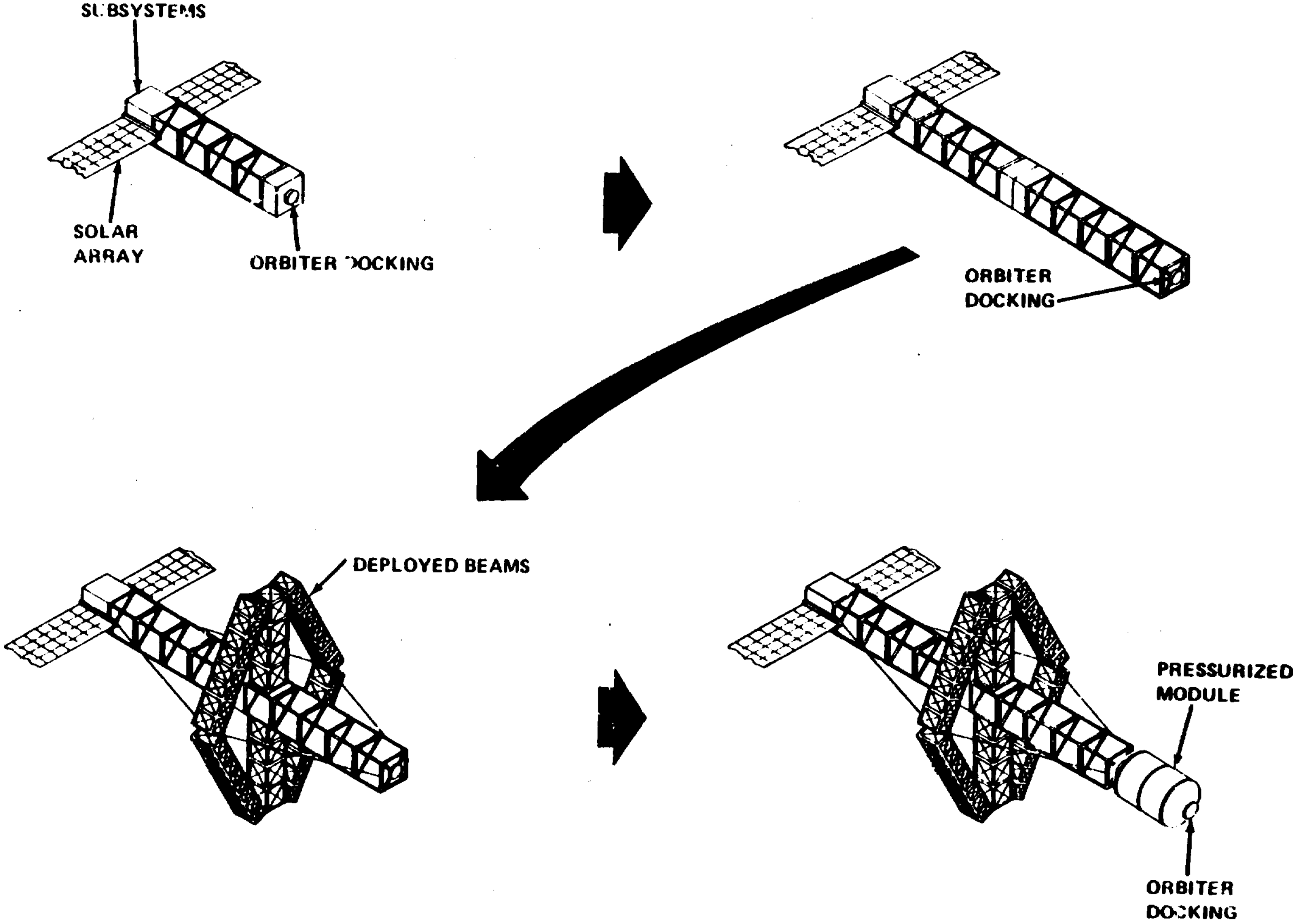
CUBE PLATFORM



SQUARE PLATFORM

SPACE SCIENCE PLATFORM

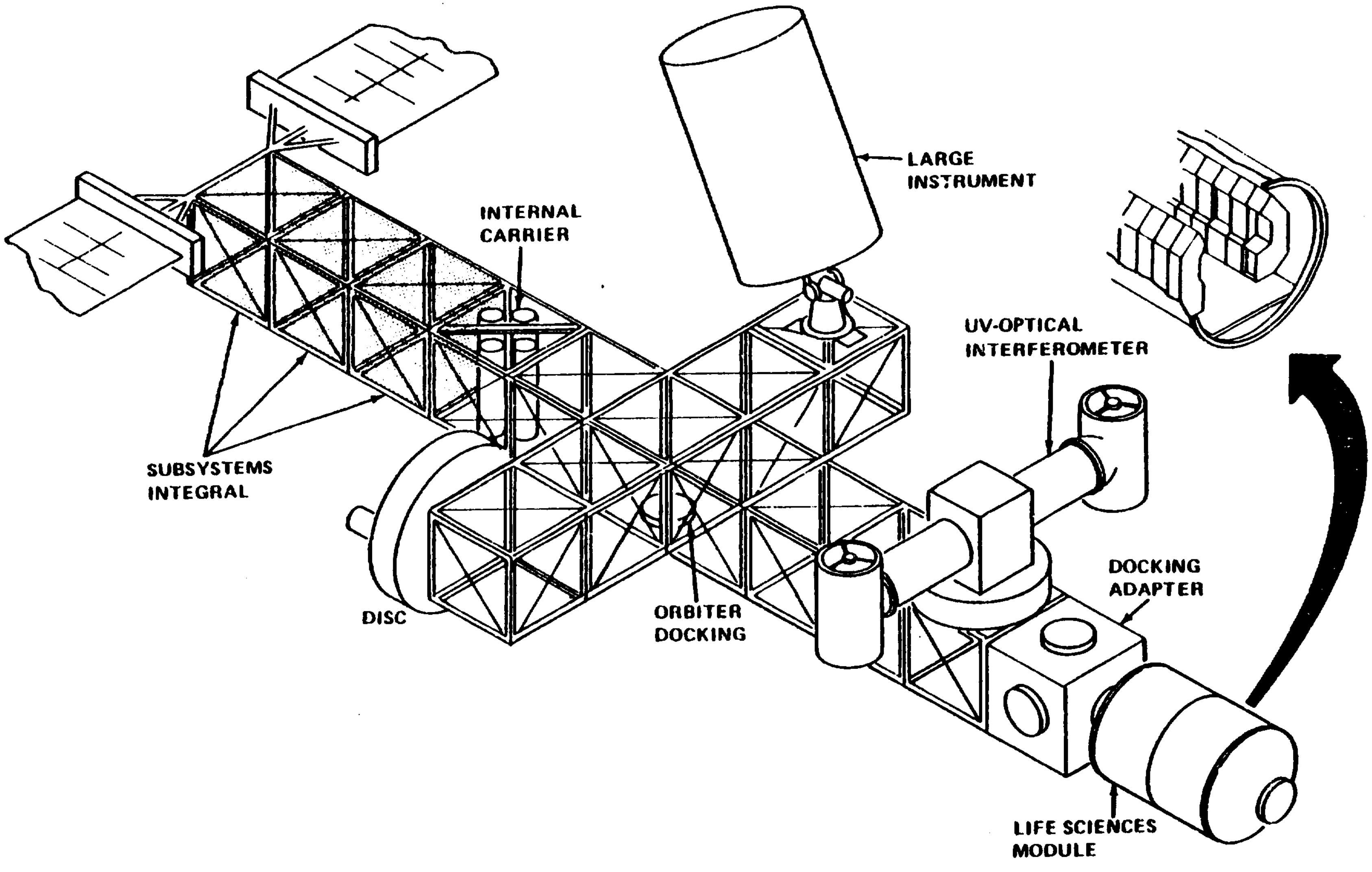
PLATFORM BUILDUP WITH CUBE ELEMENTS AND DEPLOYABLE STRUCTURE



SPACE SCIENCE PLATFORM

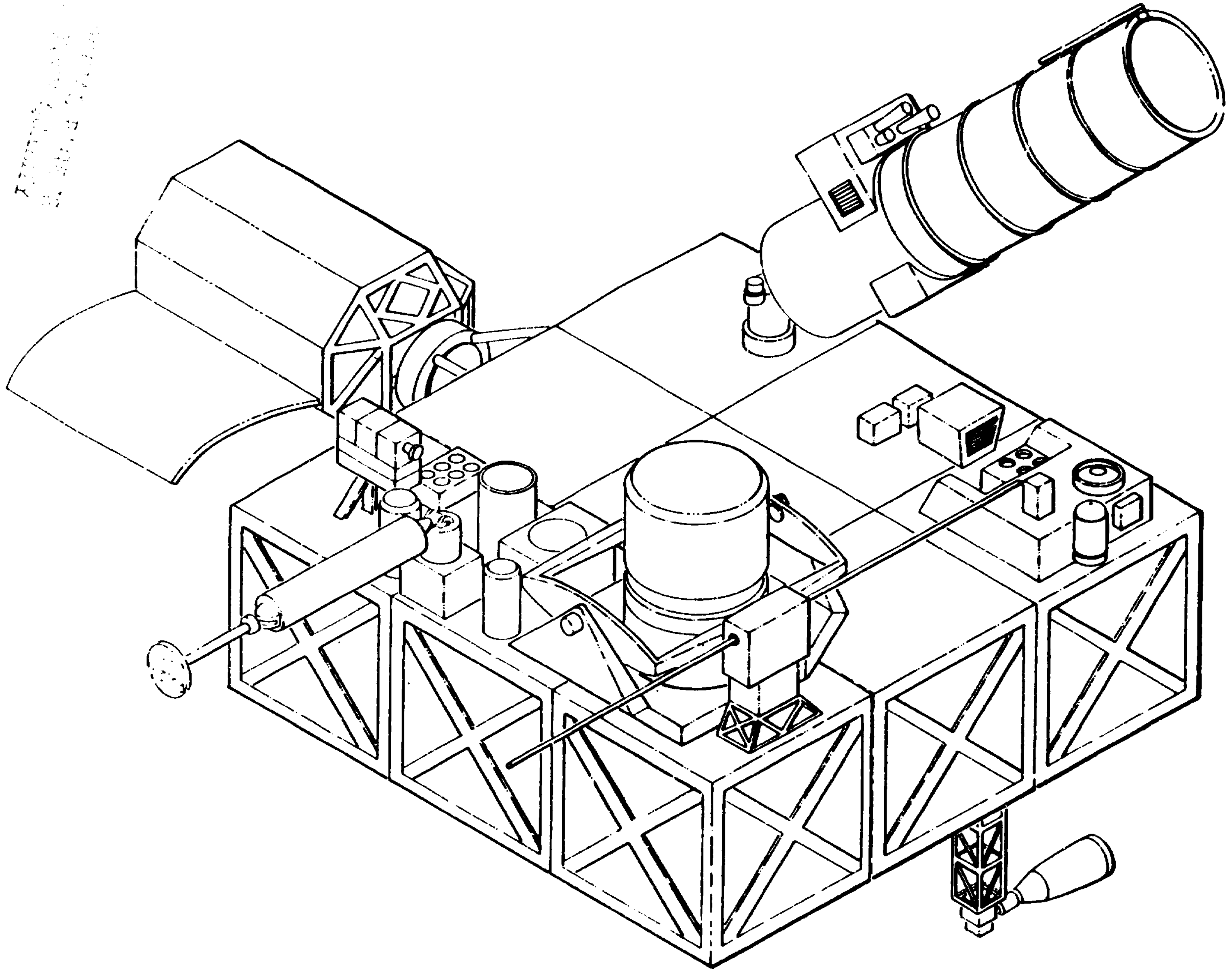
PD763-78C

CUBE PLATFORM WITH REPRESENTATIVE INSTRUMENT CARRIERS



REPRESENTATIVE PLATFORM UTILIZING GROUND BUILT STRUCTURE

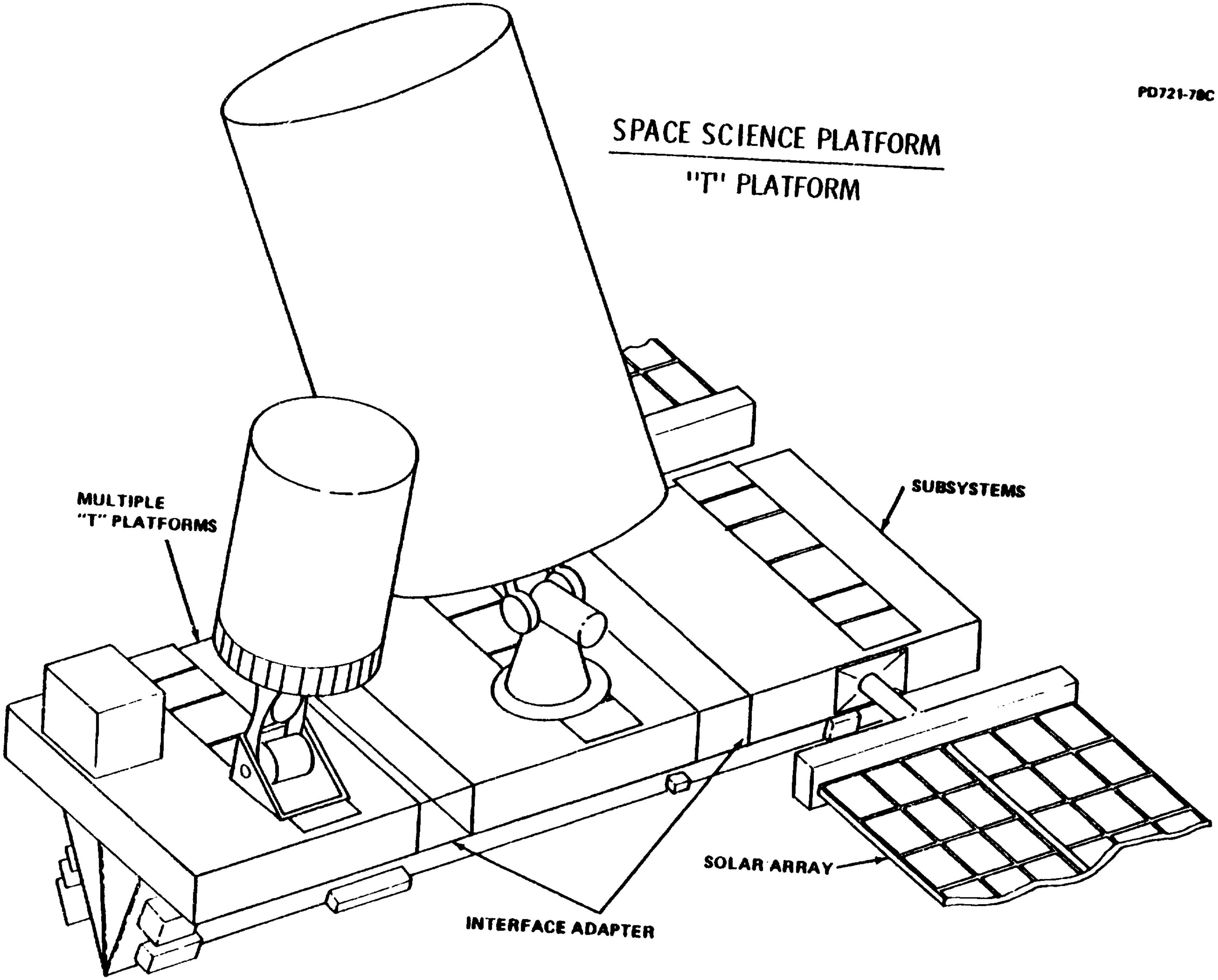
PD612-76C



PD721-78C

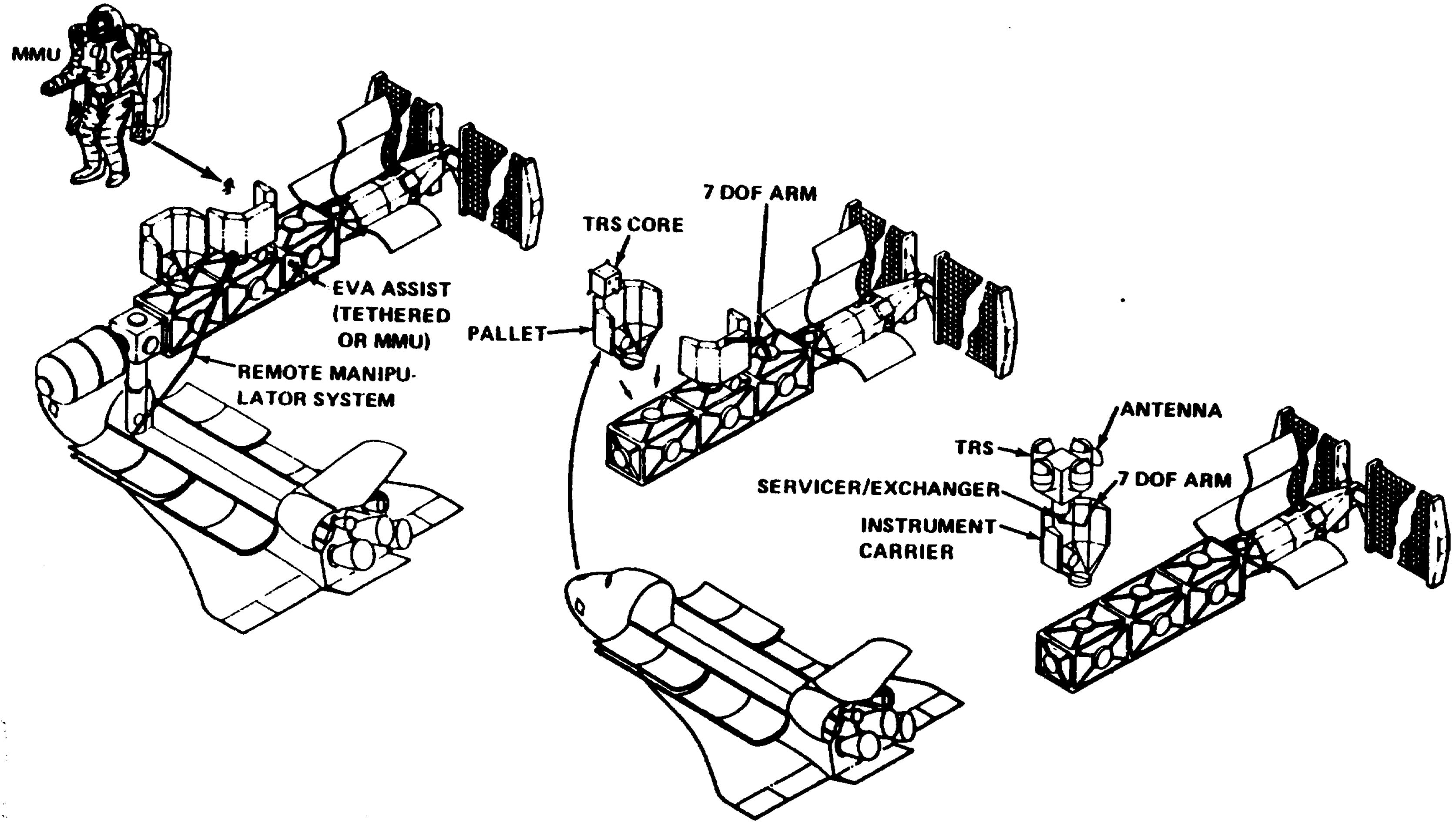
SPACE SCIENCE PLATFORM

"T" PLATFORM



SPACE SCIENCE PLATFORM
BUILDUP OPERATIONS OPTIONS/CONCEPTS

PD750-78C

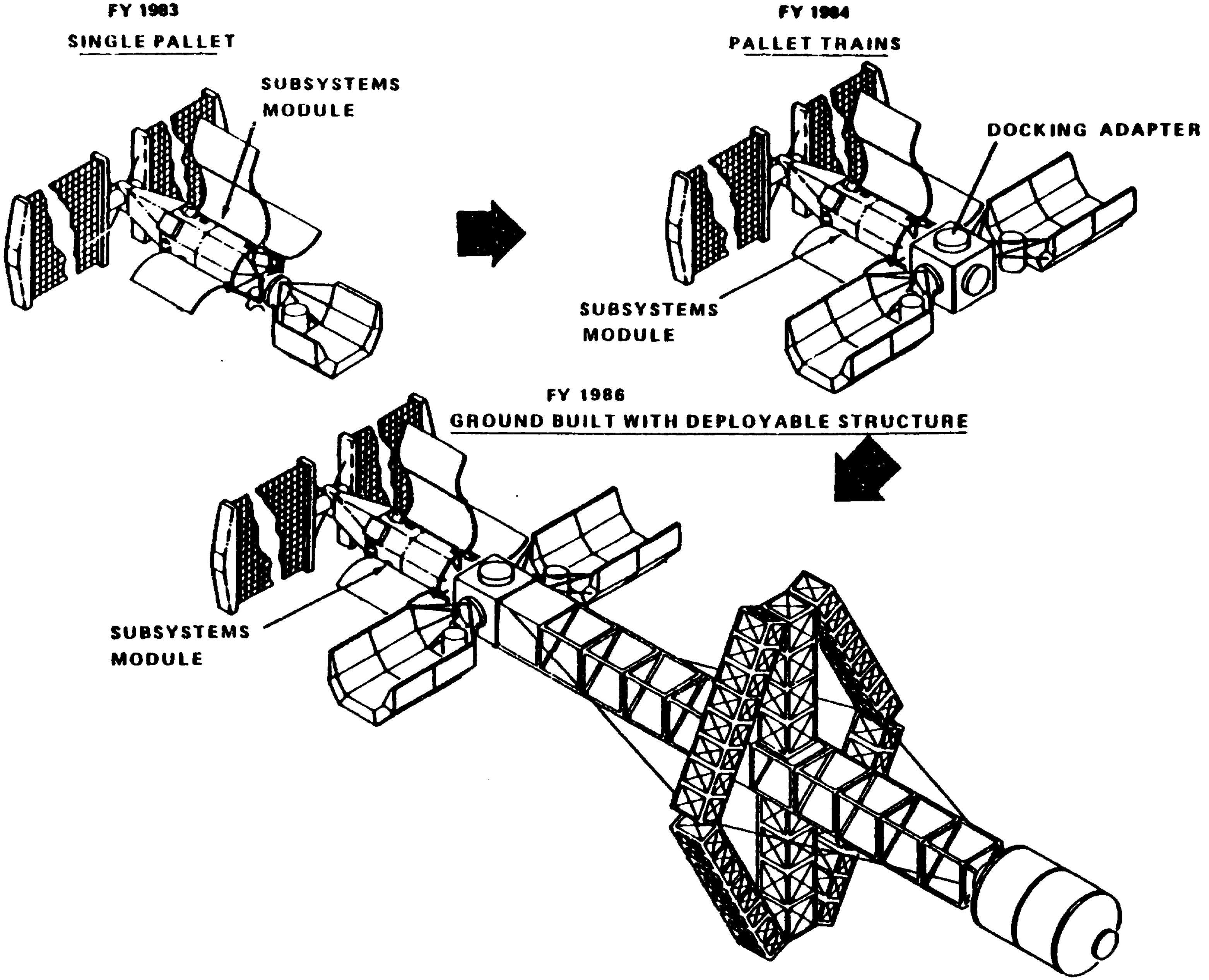


ORBITER DOCKED

ORBITER TENDED (NEAR VICINITY)

REMOTE AUTOMATED

SPACE SCIENCE PLATFORM
TYPICAL EVOLUTION SCENARIO



SPACE SCIENCE PLATFORM
DISCUSSION TOPICS

APPROACHES TO
RESOURCE PROVISIONS

CONCEPT BUILDING ELEMENTS

CONCEPT APPROACHES

- PALLETS/PRESSURE MODULE
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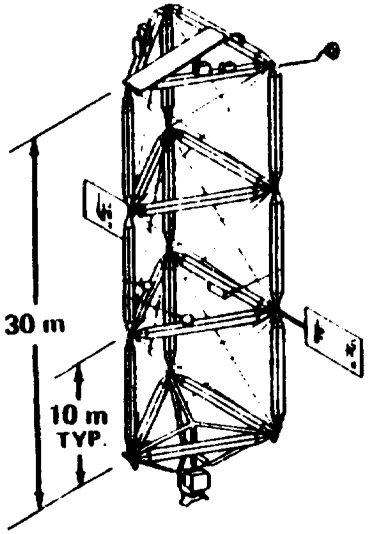
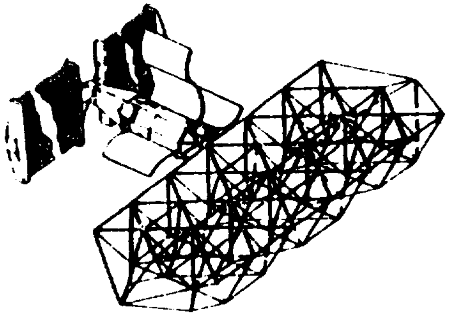
SPACE SCIENCE PLATFORM

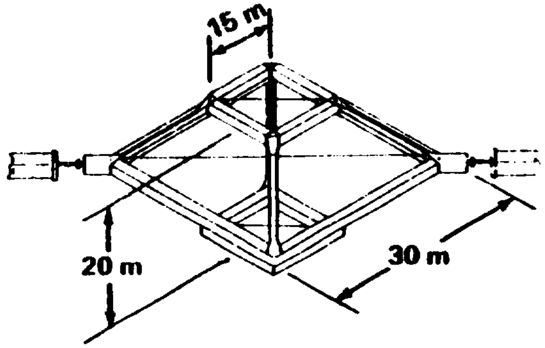
REPRESENTATIVE PLATFORMS UTILIZING SPACE-BUILT STRUCTURES



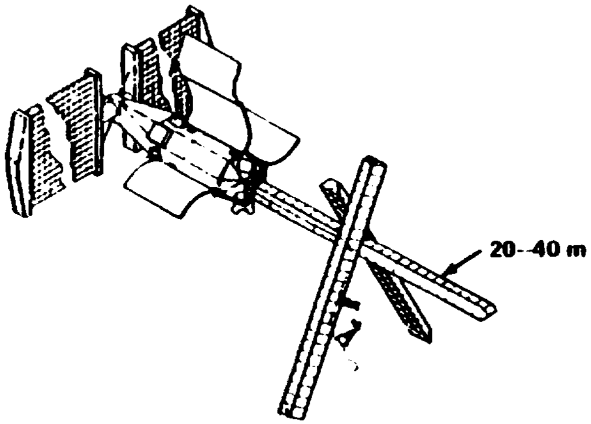
LARGE TRIANGULAR STRUCTURE



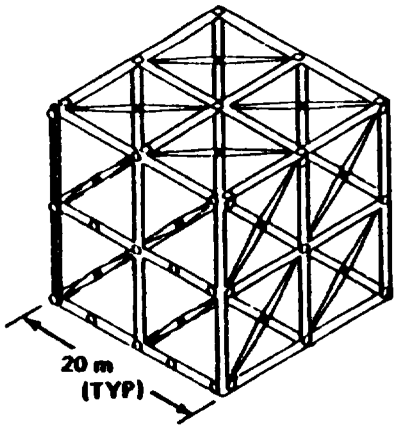
TETRAHEDRON



DIAMOND-SHAPED STRUCTURE



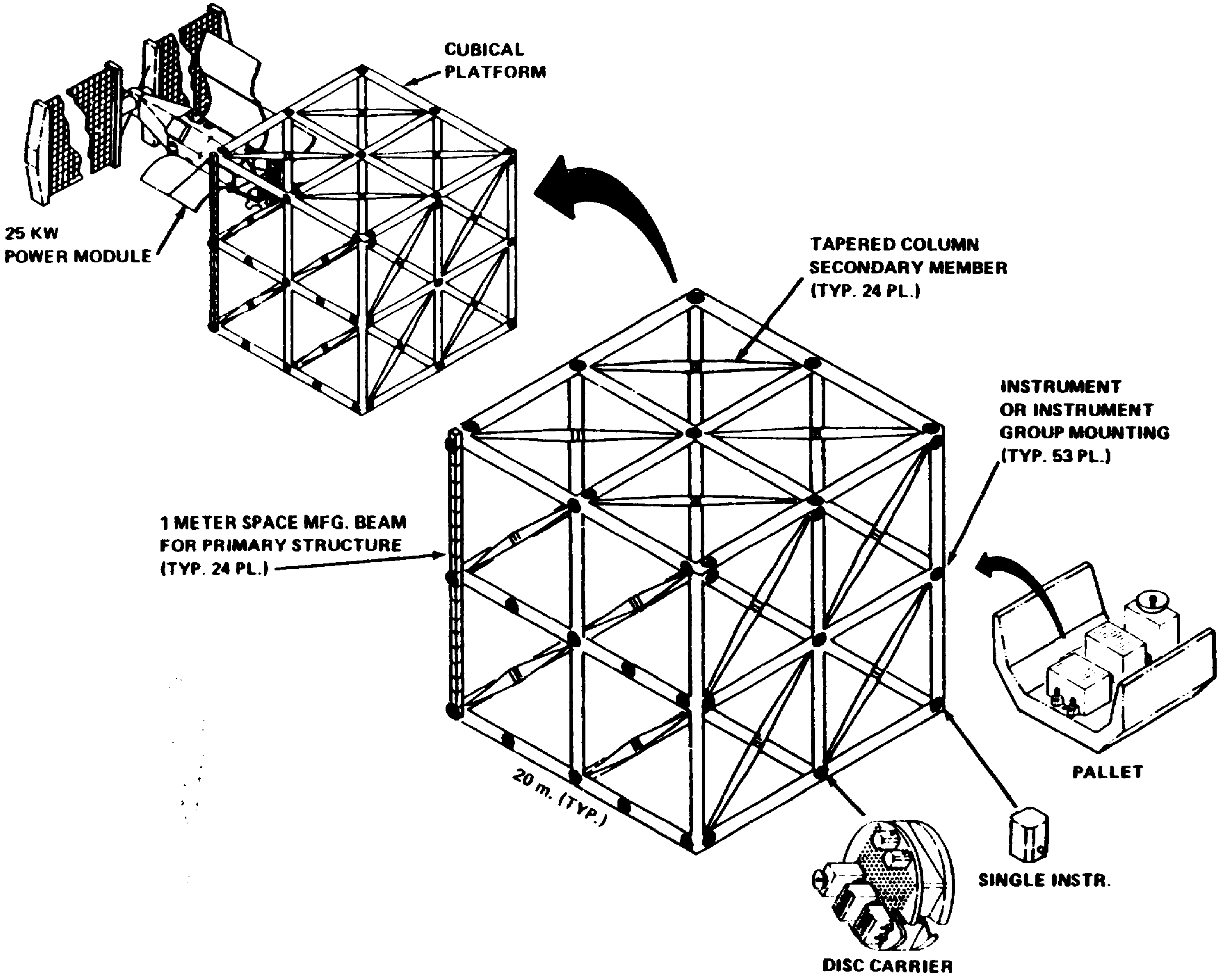
OPEN-BEAM STRUCTURE



LARGE CUBICAL PLATFORM CONCEPT

LARGE CUBICAL PLATFORM CONCEPT

PD620-78C



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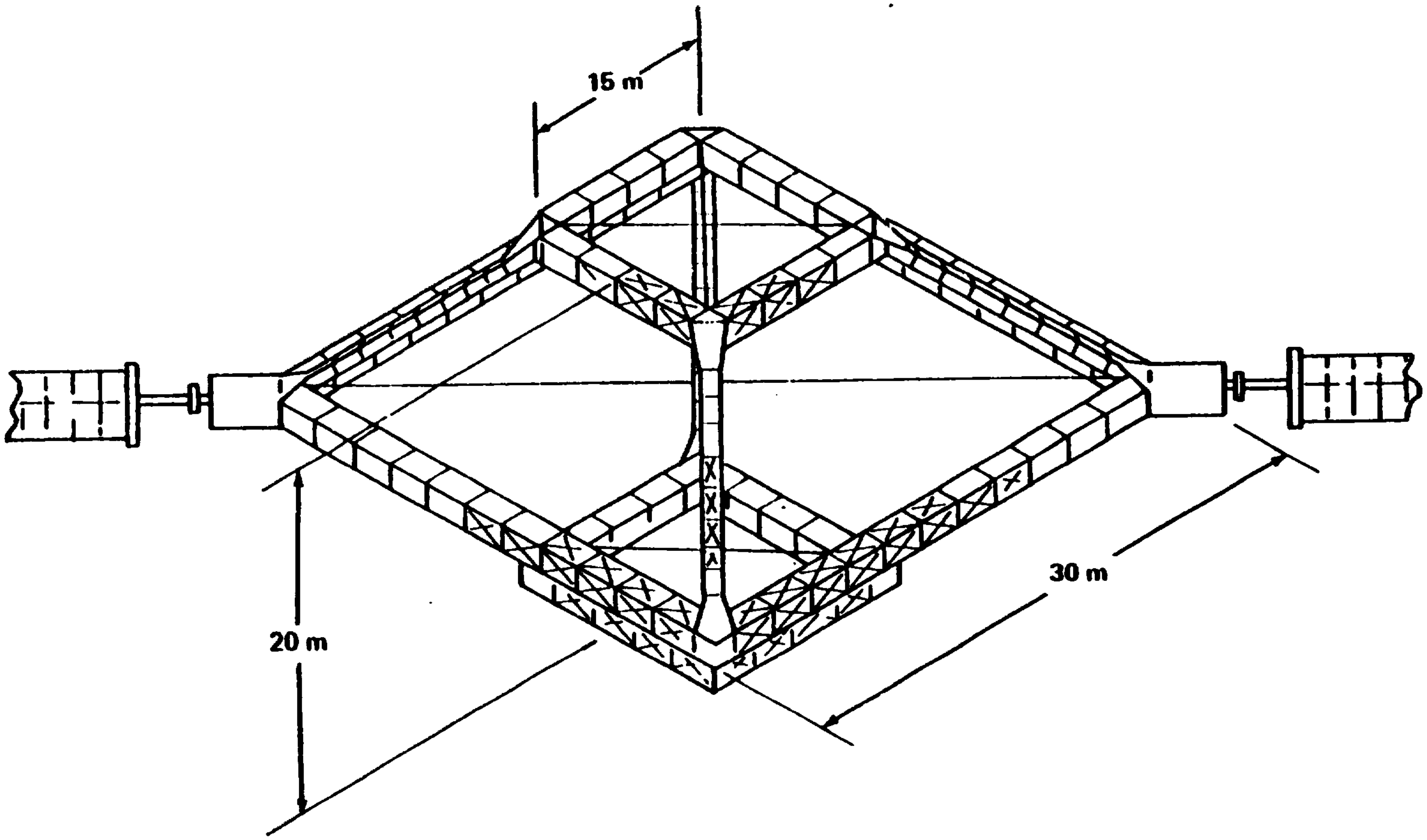
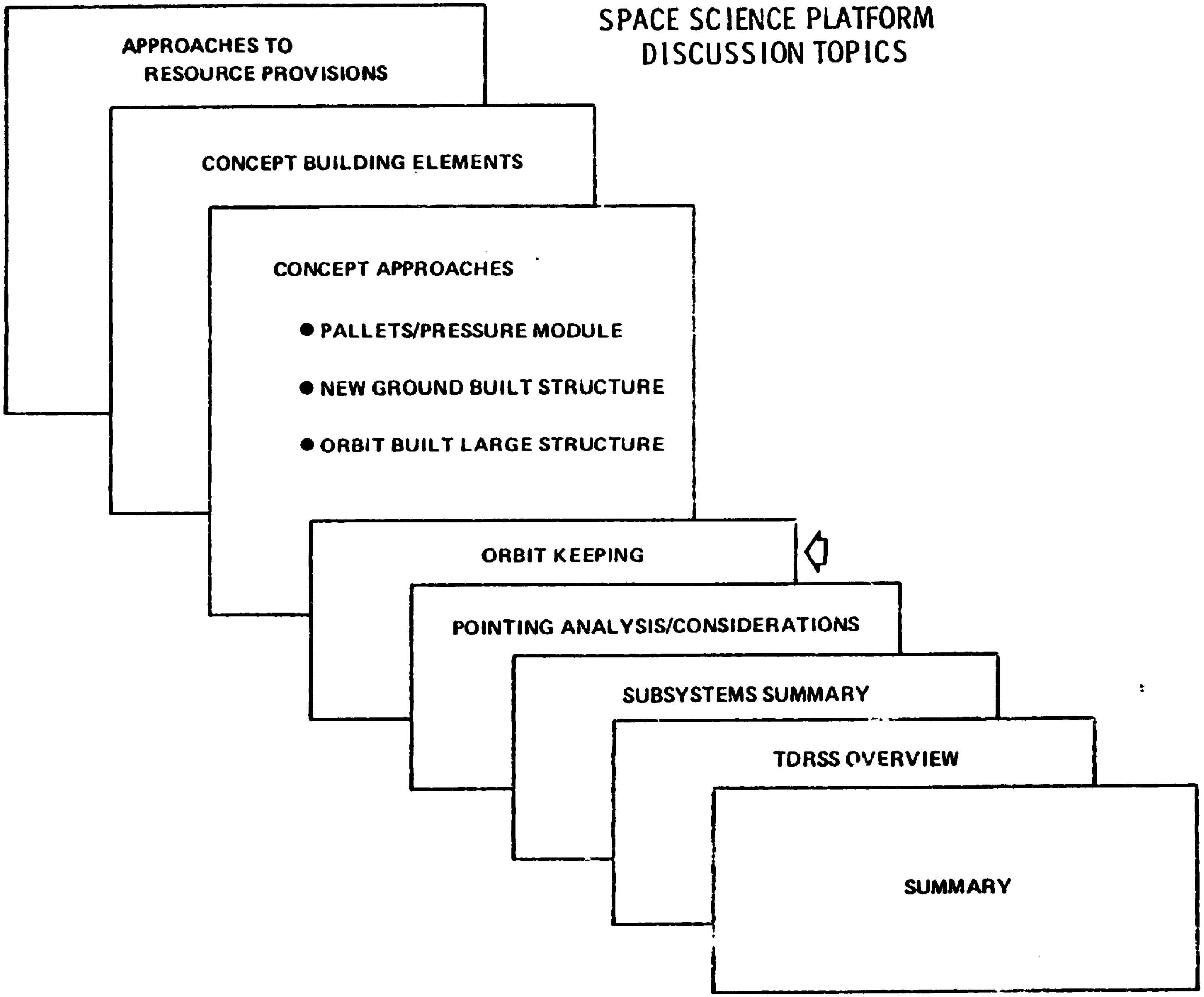
SPACE SCIENCE PLATFORM

DIAMOND-SHAPED STRUCTURE



2236-78

SPACE SCIENCE PLATFORM
DISCUSSION TOPICS



APPROACHES TO
RESOURCE PROVISIONS

CONCEPT BUILDING ELEMENTS

CONCEPT APPROACHES

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SPACE SCIENCE PLATFORM
ORBIT KEEPING

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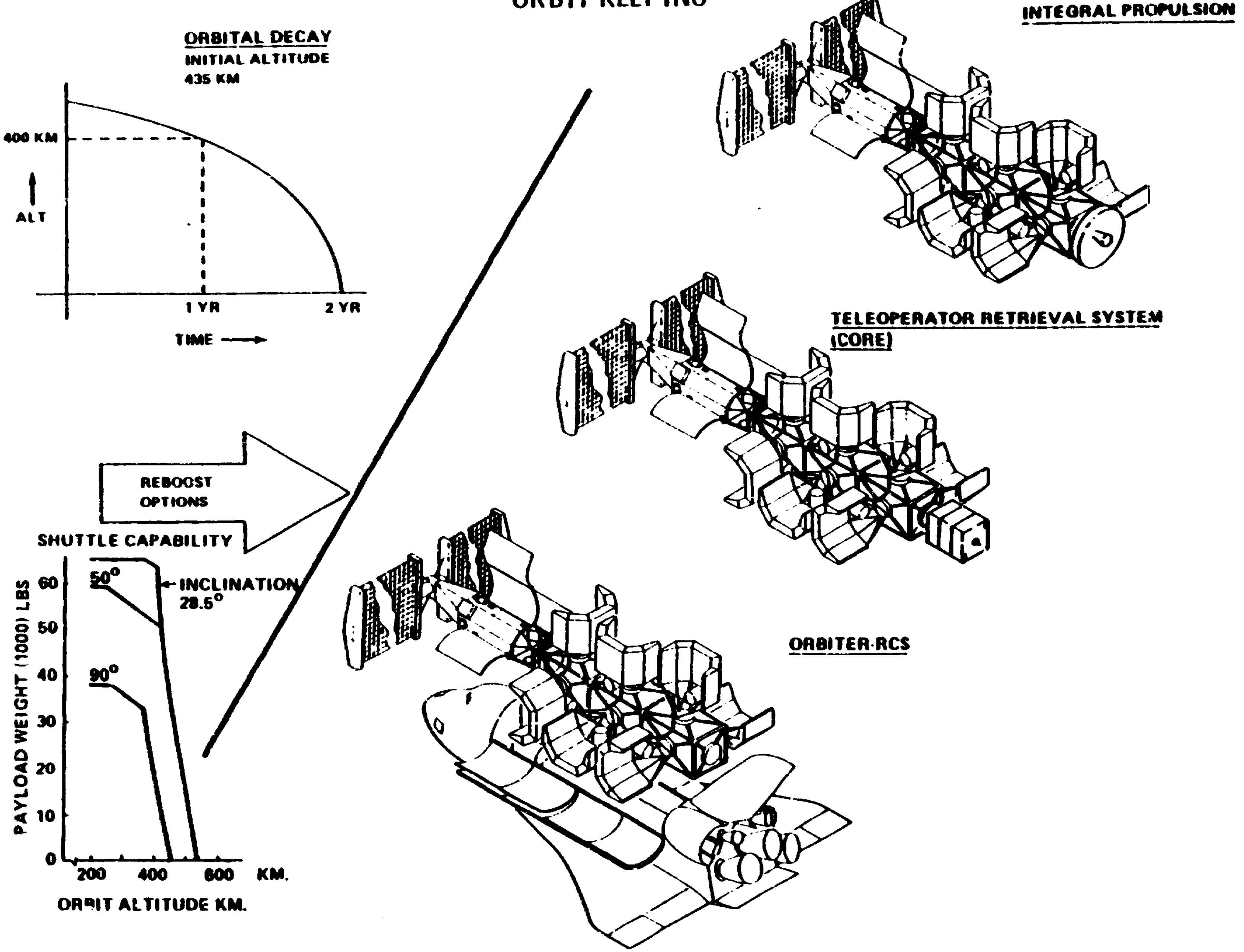

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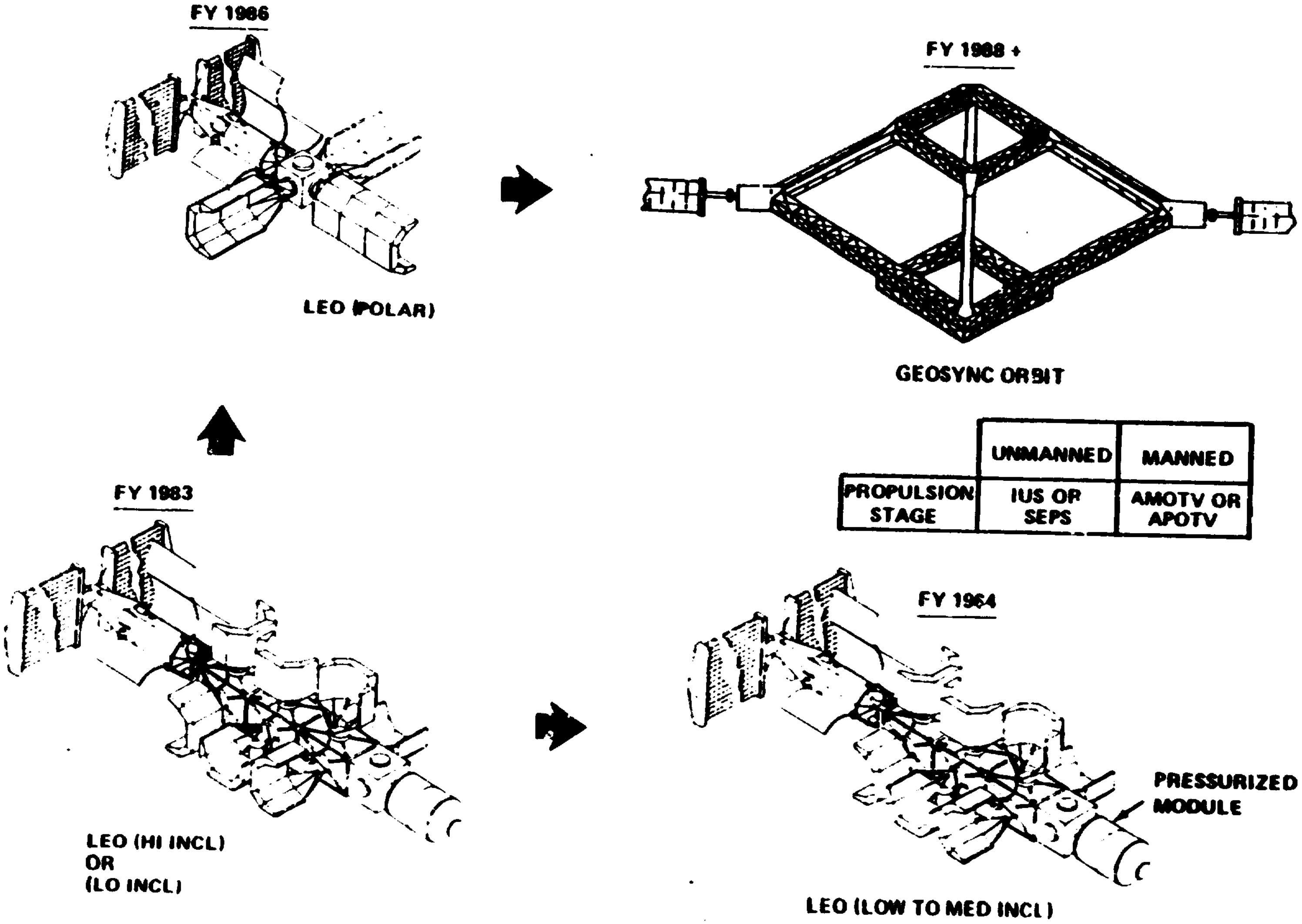
SPACE SCIENCE PLATFORM
ORBIT PLACEMENT SCENARIO



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SPACE SCIENCE PLATFORM
DISCUSSION TOPICS

APPROACHES TO
RESOURCE PROVISIONS

CONCEPT BUILDING ELEMENTS

CONCEPT APPROACHES

- PALLETS/PRESSURE MODULE
- NEW GROUND BUILT STRUCTURE
- ORBIT BUILT LARGE STRUCTURE

ORBIT KEEPING

POINTING ANALYSIS/CONSIDERATIONS ⇦

SUBSYSTEMS SUMMARY

TDRSS OVERVIEW

SUMMARY

ORIENTATION/POINTING

- VIEWING DIRECTIONS
  - SOLAR
  - EARTH
    - NADIR
    - LIMB
  - CELESTIAL
- CANDIDATE POINTING SYSTEMS

C-3

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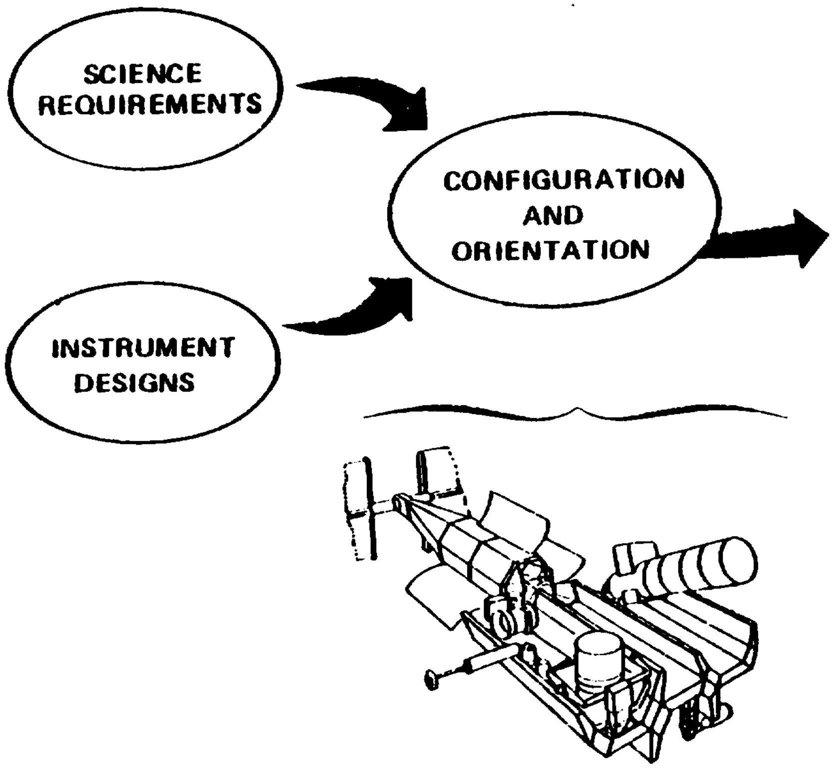
SPACE SCIENCE PLATFORM
CONFIGURATION AND ORIENTATION SERVICES

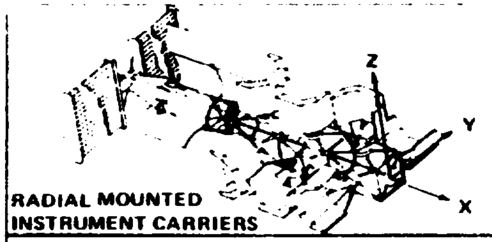


SCIENCE REQUIREMENTS

INSTRUMENT DESIGNS

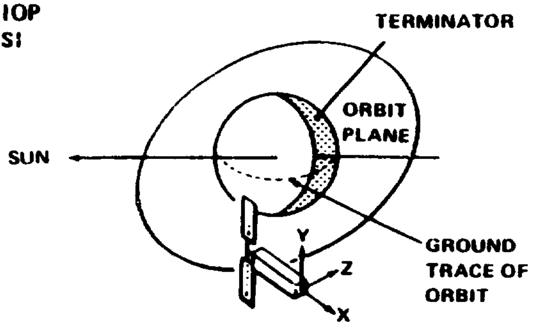
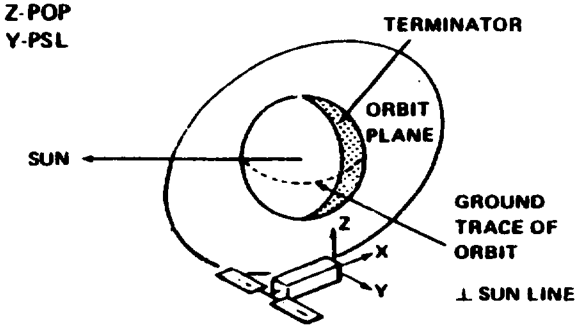
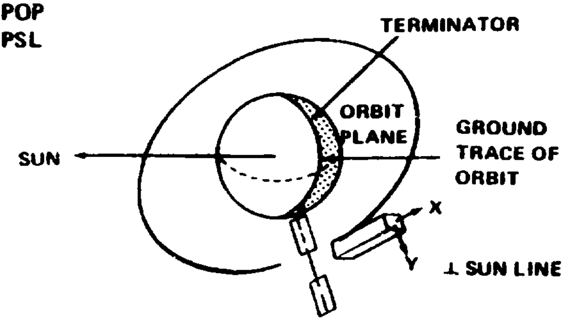
CONFIGURATION AND ORIENTATION

- ORIENTATION
- STABILIZATION
- ACCURACY
- CELESTIAL/EARTH VIEWING
- TARGET ACQUISITION
- POINTING DURATION
- INSTRUMENT ALIGNMENT



SPACE SCIENCE PLATFORM

VIEWING CAPABILITIES

ORIENTATION	AXES	SOLAR	CELESTIAL	EARTH
X-IOP Z-SI  	± X	NONE	80-90% OF CS IN 30 DAYS	LIMB AND NADIR SWEEP~2/3 REV
	± Y	NONE	80-90% OF CS IN 30 DAYS	CONTINUOUS LIMB SWEEP-NADIR AT HIGH BETAS
	± Z	CONTIUOUS EXCEPT FOR EARTH BLOCKAGE	2-46% OF CS IN 30 DAYS	CONTINUOUS LIMB SWEEP-NADIR AT LOW BETAS
Z-POP Y-PSL  	± X	CONSTRAINED TO LOW β 100% EXCEPT OCCULTATION	80-90% OF CS IN 30 DAYS	LIMB AND NADIR SWEEP~2/3 REV
	± Y	NONE	80-90% OF CS IN 30 DAYS	LIMB AND NADIR SWEEP 2/3 REV
	± Z	CONSTRAINED TO HIGH β 100%	CONTINUOUS VIEWING AREAS 95% COVERAGE IN 30 DAYS	CONTINUOUS LIMB SWEEP
X-POP Y-PSL  	± X	CONSTRAINED TO HIGH β 100%	95% OF CS IN 30 DAYS CONTINUOUS VIEWING AREAS	CONTINUOUS LIMB SWEEP~2/3 REV
	± Y	NONE	80-90% OF CS IN 30 DAYS	LIMB AND NADIR SWEEP >2/3 REV
	± Z	CONSTRAINED TO LOW β 100% EXCEPT EARTH OCCULTATION	80-90% OF CS IN 30 DAYS	LIMB AND NADIR SWEEP >2/3 REV

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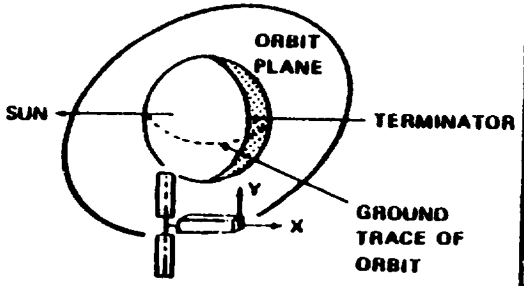
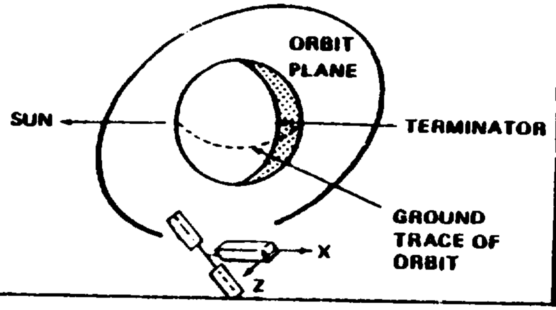
SPACE SCIENCE PLATFORM VIEWING CAPABILITIES (CONCLUDED)

ORIENTATION	AXES	SOLAR	CELESTIAL	EARTH
X-VV Y-PSL 	± X	SWEEP AT LOW β $>2/3$ REV	360° SWEEP/ORBIT 100% COVERAGE IN 18 DAYS	CONTINUOUS LIMB SWEEP; 100%
	± Y	NONE	360° SWEEP/ORBIT REV. 80-90% OF CS/ORBIT REV. LOW BETA CONTINUOUS VIEWING	HIGH BETA CONTINUOUS LIMB OR NADIR SWEEP LOW BETA CONTINUOUS LIMB SWEEP
	± Z	HIGH BETA CONTINUOUS; LOW BETA-2/3 REV- EARTH OCCULTATION	SAME AS Y AT LOW β 80-90% COVERAGE IN 30 DAYS AT HIGH β CONTINUOUS VIEWING	HIGH BETA-CONTINUOUS LIMB SWEEP LOW BETA-CONTINUOUS LIMB OR NADIR VIEWING
X-VV Z-LV 	± X	SOLAR SWEEP CONSTRAINED TO LOW β ~2/3 REV	360° SWEEP/REV; FULL COVERAGE IN 18 DAYS	CONTINUOUS LIMB SWEEP
	± Y	CONSTRAINED TO HIGH β 100%	95% COVERAGE OF CS IN 30 DAYS CONTINUOUS VIEWING AREAS	CONTINUOUS LIMB SWEEP
	± Z	CONSTRAINED TO LOW β ~2/3 REV	360° SWEEP/REV; FULL COVERAGE IN 18 DAYS	CONTINUOUS NADIR

SPACE SCIENCE PLATFORM
CANDIDATE POINTING SYSTEMS

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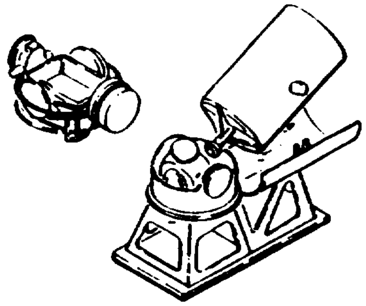
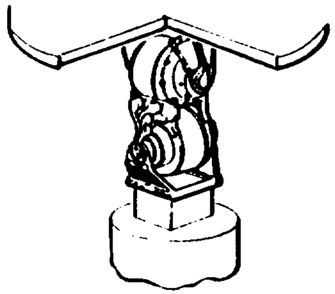
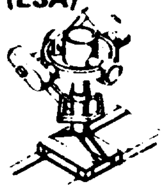
CAPABILITY	MAST 	ASPS GIMBAL SYSTEM (AGS) 	INSTRUMENT POINTING SYSTEM IPS (ESA) 
STABILITY (ARC-SEC-1σ) MAN MOTION INCLUDED	60	0.2/600 KG 0.1/7200 KG	P & Y 1 ROLL 4
PAYLOAD SERVICE MINIMUM	24 AWG 30 WIRES 8 TSP AWG 34 WIRES 50 WATTS	16 AWG 24 WIRES 22 AWG 50 WIRES 26/22 AWG 53 WIRES 17 TSP 2000 WATTS	12 TSP 3 HR LINK 3 RAU 800 WATTS
PAYLOAD ACCOMODATION	END MOUNT 1 M X.3M DIA	END PLATE (1M)	END MOUNTING RING
VIEW ANGLE	± 80° ± 40° NO ROLL	± 100° ± 60° NO ROLL	± 60° CONE ± 180° ROLL
PAYLOAD WEIGHT CAPABILITY	40 KG	7200 KG	2000 KG
COMMENTS	PLANNED FOR FIRST SPACELAB MISSION	PLANNED FOR FLIGHT IN 1982	PLANNED FOR SECOND SPACELAB MISSION

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SPACE SCIENCE PLATFORM
DISCUSSION TOPICS

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CONCEPT APPROACHES

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ORBIT KEEPING

POINTING ANALYSIS/CONSIDERATIONS

SUBSYSTEMS SUMMARY ⇦

TDRSS OVERVIEW

SUMMARY

PD737-78C

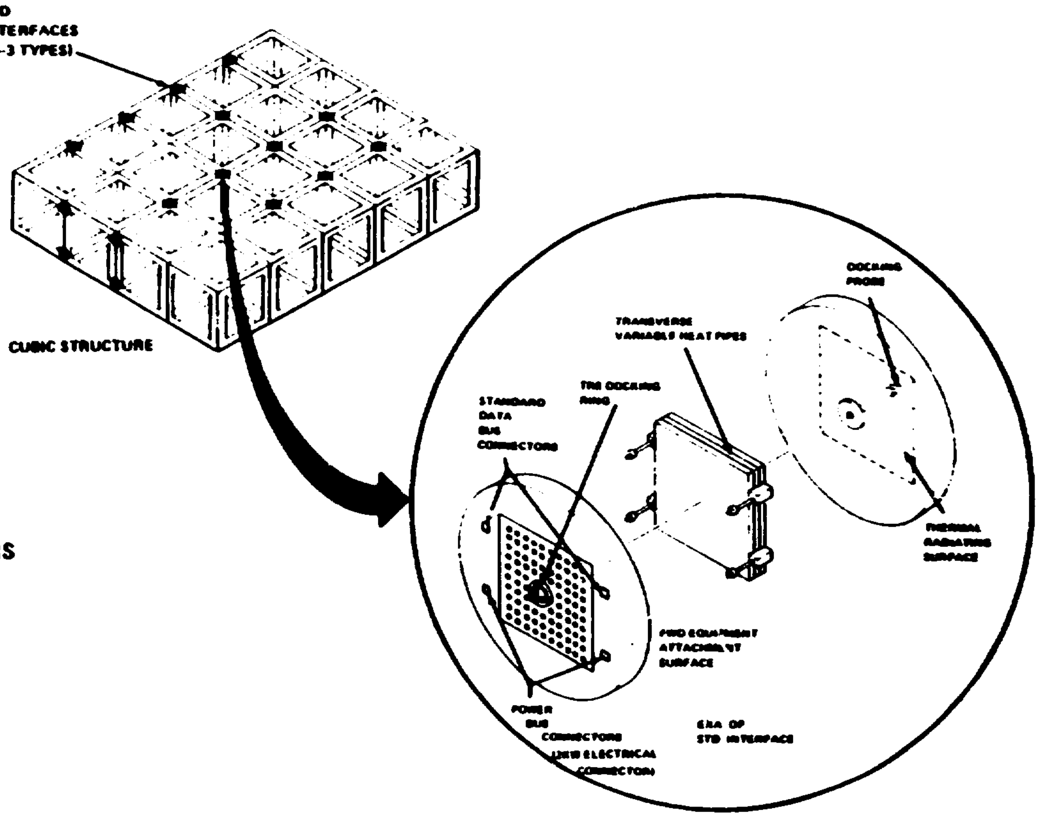
SPACE SCIENCE PLATFORM
SUBSYSTEMS SUPPORT

POWER
- 2 TO 5 kW PER GROUP
- PARALLEL GROUPS AS REQUIRED
- DC AND/OR AC

COMMUNICATIONS
- 6 TO 50 MBS
- S-BAND AND Ku BAND
- 4.2 MHz ANALOG
- STDN, TDRSS – UP AND DOWN LINKS

DATA MANAGEMENT
- CENTRAL CONTROL
- DECENTRALIZED EXPERIMENT PROCESSORS
- ONBOARD DATA STORAGE/PROCESSING
- SPACELAB (IGLOO), MMS,
- ADVANCED SYSTEMS

HEAT REJECTION
- CENTRAL THERMAL MANAGEMENT
- DECENTRALIZED EXPERIMENT CONTROL
- FINS, PAINT, HEAT PIPES, RADIATORS, FLUID LOOPS
- MULTIPLE TEMPERATURE CONTROL RANGES



SPACE SCIENCE PLATFORM
DISCUSSION TOPICS

APPROACHES TO
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CONCEPT BUILDING ELEMENTS

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ORBIT KEEPING

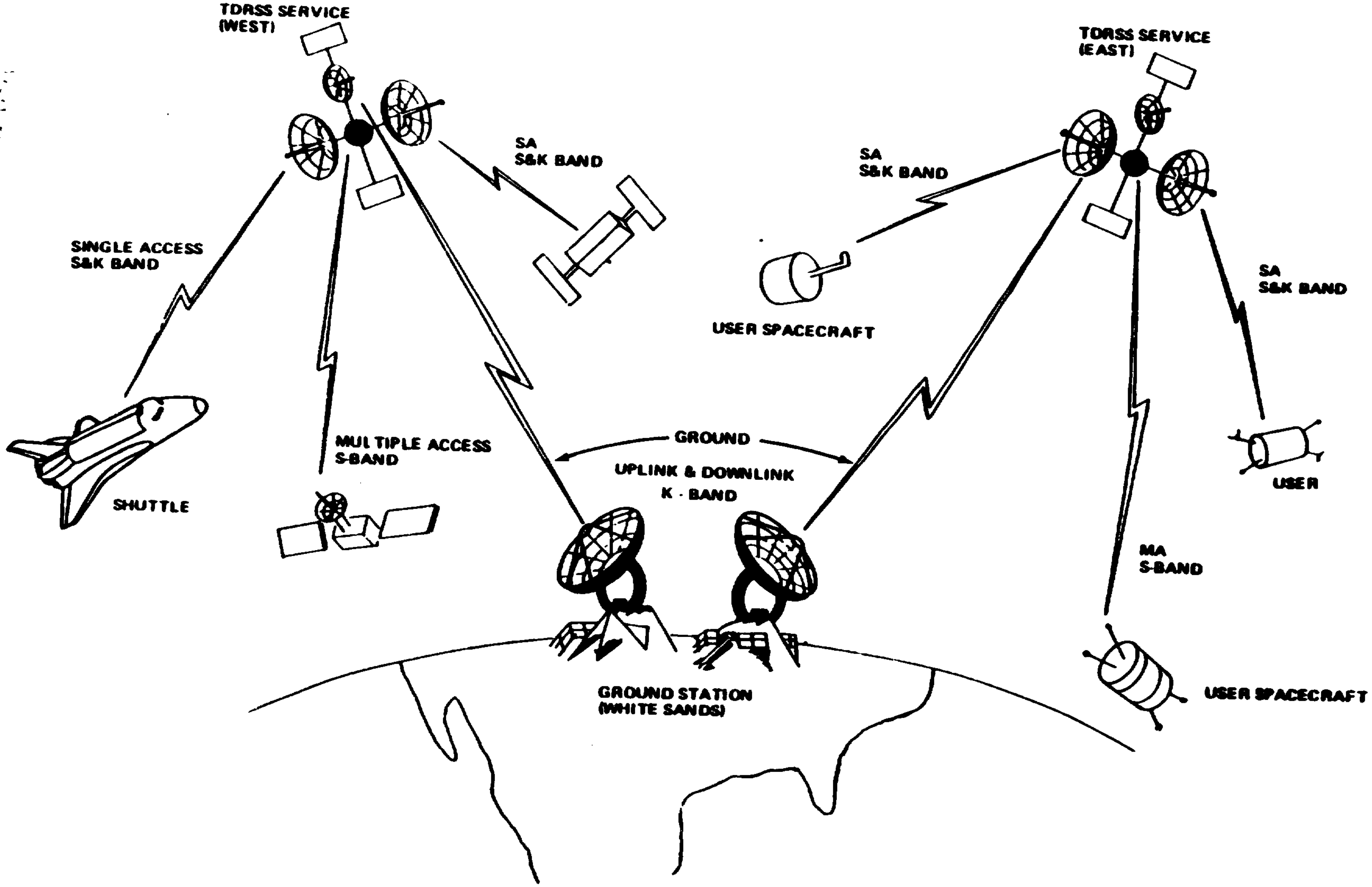
POINTING ANALYSIS/CONSIDERATIONS

SUBSYSTEMS SUMMARY

TDRSS OVERVIEW

SUMMARY

TRACKING AND DATA RELAY SATELLITE SYSTEM CONCEPT



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SUMMARY OF TDRSS CAPABILITY

CAPABILITY	MULTIPLE ACCESS	S-BAND SINGLE ACCESS	KU-BAND SINGLE ACCESS
FORWARD LINKS			
NO. OF R.F. LINKS PER TDRS	1	2	2
TOTAL NO. OF LINKS FOR TDRSS	2	4	4
MAXIMUM DATA RATE	10 KBPS	300 KBPS	25 MBPS
RETURN LINKS			
NO. OF R.F. LINKS PER TDRS	20	2	2
TOTAL NO. OF LINKS FOR TDRSS	20	4	4
MAX. DATA RATE	50 KBPS	12 MBPS	300 MBPS

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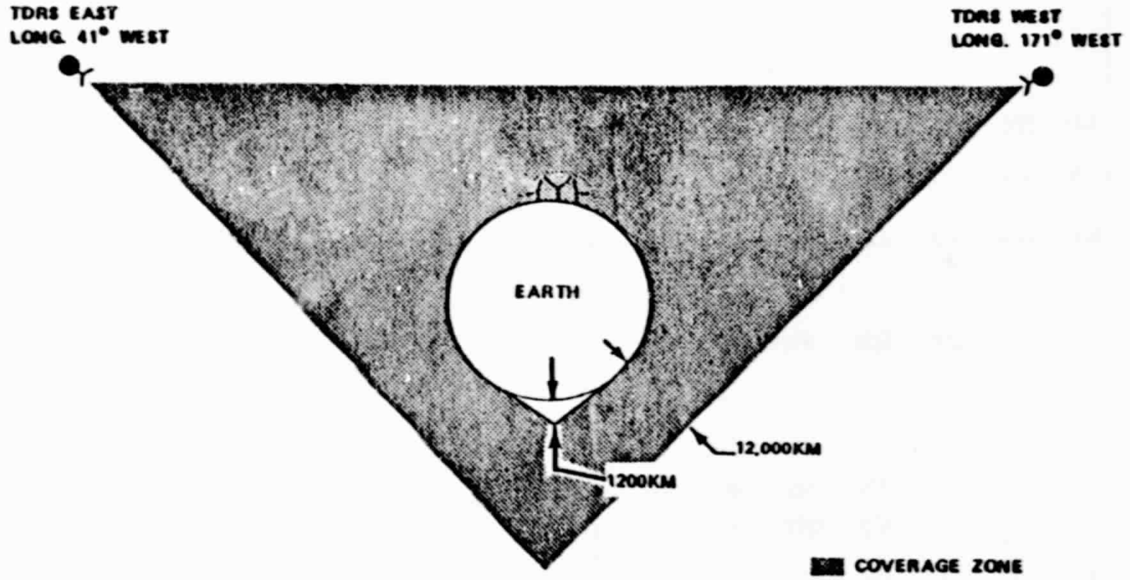
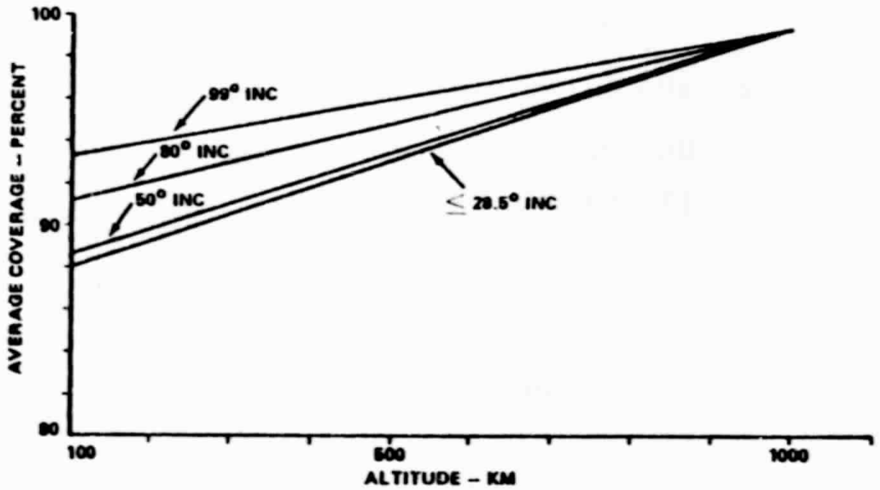
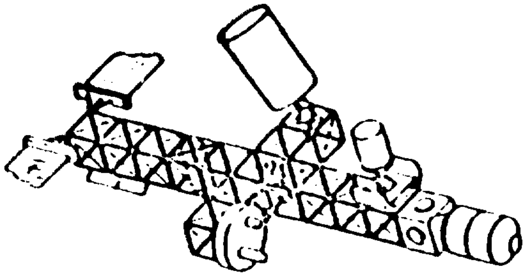
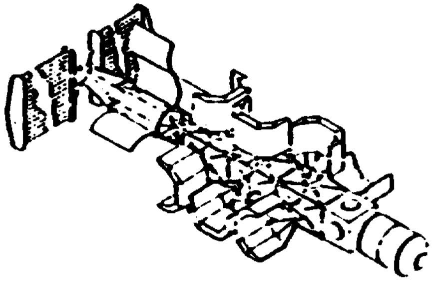
TDRSS COVERAGE







SUMMARY



- SEVERAL VIABLE APPROACHES TO PLATFORM CONCEPT IDENTIFIED
  - PALLETS / PRESSURIZED MODULES – NEW TYPE STRUCTURE – COMBINATION
- PLATFORM CAN UTILIZE POWER MODULE OR PROVIDE OWN RESOURCES
- PLATFORM SIZE AND GROWTH FLEXIBILITY CAN BE ACHIEVED

  EXAMPLE: 1-2 PALLETS ► 1-2 PALLET TRAINS ► NEW STRUCTURE W/MOUNTING OPTIONS ► ADDITIONS
- NEW TYPE STRUCTURE READILY PERMITS MULTI SURFACE MOUNTING AND ALLOWS MOUNTING OF INDIVIDUAL INSTRUMENTS, GROUPS ON PALLET, OR GROUPS ON NEW CARRIER (ie DISC)
- MULTIPLE POINTING REQUIREMENTS
  - ANTICIPATE GOOD SOURCE COVERAGE AND CUMULATIVE VIEWING TIMES
  - REPRESENTS COMPLEX POINTING SYSTEMS ANALYSIS' ACTIVITY
  - INFERS ACTIVE STABILIZATION AND CONTROL, GIMBALED ARRAYS, AND POINTING MOUNTS
- PLANNED EFFORTS IN LARGE STRUCTURES, SPACELAB DERIVATIVES, POWER MODULES, AND OPERATIONS SUPPORT HARDWARE CORRELATE WITH PROJECTED PLATFORM NEEDS