NASA Contractor Report 181707

SPACE STATION RT&E UTILIZATION STUDY

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Contract No. NAS1-18228 (Task 4)
September 1989

National Aeronautics and
Space Administration

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LIST OF ACRONYMS

A&R	Automation and Robotics
ADS	Attitude Determination System
AFGL	Air Force Geophysics Laboratory
AFRPL	Air Force Rocket Propulsion Lab
AFSD	Air Force Space Division
AFTAC	Air Force Tactical Air Command
AFWAL	Air Force Wright Aeronautical Laboratories
AMD	Aerospace Medical Division
APAE	Attached Payload Accommodation Equipment
ARC	Ames Research Center
BAC	Boeing Aerospace Company
CELSS	Closed Experimental Life Support System
CMS	Contamination Monitoring System
CSS	Crew Support Station
CSTI	Civil Space Technology Initiative
DOD	Department of Defense
DSN	Deep Space Network
ELV	Expendable Launch Vehicle
EM	Electromagnetic
EMU	EVA Mobility Unit
EVA	Extra Vehicular Activity
FF	Free-Flyer
FTS	Flight Telerobotic Servicer
GDC	General Dynamics Corporation
GE	General Electric
GEM	Gaseous Environment Monitor
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
IVA	Intra-Vehicular Activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center

LIST OF ACRONYMS (continued)

LDEF	Long Duration Exposure Facility
LDR	Liquid Droplet Radiator
LeRC	Lewis Research Center
LMSC	Lockheed Missiles and Space Company
LSE	Laboratory Support Equipment
LSF	Laboratory Support Facility
MDAC	McDonnell Douglas Astronautics Corporation
MIT	Massachusetts Institute of Technology
MM	Martin Marietta
MMPF	Microgravity and Materials Processing Facility
MPA	Multiple Payload Adapter
MRDB	Mission Requirements Data Base
MSC	Mobil Servicing Center
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NDT	Non-Destructive Testing
OAST	Office of Aeronautics and Space Technology
OMV	Orbital Maneuvering Vehicle
OTV	Orbital Transfer Vehicle
PI	Principal Investigator
PIA	Payload Interface Adapter
PMV	Proximity Maneuvering Vehicle
PPS	Payload Pointing System
RADC	Rome Air Development Center
RF	Radio Frequency
RME	Radiation Measurements Experiment
RT&E	Research, Technology and Engineering
SBR	Space-Based Radar
SEM	Scanning Electron Microscopy
SIA	Station Interface Adapter
S/C	Spacecraft
SRRL	Space Robotics Research Laboratory
SS	Space Station

LIST OF ACRONYMS (concluded)

TBD	To Be Determined
TDM	Technology Development Mission
TDMX	Technology Development Mission Experiments
TES	Thermal Energy Storage
UAH	University of Alabama in Huntsville
USAF	United States Air Force
VHSIC	Very High Speed Integrated Circuit
VLBI	Very Long Baseline Interferometer
VLSI	Very Large Scale Integration

I. INTRODUCTION

Outfitting equipment will transform the basic accommodations of the Space Station into a functional laboratory in space in the same way that specialized instrumentation and analysis equipment transforms a building into a laboratory here on Earth. Requirements for specific outfitting items depend on the nature of user in-space research interests and vary from discipline to discipline. Since the Space Station will be shared by a number of user communities, it is important that the outfitting needs of each community be understood and planned for.

Considerable effort has been invested in establishing outfitting requirements for the life science and microgravity users. Similar attention had not been paid to outfitting for technology development users leading to a concern that requirements were being overlooked. Initial efforts addressing this concern included studies by Battelle[1] and General Research Corporation[2] that identified support equipment requirements at a generic level. The current study goes a step further by examining a broader range of technology missions [including some Department of Defense (DOD) concepts], by keying specific outfitting needs to individual missions, and by comparing identified needs with planned outfitting for other user classes.

Outfitting equipment includes common support equipment, subsystem augmentation equipment, and unique subsystems needed to enhance user productivity. It will be developed under the Space Station program to provide capabilities to meet requirements that are common to a number of users. Thus, accomplishing study objectives meant (1) determining for individual experiments what will be needed in the way of support or augmentation equipment, and (2) determining which of those needs are common to other missions.

The study approach began with a review of descriptive information on equipment, activities, and resource requirements for a set of 241 candidate technology missions arranged into seven technical themes. For each mission an equipment list was generated that included both support equipment and experiment equipment thought by nature to have multi-use potential. These lists were checked for commonality with equipment currently in planning (Laboratory Support Equipment, Laboratory Outfitting Subsystems, etc.) to identify by subtraction those needs that are not yet being addressed. The focus of the study was on these residual needs, and the outfitting issue still to be resolved is which of these items should be provided by the Space Station program as outfitting equipment and which should be developed as user- provided equipment. User demand will certainly be a factor in this decision, and the number of missions needing each item was tallied as a reflection of common-use potential.

The time phasing of technology outfitting requirements was also examined by organizing payload sets into flight scenarios. The intent was to identify potential planning issues relating to outfitting implementation. The approach used theme-oriented mission complements to provide a representative set of

outfitting requirements during the initial phases of Space Station operations. Mission selection considered Office of Aeronautics and Space Technology (OAST) planning, the Pathfinder and Civil Space Technology Initiative (CSTI) programs, and accommodation drivers. Mission timing reflected the desired start year and duration.

The Space Station RT&E (Research, Technology, and Engineering) Utilization Study is an initial step in a path that may lead ultimately to the development of additional outfitting equipment. It was intended as a systematic survey of requirements for the full range of technology development missions proposed for early Space Station, and an extensive list of potential outfitting items was compiled as a result. However, the current study was performed without the benefit of interaction with technology principal investigators (PIs). PI inputs will clearly play a vital role in carrying this effort to the next stage by refining and validating the outfitting needs identified herein and by establishing priorities and performance specifications for equipment development.

REFERENCES

1. Space Station Technology Development Mission Analysis, Battelle, Columbus Division for NASA/ Lewis Research Center, Contract NAS3-23895, August 15, 1986.

2. Laboratory Services for RT&E and Microgravity Science and Applications Experiments on the Space Station Complex, General Research Corporation for NASA/Office of Aeronautics and Space Technology, June 1987.

II. THE TECHNOLOGY DEVELOPMENT MISSION SET

This section describes the approach used to organize and characterize the technology mission set to drive out significant relationships and trends pertaining to Space Station outfitting.

A. Data Sources

The current study relied heavily on the results of preceding experiment definition efforts as presented in the set of reference documents listed in Appendix A. Within these documents varying levels of definition were found for a total of 241 candidate technology development missions (TDMs); they included concepts submitted by NASA in-house personnel, concepts developed under contract, and concepts from the DOD. Nearly all of these missions are covered to some degree in the following four documents:

- The Mission Requirements Data Base (MRDB) for TDMX payloads
- Proceedings of the Williamsburg workshop
- The Battelle experiment definition study report
- The Air Force Space Station Working Group report.

A profile of the mission set with respect to these sources is presented in Figure II-1. Many of the missions are described in additional detail in the other documents in Appendix A.

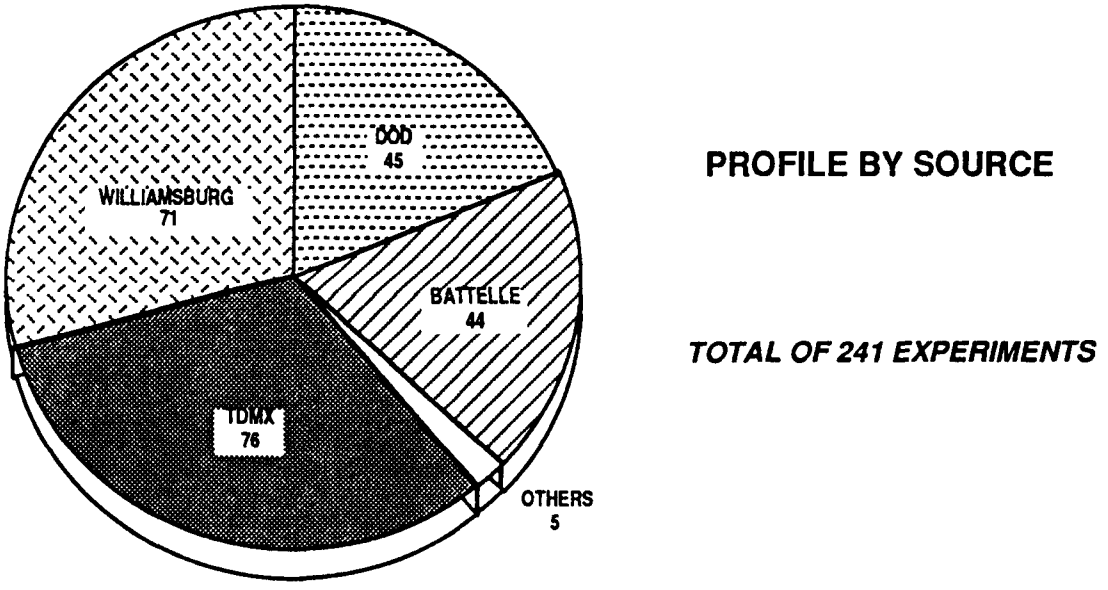


FIGURE II-1. SOURCES OF EXPERIMENT DEFINITION DATA

B. Representation of OAST Themes

At the time of the study the NASA Office of Aeronautics and Space Technology (OAST) classified technology development missions (TDMs) into seven themes. They are:

- Space Structure (Dynamics and Control)
- Fluid Management
- Space Environmental Effects
- Energy Systems and Thermal Management
- Automation and Robotics
- Information Systems
- In-Space Operations.

While the names are indicative of theme scope, definitions appearing in the Amended Program Solicitation for Industry and University In-Space Technology Experiments (issued October 24, 1986) were used where clarification was needed. This document is referred to informally as the "outreach" solicitation. Within the mission set all seven themes were well represented as indicated in Figure II-2.

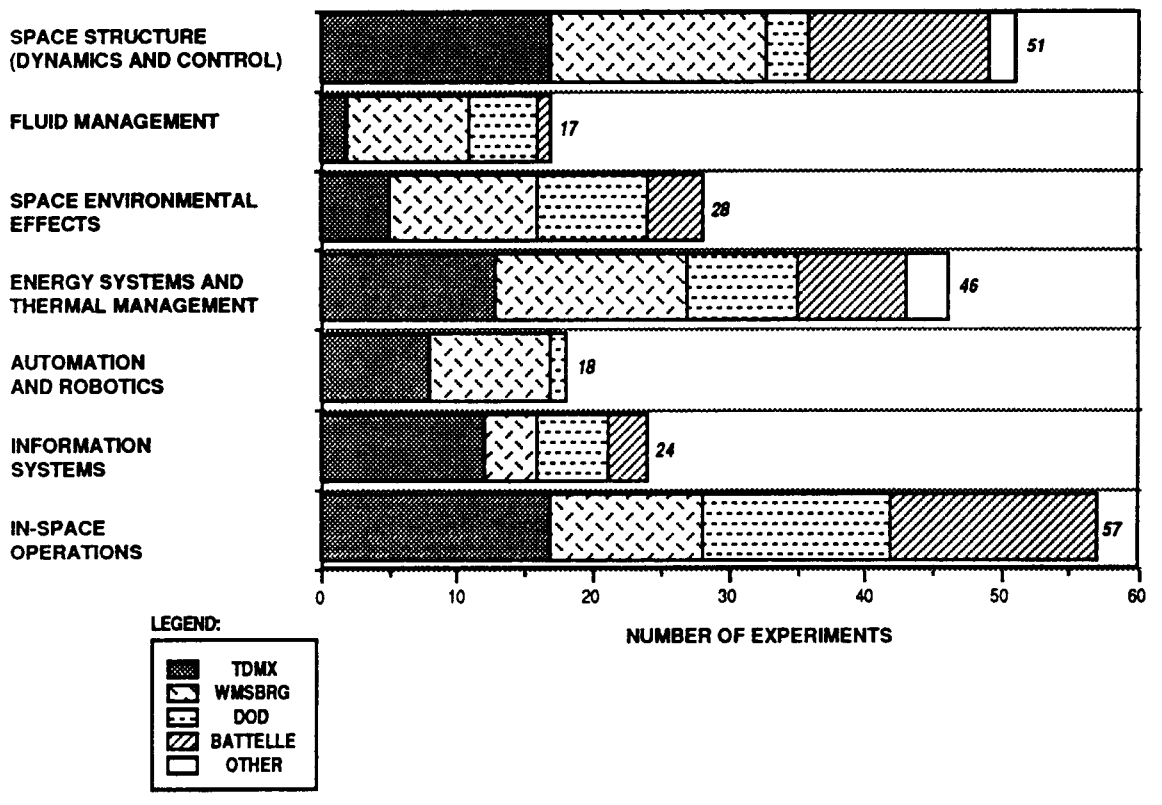


FIGURE II-2. PROFILE OF SEVEN TECHNOLOGY THEMES BY DATA SOURCE

C. Organizing the Mission Set

Grouping missions with similar or related in-space objectives was an early goal in the study, because similar missions should have common requirements for outfitting equipment. The following classification hierarchy was used to achieve this:

- Theme
- Subtheme (or area)
- Project
- Mission (or experiment).

A complete listing of the study mission set, presented in the context of this classification scheme, can be found in Appendix B.

For missions appearing in the preceedings of the Williamsburg conference the Williamsburg theme assignments were used as a point of departure. Minor adjustments were made based on theme definitions in the 1986 OAST "outreach" solicitation. Subthemes and projects were defined as appropriate.

Within this scheme each project was intended to address a single technology development issue or technology application. Project groups contained one or more missions as appropriate. Multiple missions within a project group are often closely related in their objectives and might be consolidated into a single mission or be conducted as a coordinated experiment sequence using a common testbed.

D. Mission Types

In evolving from initial discovery to end application a technology development progresses through several phases of maturity, and in-space experimentation may be beneficial or necessary at any point along the way. Significant differences typically exist from phase to phase in requirements for experiment hardware, accommodations, and outfitting. To account for such differences missions were classified as research-type, technology development-type, or demonstration-type. A similar classification of missions appears in Volume 8 of the Williamsburg proceedings, In-Space Operations.

A research-type mission involves basic or applied research that contributes to the understanding of in-space phenomena. It creates or expands the knowledge base required for designing hardware components that utilize or cope with the subject phenomena. Research-type activities tend to be result-driven and may require outfitting equipment for in-space analysis of results.

Technology development-type missions involve in-space testing of component prototypes and critical function demonstration to establish proof of concept. They often utilize a test bed configured to facilitate the changeout of components of alternative design.

Finally, demonstration-type missions involve the monitoring of end item performance to establish proof of maturity. Demonstration-type activities tend to involve assemblies configured as complete systems. Many of the demonstration missions were similar to what a hardware project would conduct as part of an advanced development program or as a preoperational checkout of a new space system.

NASA uses eight levels of technology maturity to provide an objective gauge of technology readiness (see, for example, the Battelle report, page 2-1). Table II-I lists these eight maturity levels and shows how they correspond to the three phases of the technology development cycle defined in the current study.

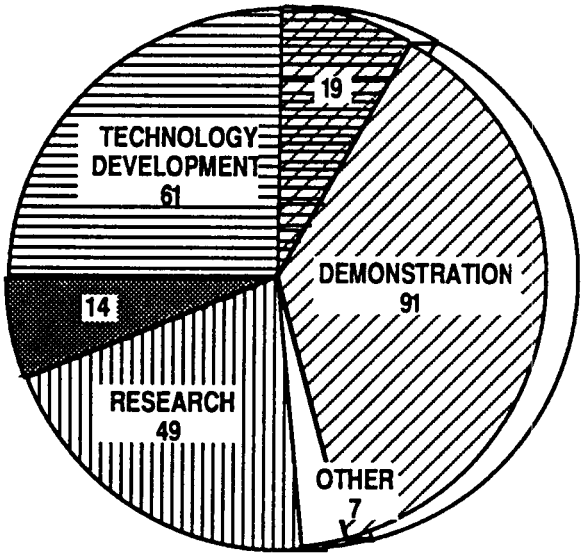
A profile of the mission set by type is presented in Figure II-3. A number of missions span two phases as indicated by the overlap regions. The "other" group contains four concepts that were judged not suitable as technology missions, two concepts that included research and demonstration activities, and one concept that could not be classified based on the information available.

A profile of the seven OAST themes by mission type is presented in Figure II-4. The differences in emphasis between themes merely reflects the role that in-space activities play in the technology development cycle for each theme. A strong research-phase emphasis is indicated for the Space Environmental Effects theme, while the Automation and Robotics and Information Systems themes are represented more heavily by demonstration-type missions.

TABLE II-1. CORRELATION BETWEEN EXPERIMENT TYPES AND NASA LEVELS OF TECHNOLOGY MATURITY

EXPT. TYPE	LEVEL OF TECHNOLOGY MATURITY
R	Level 1 - Basic principles observed and reported
R	Level 2 - Conceptual design formulated
T	Level 3 - Conceptual design tested analytically or experimentally
T	Level 4 - Critical function/characteristic demonstration
T	Level 5 - Component/brassboard tested in relevant environment
T	Level 6 - Prototype/engineering model tested in relevant environment
D	Level 7 - Engineering model tested in space
D	Level 8 - Operations

R = Research, T = Technology Development, D = Demonstration



PROFILE BY EXPERIMENT TYPE

FIGURE II-3. PROFILE OF MISSION SET BY TYPE SHOWS HEAVY EMPHASIS ON DEMONSTRATION (PROOF OF MATURITY) EXPERIMENTS

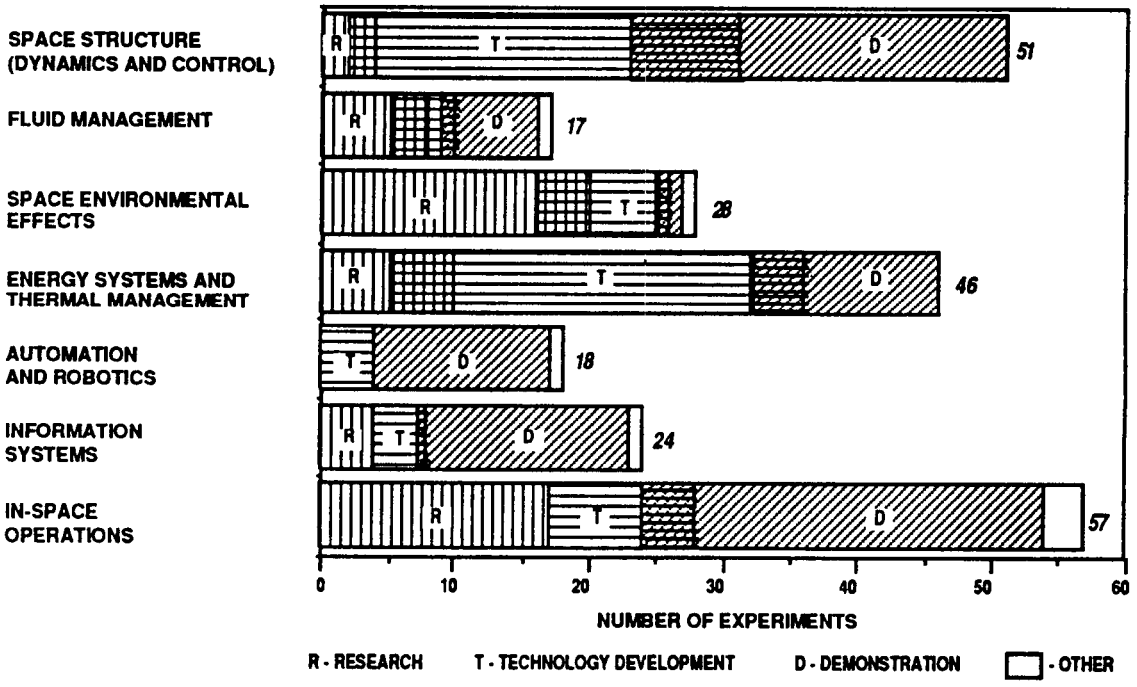


FIGURE II-4. PROFILE OF TECHNOLOGY THEMES BY EXPERIMENT TYPE SHOWS VARIATION IN EMPHASIS FROM THEME-TO-THEME.

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III. DEVELOPMENT OF OUTFITTING REQUIREMENTS

The primary output of the study is a list of outfitting equipment needed to support technology development missions on the Space Station. This list was developed in three steps: (1) identifying outfitting needs of individual missions, (2) establishing commonality with planned outfitting for microgravity and life sciences users, and (3) analyzing the residual needs for multi- use potential.

A. Identifying Outfitting Needs

The question of what outfitting equipment should be provided for technology development missions is not an easy one to answer. On a fundamental level the technical domain spanned by the set of technology development missions has tremendous breadth. As a result, the objectives, measurement methods, and experiment equipment that pertain to one segment of the technology mission set may have no relevance for other segments. Consider space structures and fluid management experiments as a case in point. On a more practical level there is simply a lack of explicit requirements definition for technology development missions at this stage of the Space Station program. As a result, the process of identifying outfitting needs required a liberal amount of interpretation based on an understanding of mission objectives and research methodologies.

The matter of information completeness and quality is addressed further here because it points out the need for additional emphasis on outfitting requirements in future mission definition efforts. To direct attention to the best information on each technology mission early in the study a formal assessment was made of the level of descriptive detail available in the resource documentation. A scale of 1-5, defined in Table III-1, was used to quantify the completeness of the information for each mission. Level "1" meant verbal description only while level "5" signified a complete description of the experiment system and associated support equipment commensurate with results of the Microgravity and Materials Processing Facility (MMPF) Study[1]. This means that top-level physical characteristics and resource requirements

TABLE III-1. CHARACTERIZATION OF MISSION DESCRIPTIONS FOR COMPLETENESS.

(1)	Verbal description only
(2)	MRDB entry
(3)	Descriptive text/data plus equipment sketch
(4)	Full experiment description with support equipment listed
(5)	Full experiment description with support equipment characterized

were defined for the support equipment as well as the basic experiment equipment. A profile of technology missions by level of definition is presented in Figure III-1. In only a few cases were support equipment needs identified item-by-item (Level 4), and support equipment items were not characterized (Level 5) for any of the missions.

In reviewing the mission descriptions a broad view was adopted of what constituted outfitting equipment since clear guidelines did not exist. Outfitting candidates were considered to be any item not provided by the PI plus any items in the PI-provided experiment system that were deemed to have multi-use potential. They included the following:

- Key items of Payload Attachment Equipment (Payload Pointing System, Crew Support Station, etc.)
- Key items of standard subsystem equipment (video recorder, graphics terminal, etc.)
- Special systems and facilities [Orbital Maneuvering Vehicle (OMV), service hanger, Mobile Servicing Center, etc.]
- Experiment equipment with potential for general use.

For each of the 241 missions the descriptive information on activities and equipment was analyzed to establish potential outfitting needs. Mission-level equipment lists were developed and consolidated in a computerized data base that ultimately contained over 1700 entries. A commercially available data base management program was used to facilitate cataloging and processing of the outfitting needs data.

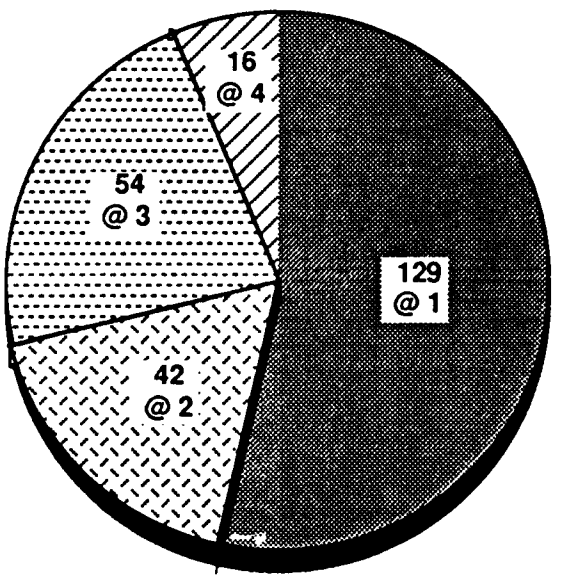

FIGURE III-1. PROFILE OF MISSION SET BY LEVEL OF DEFINITION SHOWS THAT SUPPORT EQUIPMENT NEEDS WERE NOT EXPLICITLY IDENTIFIED IN MOST CASES (LEVEL 4 OR 5).

Figure III-2 shows the equipment entries for a single mission. Each entry included the equipment item name, a category identifier, a mission activity phase, and an optional comment to explain the need and state special requirements as appropriate. The activity phase was included to provide traceability of outfitting needs to specific aspects of mission operations and was thought to have future value in validating study findings. The six activity phases recognized were:

(1) Initial setup/assembly
(2) Experiment operations
(3) On-board quick-look analysis
(4) Maintenance, servicing, reconfiguration
(5) Deactivation/disassembly
(6) On-board storage.

FLUID MANAGEMENT

Support Equipment Requirements

SUBTHEME: Spacecraft Fire Safety

MISSION CODE	EQUIPMENT ITEM	EQP CAT	MISSION PHASES	SPECIAL REQUIREMENTS/ COMMENTS
	FLAME SPREAD MECHANISMS			
FM-007	Spacecraft Fire Safety Technology			
	Camera locker	LSE	6	For high-speed cinema camera
	Camera, high-speed cinema		2	Milliken DBM4A or equivalent
	Cleaning equipment	LSE	4	Swabs, fluids, etc.
	Data recorder, digital	Std	2,3	
	Data terminal, graphics	Std	2,3	
	Film locker, cinema		6	Cinema film storage
	Gas chromatograph/mass spectrometer		3	Analysis of gas combustion products
	Gas sampling bottles		6	Store combustion gas samples for analysis/ transport
	Gas storage/supply, lab	LSS	4,6	O_2, N_2
	Image intensifier		2	Film and video images
	Interferometer, holographic		2	
	Laser Doppler anemometer		2	
	Photo processor unit		2,3	Development of holographic plates
	Sample containers		6	Storage/transport of experiment samples
	Storage locker, EM-shielded	LSE	6	Store video cassettes
	Storage, sample	LSS	6	
	Vacuum vent	LSS	2,4	
	Video	Std	2	
	Video recorder	Std	2,3	
	Waste disposal system	LSS	6	Charred sample material, ash and spent cleaning materials

Mission Phases: 1 - setup/assembly; 2 - experiment operations; 3 - quicklook analysis of results; 4 - maintenance, servicing, reconfiguration; 5 - deactivation/disassembly; 6 - on-orbit storage.

FIGURE III-2. EXTRACT FROM FLUID MANAGEMENT DATA BASE WHICH SHOWS LISTING OF OUTFITTING/MULTI-USE ITEMS FOR A SINGLE MISSION.

B. Commonality with Outfitting Needs of Other Users

Once compiled, the mission equipment needs were analyzed to determine which of the items relate to outfitting equipment already in planning. The list of such items used in this analysis is presented in Table III-2 and includes the following classes of equipment:

- Laboratory Support Equipment
- General Laboratory Support Facility
- Laboratory Outfitting Subsystems
- Attached Payload Accommodation Equipment
- Standard accommodation (subsystem) equipment.

TABLE III-2. LIST OF LSE AND OTHER STANDARD ITEMS CHECKED FOR COMMONALITY WITH TECHNOLOGY OUTFITTING NEEDS

Laboratory Support Equipment - LSE	Laboratory Outfitting Subsystems - LSS
Autoclave	Acceleration monitor, lab
Battery charger	Chemical storage facility
Camera locker	Cleanup/decontamination equipment
Camera, 35 mm	Gas storage/supply, lab
Cleaning equipment	Materials transport system
Cutting/polishing system	Storage, process materials
Dosimeter, passive	Storage, sample
Electrical conductivity probe	Vacuum vent
Etching equipment	Waste disposal system
Film locker	Water service, lab grade
Fluid handling tools	
Freeze dryer	Attached Payload Accommodation Equipment - PAE
Freezer	Attitude Determination System (ADS)
Freezer, cryogenic	Contamination Monitoring System (CMS)
Hand tools, general purpose	Crew Support Station (CSS)
Incubator	Deck Carrier
Mass measurement device, micro	Multiple Payload Adapter (MPA)
Mass measurement device, small	Payload Interface Adapter (PIA)
Microscope system	Payload Pointing System (PPS)
Multimeter, digital	Station Interface Adapter (SIA)
Oscilloscope, digital recording	
pH meter	Standard Subsystem Equipment - Std
Refrigerator	Airlock, hyperbaric
Specimen labelling tools	Data recorder, digital
Storage locker, EM-shielded	Data terminal, graphics
Surgery/dissecting tools	Docking port
Thermometer, digital	Hand tools, EVA general purpose
Ultraviolet sterilization unit	Mobile Servicing Center (MSC)
Washer/sanitizer, equipment	Storage, pressurized
X-ray system	Video
	Video recorder
General Laboratory Support Facilities - LSF	Video, external
Glovebox, life sciences	Workstation, maintenance
Glovebox, materials processing	
Workbench, laboratory sciences	

The contract end item specification from the Space Station Work Package 1 solicitation was used as a reference for the lab support items. The Work Package 3 solicitation was referenced for attached payload accommodations. In Figure III-2 those items covered by current planning are identified by an appropriate entry in the "Equipment Category" column. The focus of the study, however, was on needs that are not being addressed by current planning--referred to here as residual needs.

C. New Outfitting Items for Technology Missions

The question to be resolved is "which of the residual needs should be met by the Space Station program and which should be met by the PIs themselves?" User demand and suitability are two factors that come into play in providing an answer.

With regard to user demand, the guiding philosophy is that multiple-use items qualify as outfitting candidates while experiment unique items should be provided by the experiment project. To identify the high demand items the mission equipment lists were consolidated at several levels, and the number of missions needing a given item of support equipment was tallied at each level. The resulting user counts are presented at the theme level in Appendix C, at the project level in Appendix D, and for the entire mission set in Appendix E. The demand profile for the entire set of residual equipment needs is reflected in Figure III-3. It suggests that mission count is not a strong descriminator in selecting outfitting candidates. This was not unexpected due to the diversity of technology research interests.

Possibly more important than user demand is how the support equipment items will interface with the rest of the mission apparatus. Here the guiding philosophy is that if the item can be left on orbit and used separately from the mission apparatus or attached/ detached as needed, then it is suitable as an outfitting item. If on the other hand the item is deeply imbedded or integrated in the mission apparatus, then it might better be developed as an experiment-provided item or offered for experiment use as part of a technology program standard inventory.

A short list of items that are the more likely prospects for new development is presented in Table III-3. The items and counts differ in several respects from what is shown in Appendix E. Specifically, the telerobotic and teleoperations workstations have been combined, as have the large and medium antenna positioners and the laser measurement unit and laser range sensor. Also, a proximity maneuvering unit is suggested instead of the OMV where a mobility platform for range tests is required.

REFERENCES

1. Microgravity and Materials Processing Facility Study Data Release, Teledyne Brown Engineering and Boeing Aerospace Company for NASA/George C. Marshall Space Flight Center, Contract NAS8-36122, February 1987.

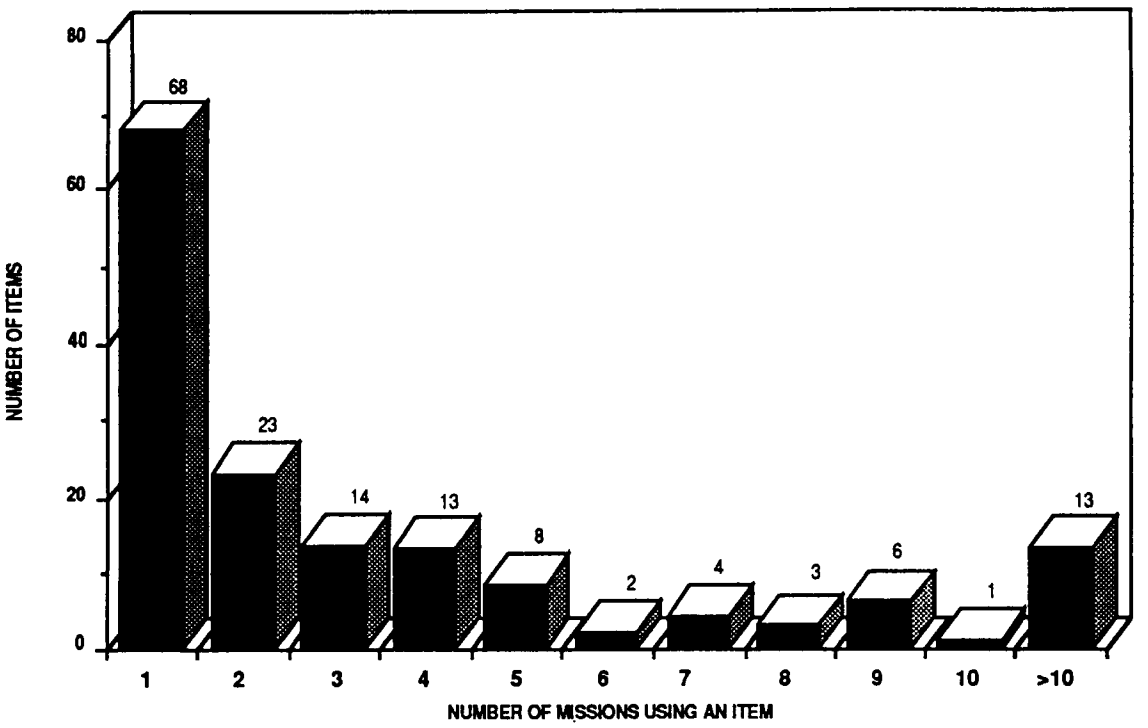

FIGURE III-3. EQUIPMENT DEMAND PROFILE SHOWS THAT FEWER THAN 20% OF THE CANDIDATE OUTFITTING ITEMS ARE ASSOCIATED WITH MORE THAN FIVE (5) MISSIONS

TABLE III-3. EQUIPMENT ITEMS WITH HIGH POTENTIAL AS NEW DEVELOPMENT CANDIDATES

ITEM	MISSION COUNT	COMMENTS
Accelerometer package, external	29	Monitor disturbances at pointing/structure attachment base.
Sample containers	19	Mostly for exposure sample storage/transport.
Workstation, telerobotics/operations*	17	
Mass spectrometer	14	Environment (including plumes) monitoring/mapping. May be covered by contamination monitoring system.
Exposure tray	13	
Pointing mount, two-axis solar	12	Solar array and radiator pointing. Needs study. PPS is overkill and configured more for astronomy payloads.
Imaging radiometer	11	Broad applications for structures, photovoltaics, propulsion, and maintenance.
Propellant storage/transfer facility	9	Long-term.
Laser measurement unit*	8	Range/angle measurement for structural dynamics and range test support.
Plasma diagnostic package	8	Environment characterization, electric power/thruster interaction.
Camera, high speed cinema	7	Two-phase fluid and tribology applications.
Video, low light (external)	7	Plume diagnostics and possibly high voltage interactions.
Proximity maneuvering vehicle (PMV)*	6	Mobility platform for RF/laser range tests.
Antenna positioner*	5	Conventional antenna pointing system (pedestal and gimbals) for large/medium size antennas. Study PPS suitability as an alternative.
Reflectometer	5	Environmental effects measurements.
Tether tracking system	5	Long-term.
Transmitter/receiver, RF	5	Command/data link for portable and proximity mobile equipment.
Retroreflective targets	3	Support structural dynamics tests and maybe proximity operations.
Scanning electron microscope system	3	On-board materials analysis.
Radiation monitor	2	Measure cosmic ray flux in external environment.
Image intensifier	1	Low light observations for film/video recording.

* - Indicates items have been combined relative to Appendix E list.

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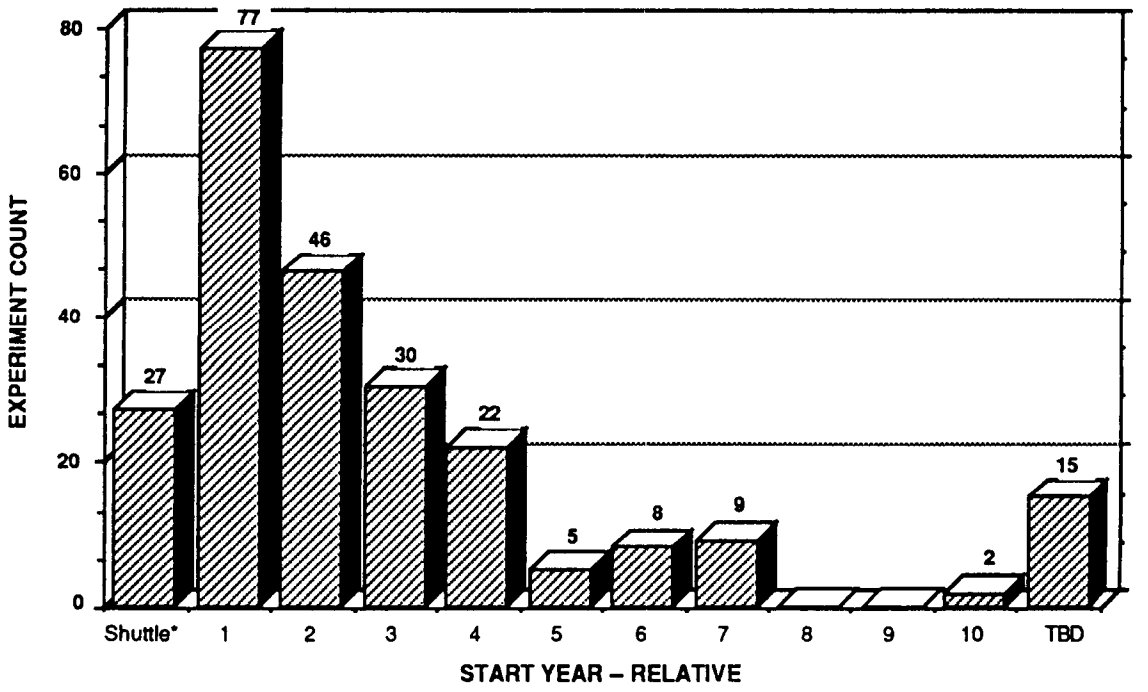
IV. OUTFITTING IMPLEMENTATION

Coordinating the time-phased development of outfitting equipment with the manifesting of individual experiments will be a major planning challenge. Strawman mission groups for theme-oriented laboratories were used in the current study as a vehicle for developing initial insights into potential planning issues. The missions were selected to be representative of theme goals and were organized into scenarios that reflected the start dates, durations, and accommodation modes requested in the reference materials. The time phasing of outfitting requirements simply tracks the resulting scenarios.

It was anticipated that the mission demand model, as reflected in the desired start dates, would exhibit significant growth with time in line with the anticipated evolutionary buildup of the Space Station. In reality, however, everyone wants to fly early. This trend, clearly evident in Figure IV-1, skews the time phasing of the identified outfitting requirements. While there is a need to replan the technology mission set into a coherent, evolutionary sequence to provide a firmer foundation for a variety of study purposes, such an effort was considered beyond the scope of the current study. Instead, mission scenarios were developed within the existing demand model and truncated in the out years as the mission count tapered off.



*Experiments proposed for the Shuttle but which might fly on the Space Station.

FIGURE IV-1. PROFILE OF EXPERIMENT SET BY START YEAR

A. Mission Selection and Scenario Development

Mission selection was an iterative process that took into consideration Office of Aeronautics and Space Technology (OAST) planning, NASA technology program goals, mission accommodation drivers, desired start year, and an assessment of feasibility and priorities. Level of definition was only a consideration where there was a choice between well-defined and poorly-defined missions. With regard to ongoing NASA technology programs, the set of candidate missions was checked for relevance to both the Pathfinder program and the Civil Space Technology Initiative (CSTI).

Although specific resource quotas were not employed, a goal of the selection process was to work within a modest envelope of Space Station accommodations. Thus, initial selections were reviewed and refined as necessary to avoid serious accommodation drivers. Likewise, further adjustments were necessary in some cases to minimize bunching near the start of Space Station operations.

The scenarios were intended to show an incremental buildup of support equipment for each theme. It was expected that as a result of this exercise, a core set of support equipment could be identified that would capture most of the requirements of the missions in the theme. Such core equipment might then constitute the outfitting for a theme-oriented laboratory such as a Fluid Management, Information Systems, or Space Structures Laboratory. However, even within the individual technology themes there is a considerable diversity of experiment objectives, and this diversity is reflected in turn in the outfitting scenarios. As a consequence, this endeavor was inconclusive.

The results of the mission selection and scenario development process are presented for each of the seven themes in the sections that follow along with findings regarding associated outfitting needs.

B. Space Structure (Dynamics and Control)

Mission selection, payload resource requirements, mission time phasing, and potential support equipment needs for the Space Structure (Dynamics and Control) theme are covered in the next four tables and/or figures. Table IV-1 presents the classification scheme developed for the Space Structure (Dynamics and Control) theme and shows how the missions were distributed among subthemes and projects. In this particular theme it is common for mission objectives to span multiple projects. In these cases the project assignment reflects the area of primary technical emphasis. The columns labeled pathfinder and CSTI, indicate where projects relate to these two OAST programs. Pathfinder covers lunar base and Mars mission technologies while CSTI focusses on specific systems technologies to augment the more general and longer-range Research and Technology Base program. The column labeled OAST indicates which project-level groups are represented in current planning for Space Station Phase I. Finally, the right-hand column of Table IV-1 identifies the individual missions selected for the theme complement. Representation

TABLE IV-1. SELECTION OF EXPERIMENTS FOR SPACE STRUCTURE (DYNAMICS AND CONTROL) RT&E FACILITY

SUBTHEME/PROJECTS	COUNT	PATH-FINDER	CSTI	OAST	COMMENTS	SELECTED EXPERIMENTS
Advanced Structures						
Assembly	5	√			Use normal EVA assembly operations to build experience base.	
Segmented Optics	3		√	√	Demonstrates technology base for future science and DoD missions.	TDMX2421
Thin Film/Inflatable Structures	5				Use Shuttle mission to establish feasibility.	
Trusses	1				Evaluate in application context.	
Welding	2	√			Short duration. May be accomplished on a Shuttle mission.	
Mechanisms/Controls						
Attitude Control	2				Demonstrate/evaluate in application context.	
Pointing/Isolation	3	√			Potential user accommodation benefits.	TDMX2432
Sensors/Actuators	5				Evaluate in application context.	
Tribological Effects	5				Contributes to technology base for dynamic machinery/structures.	SS-016
Structural Dynamics						
Antennas/Reflectors	11		√	√	Coordinate with communication and sensor technology missions.	TDMX2071, TDMX2411
Large Structures (General)	3	√	√		Evaluate in application context.	
Space Station Dynamics	3				Significant experiment opportunity. Requires planning/preparation.	SS-017
Thermal Design	3				Combine with other structural dynamics experiments.	MS-14
	51					

of project-level groups in the complement involved judgements about alternatives for achieving project objectives including mission consolidation and use of the shuttle. A synopsis of the selection rationale is presented in the comments column.

Top-level payload characteristics and resource requirements for the selected missions are presented in Table IV-2. Mission equipment includes primarily attached payload elements with internal controls. However, mission SS-017, the Space Station Structural Characterization Experiment, uses a distributed network of payload elements and therefore does not fit the standard attached or pressurized payload mold.

TABLE IV-2. ACCOMMODATION REQUIREMENTS FOR SPACE STRUCTURE (DYNAMICS AND CONTROL) EXPERIMENTS

PROJECT/EXPERIMENTS	MISSION CODE	START YEAR	EXPT TYPE	DEFN CODE	DBL RACKS	ATTACH PORTS	WEIGHT (lb) EXPT	WEIGHT (lb) LOG	PWR (kW)	OTHER CONSIDERATIONS
Segmented Optics										
Active Optic Technology	TDMX2421	1	T/D	3	1.8	1	4620	485/ 2m	0.2	Sun and Earth avoidance. LHe resupply.
Pointing/Isolation										
Pointing and Isolation Devices	TDMX2432	1	D	4	0.1	1	3140		0.3	Mass includes pointed payload. Combine with TDMX2421.
Tribological Effects										
Polymeric Materials for Space Mechanisms	SS-016	1	R	2		MPA	13		0.05	Small payload. May use Multiple Payload Adapter (MPA).
Antennas/Reflectors (Dynamics)										
Flight Dynamics Identification	TDMX2071	1	R/T	3	1	1	584	1/yr	0.7	
Advanced Adaptive Control	TDMX2411	2	T	3	1	sh.	595	1/yr	1.4	Uses residual equipment from TDMX2071.
Space Station Dynamics										
SS Structural Characterization Experiment	SS-017	1	D	2		*	TBD		2	*Includes retroreflectors plus distributed network of sensors.
Thermal Design										
Thermal Design of Composite Antenna Dish	MS-14	5	D	1						Include under TDMX2071/2411

An accommodation scenario for the selected mission complement is depicted in Figure IV-2. The time phasing has been adjusted slightly to minimize the envelope of requirements for rack space and external attachment. Potential outfitting needs for the initial years of this scenario are presented in Table IV-3. It includes items believed to have common-use potential plus key items of standard equipment. Certain standard items such as payload attachment equipment, racks, standard data processors, and keyboard/data display units were taken for granted and do not appear in the lists. Outfitting needs for other space structures projects can be found in Appendix D.

A significant number of the proposed missions in the Space Structure (Dynamics and Control) theme involve large test articles representative of segmented optics, antenna, and spacecraft applications. Since these structures will undoubtedly be expensive to launch and deploy, it is important that each test structure be exploited to the fullest. In this regard the Space Station itself, as the space program's largest structure, represents an important opportunity to pursue technology experiment objectives not only in structural dynamics but also in assembly and thermal design.

Several missions have been proposed that use the Space Station as a dynamics test article. However, the accommodation of dynamics measurement equipment is a matter of concern because it includes a multitude of distributed elements (retroreflectors, accelerometers, acoustic sensors, strain gauges, temperature sensors, etc.) that can more effectively be installed on the ground than through EVA

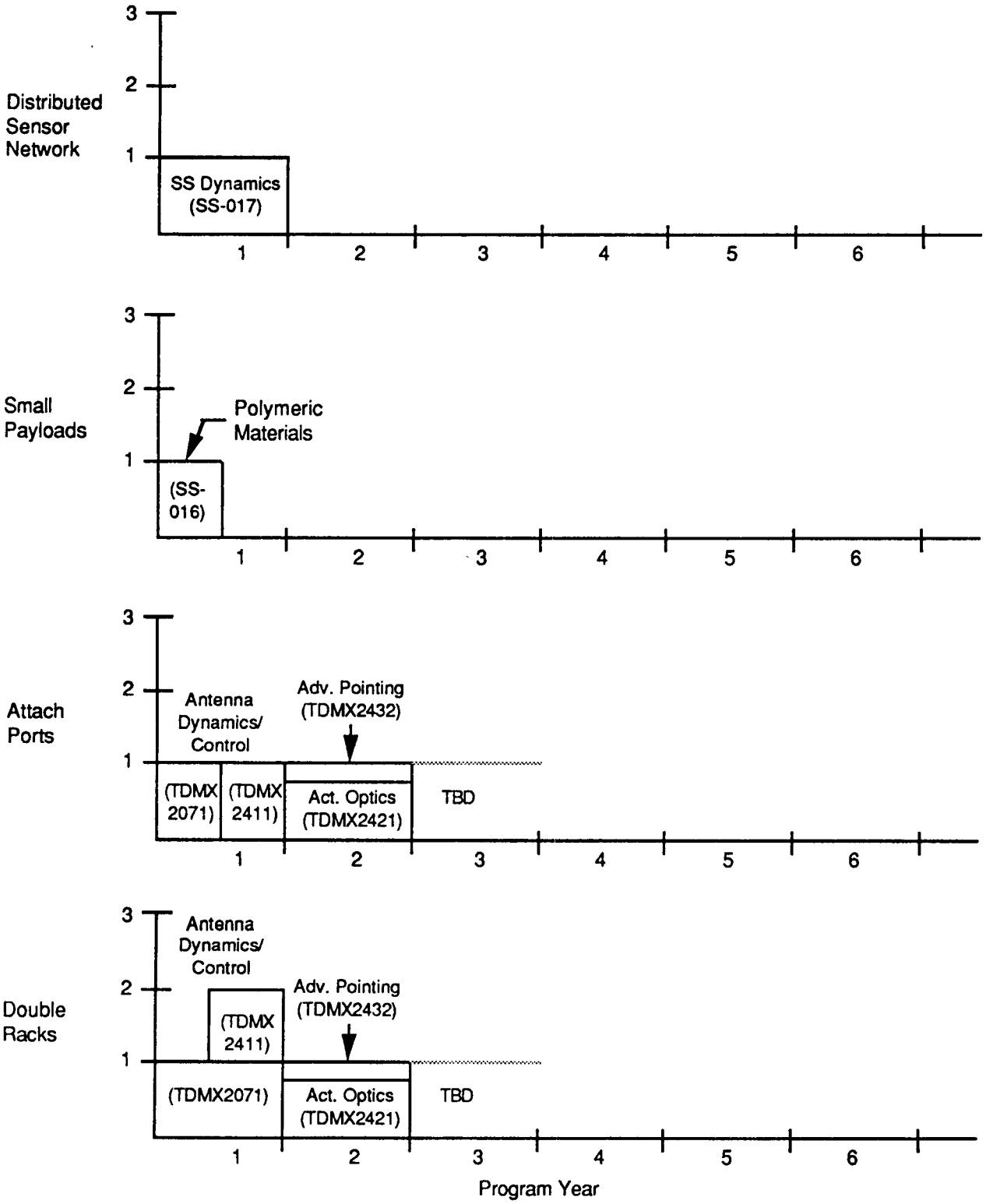


FIGURE IV-2. MISSION SCENARIO FOR SPACE STRUCTURE (DYNAMICS AND CONTROL) THEME

operations. It is imperative therefore that the sensor set needed for technology experimentation be defined at an early date so that every effort can be made to incorporate those sensors into the Space Station design as necessary. It is assumed that some level of instrumentation will be included to verify Space Station structural performance and monitor structural health status. The concern is that these "engineering" measurements may not be adequate to support technology research objectives and that it may not be feasible to install additional sensors once the Space Station is in orbit.

TABLE IV-3. OUTFITTING NEEDS FOR EARLY-YEAR SPACE STRUCTURE (DYNAMICS AND CONTROL) MISSIONS

	PROGRAM YEAR 1					
	ANTENNAS/REFLECTORS		SPACE STATION DYNAMICS		TRIBOLOGICAL EFFECTS	
STATUS	ITEM	CAT	ITEM	CAT	ITEM	CAT
Planned	Data recorder, digital Hand tools, EVA general purpose Video recorder Video, external	Std Std Std Std	Data recorder, digital	Std	Contamination monitor Data recorder, digital	PAE Std
Common-Use Potential	Accelerometer package, external Cleaning materials, EVA Computer (VAX 11/780 equivalent) Laser measurement unit Proximity sensor		Laser measurement unit Retroreflective targets Storage, unpressurized		Mass spectrometer Radiometer	

C. Fluid Management

Following the pattern established in the previous section, mission selection, payload resource requirements, mission time phasing, and potential support equipment needs for the Fluid Management theme are addressed in the next four tables and/or figures. The mission classification scheme is presented in Table IV-4. The mission count numbers indicate that the primary in-space research emphasis for this theme lies in two areas: (1) understanding two-phase fluid phenomena and (2) demonstrating and evaluating cryogen storage technologies. Missions selected for scenario development (identified in the right-hand column) are broadly representative of the range of Fluid Management topics and include a mixture of internal and attached payloads. Top-level payload characteristics and accommodation requirements for the selected missions are presented in Table IV-5. The accommodation scenario is depicted in Figure IV-3.

Potential outfitting needs for the initial years of the scenario are presented in Table IV-6. The combustion and fluid behavior payload equipment will reside within the laboratory module and support research-type mission activities. Both fall within the scope of the MMPF study and an extensive list of outfitting requirements for experiment support can be found in the MMPF data base. The cryogen

TABLE IV-4. SELECTION OF EXPERIMENTS FOR FLUID MANAGEMENT RT&E FACILITY

SUBTHEME/PROJECTS	COUNT	PATH-FINDER	CSTI	OAST	COMMENTS	SELECTED EXPERIMENTS
Fluid Behavior						
Helium	1			√*	Requires lab LHe service. Recommended flying on Spacelab.	
Liquid Streams	1			√	Results needed for advanced radiator concepts	FM-004
Two-Phase Fluids	5			√*	Results in technology data bases for advanced two- phase systems	FM-003
Fluid Storage/Transfer						
Cryogens	7	√			Chemical propulsion, life support, and lab support applications. Consider demonstrating in application context.	TDMX2311
Cryogens -- Helium	1				Needed for IR sensors and in-space research	FM-002
Sensors/Gauges	1				Consolidate with two-phase fluids experiments	
Spacecraft Fire Safety						
Flame Spread Mechanisms	1				Results in improved fire prevention/extinction knowledge for future manned systems	FM-007
TOTAL	17					

*Preliminary manifesting

TABLE IV-5. ACCOMMODATION REQUIREMENTS FOR FLUID MANAGEMENT EXPERIMENTS

PROJECT/EXPERIMENTS	MISSION CODE	START YEAR	EXPT TYPE	DEFN CODE	DBL RACKS	ATTACH PORTS	WEIGHT (lb) EXPT	WEIGHT (lb) LOG	PWR (kW)	OTHER CONSIDERATIONS
Liquid Streams										
Liquid Stream Space Technology	FM-004	TBD	R/T	3		(1)	1000	TBD	1.0	Uses 60 ft by 3 ft flight tube
Two-Phase Fluids										
Two-Phase Fluid Behavior and Management	FM-003	2	R/T	3	1		440	110/ TBD	1.3	Low-g (10^{-4})
Cryogens										
Long-Term Cryogenic Fluid Storage	TDMX2311		D	4						
Phase I - Storage		2				1	4290		0.1	Low-g (10^{-3}). Numbers reflect incremental buildup of modular system.
Phase II - Transfer		4					+950			
Phase III - Refrigeration		5					+1760		+2.5	
Cryogens - Helium										
Helium Transfer in Space	FM-002	5	R/D	3		1	7055	TBD	0.1	
Flame Spread Mechanisms										
Spacecraft Fire Safety Technology	FM-007	1	R/T	3	1		440	TBD	2.0	

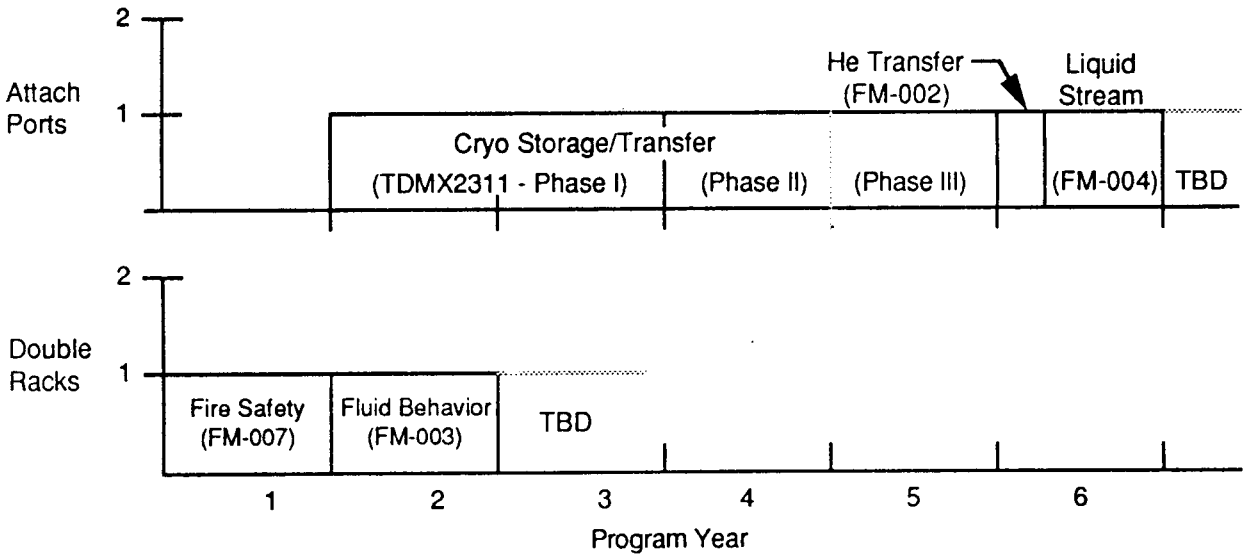


FIGURE IV-3. MISSION SCENARIO FOR FLUID MANAGEMENT THEME

TABLE IV-6. OUTFITTING NEEDS FOR EARLY-YEAR FLUID MANAGEMENT MISSIONS

	PROGRAM YEAR 1				PROGRAM YEAR 2	
	FLAME SPREAD MECHANISMS		TWO-PHASE FLUIDS		CRYOGEN STORAGE/TRANSFER	
STATUS	ITEM	CAT	ITEM	CAT	ITEM	CAT
Planned	Cleaning Equipment	LSE	Camera locker	LSE	Contamination monitor	PAE
	Gas storage/resupply	LSS	Camera, 35 mm	LSE	Data recorder, digital	Std
	Vacuum vent	LSS	Film locker	LSE	Hand tools, EVA general purpose	Std
	Waste disposal system	LSS	Fluid handling tools	LSE		
	Data recorder, digital	Std	Acceleration monitor, lab	LSS		
	Data terminal, graphics	Std	Chemical storage facility	LSS		
	Video	Std	Vacuum vent	LSS		
	Video recorder	Std	Video	Std		
			Video recorder	Std		
Common-Use Potential	Camera, high-speed cinema		Camera, high-speed cinema		Leak detector, H_2/He	
	Gas chromatograph/mass spectrometer		Film magazines			
	Gas sampling bottles					
	Image intensifier					
	Interferometer, holographic					
	Laser Doppler anemometer					
	Photo processor unit					
	Specimen containers					

storage/transfer payload, on the other hand, is a self contained system requiring minimal support for periodic reconfiguration and environmental monitoring. With regard to the items below the line in Table IV-6, the gas chromatograph/mass spectrometer, image intensifier, and high-speed cinema camera are the more likely candidates for outfitting additions. Combustion and fluid behavior experiments proposed for Spacelab relied heavily on high-speed cinema for recording observations. Today it might be possible to meet that need with a high quality video system.

In the way of additional comments, the liquid stream experiment was selected because of advanced radiator and other potential applications. However, this mission is not as well defined as the assigned definition code would suggest, and further definition and refinement will be necessary to achieve viability of the concept. There may also be a role for a precursor pressurized volume (rack- mounted) experiment to study droplet formation and collection before the attached payload described here or the liquid droplet radiator prototypes described later are flown. Finally, none of the mission concepts considered instrumenting fluid systems of the Space Station (including the logistics module) or other space systems. This may be a cost effective way of achieving some of the Fluid Management experiment objectives.

D. Space Environmental Effects

The need to validate predictive models of the Space Station environment and to establish the durability and performance of materials and electronics will create an emphasis on environmental effects experiments early in the Space Station program. The Space Environmental Effects theme includes 28 proposed missions distributed among project groups as indicated in Table IV-7. Missions selected for the strawman scenario are broadly representative of the range of theme interests with the exception of environmental effects on solid rocket motors.

The mission complement includes a mixture of internal and attached payloads. Top-level payload characteristics and accommodation requirements are presented in Table IV-8, and an implementation scenario for the selected missions is depicted in Figure IV-4. Two points are significant. The Mobile Servicing Center with its robotic arm should be an important support system for environment mapping. Secondly, environmental effects experiments typically have preferential mounting requirements with respect to one or more of three key directions -- ram, wake, or solar facing. Thus, mission TDMX2011 is shown as occupying three attachment ports.

TABLE IV-7. SELECTION OF EXPERIMENTS FOR SPACE ENVIRONMENTAL EFFECTS RT&E FACILITY

SUBTHEME/PROJECTS	COUNT	PATH-FINDER	CSTI	OAST	COMMENTS	SELECTED EXPERIMENTS
Environment Characterization						
External Environment	5			√*	Significant impact on operational ground rules and user research interests.	SE-017
Internal Environment	4			√	Habitability impacts. Coordinate also with data system effects experiments.	AFSE-001, AFSE-002, SE-005, TDMX2521
Environmental Effects						
Coatings/Surface Effects	7			√*	Include in Space Station LDEF.	TDMX2011
Data System Effects	3	√		√*	Coordinate with internal environment radiation measurements.	TDMX2442, TDMX2443
Facilities	2				Includes "Wake Shield" and variable gravity facility.	SE-014
Micro-meteroid Impacts	2				Include in Space Station LDEF.	SS-010
Solid Rocket Motors	2				DoD interest. Accommodate on remote facility for safety reasons.	
Structural Materials	3				Include in Space Station LDEF.	AFSE-005
	28					

*Preliminary manifesting

TABLE IV-8. ACCOMMODATION REQUIREMENTS FOR SPACE ENVIRONMENTAL EFFECTS EXPERIMENTS

PROJECT/EXPERIMENTS	MISSION CODE	START YEAR	EXPT TYPE	DEFN CODE	DBL RACKS	ATTACH PORTS	WEIGHT (lb) EXPT	WEIGHT (lb) LOG	PWR (kW)	OTHER CONSIDERATIONS
External Environment										
Environmental Contamination Characteristics Experiment	SE-017	1	R	1		TBD				Will likely use the MRMS as a probe positioner for environment mapping.
Internal Environment										
Radiation Measurements Experiment (RME)	AFSE-001	0	R	3	*		4			*Portable units require storage only.
Heavy Ion and Neutron Environments in S/C	AFSE-002	1	R	1	TBD		TBD		TBD	
In-Situ Trace Contaminant Analysis Analysis	SE-005	1	T	1	0.5		250		1.5	
Acoustics Control Technology	TDMX2521	1	T/D	3	0.2		93		0.1	Mostly portable equipment.
Coatings/Surface Effects										
Spacecraft Materials & Coatings	TDMX2011	1	R/T	4		3	2138	170/ 3m	0.5	Space Station LDEF. Panel/tray assemblies attached in three locations (ram, wake, sun).
Data System Effects										
Transient Upset Phenomena - VLSI	TDMX2442	1	T	4	0.2		220	22/ 3m	0.1	
VHSIC Fault Tolerant Processor	TDMX2443	1	T	4	0.1		220	22/ 6m	0.3	
Facilities										
Space Ultra-Vacuum Facility: Wake Shield	SE-014	1	D	3		1				Equipment characteristics TBD.
Micro-Meteroid Impacts										
Micro-Meteorite Protection	SS-010	4	R/T	1		1	440			Consolidate with TDMX2011.
Structural Materials										
Composite Durability in Space	AFSE-005	1	R	1						Consolidate with TDMX2011.

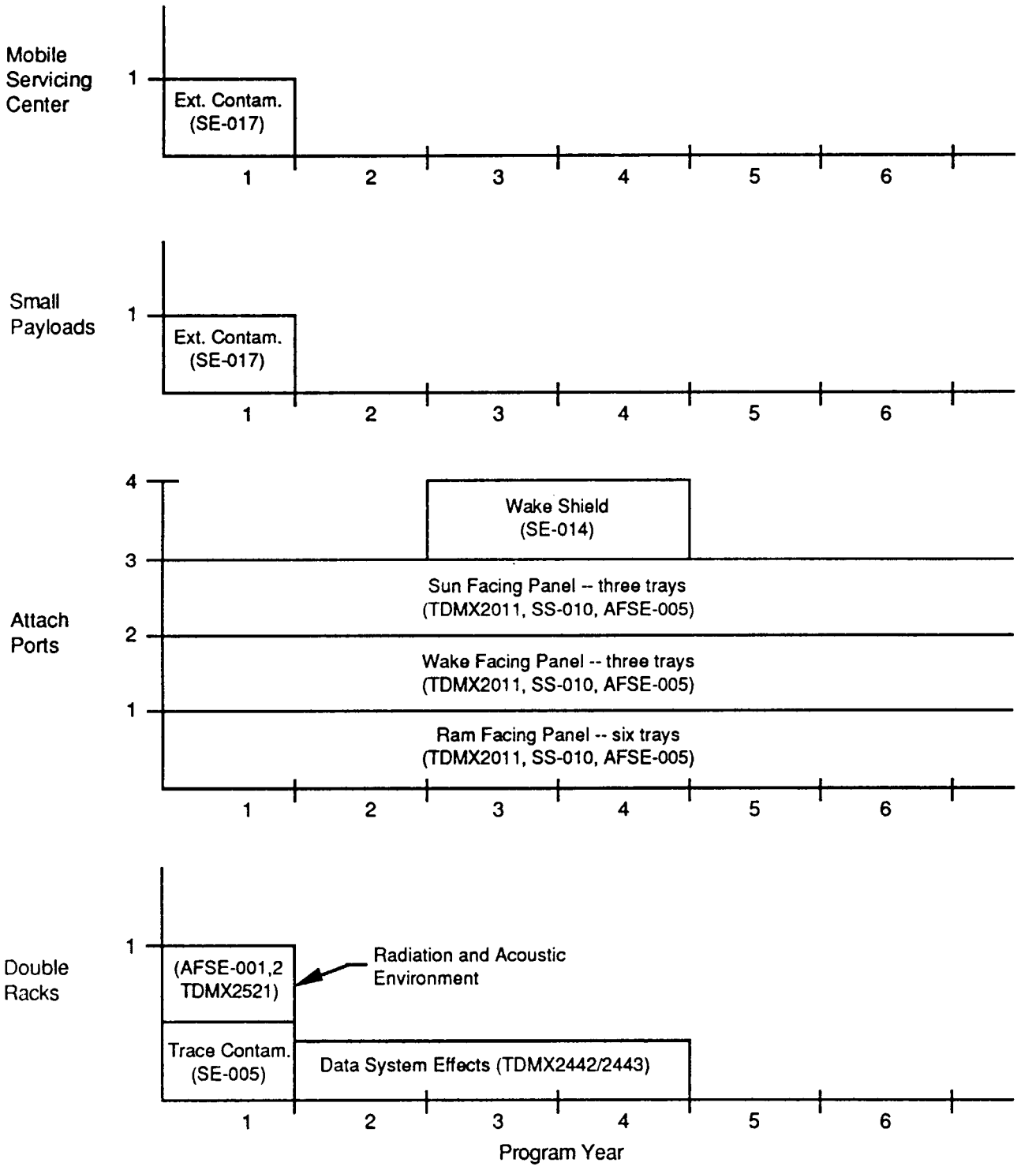


FIGURE IV-4. MISSION SCENARIO FOR SPACE ENVIRONMENTAL EFFECTS THEME

Potential outfitting needs for the Space Environmental Effects theme are listed in Table IV-9. A mass spectrometer is shown as a support item for both environment characterization and effects experiments. It is possible that this need is already covered by the contamination monitoring system.

The accommodation of exposure samples is a matter that may warrant additional study. The experiment system proposed for mission TDMX2011 uses three large panels that serve as a host structure for a number of exposure trays similar to those used on the Long Duration Exposure Facility (LDEF). This system uses little in the way of power and data resources but requires long-term attachment. For this reason an approach should be developed for accommodating exposure samples that doesn't put them in competition with major payloads for attachment and resource interfaces.

TABLE IV-9. OUTFITTING NEEDS FOR EARLY-YEAR SPACE ENVIRONMENTAL EFFECTS MISSIONS

	PROGRAM YEAR 1					
	INTERNAL ENVIRONMENT		EXTERNAL ENVIRONMENT		COATINGS/SURFACE EFFECTS	
STATUS	ITEM	CAT	ITEM	CAT	ITEM	CAT
Planned	Battery Charger	LSE	Contamination monitor	PAE	Camera locker	LSE
	Dosimeter, passive	LSE	Data recorder, digital	Std	Camera, 35 mm	LSE
	Storage locker, EM-shielded	LSE	Mobile Servicing Center (MSC)	Std	Film locker	LSE
	Data recorder, digital	Std			Microscope system	LSE
	Storage, pressurized	Std			Workbench, laboratory sciences	LSF
					Storage, sample	LSS
					Contamination monitor	PAE
					Data recorder, digital	Std
					Hand tools, EVA general purpose	Std
Common-Use Potential	Audiometer		Exposure tray		Exposure tray	
	Noise dosemeter		Mass spectrometer		Mass spectrometer	
	Noise monitor		Sample containers		Sample containers	
	Power amplifier				Stress test machine	
	Radiation monitor, external					
	Radiation monitor, internal					
	Sample containers					
	Sound level meter					
	Tape recorder, audio					

E. Energy Systems and Thermal Management

The mission classification scheme for the Energy Systems and Thermal Management theme is presented in Table IV-10. The major areas of interest include electrical power system, propulsion, and heat rejection technologies. Mission equipment for this theme involves primarily large test beds that facilitate the evaluation of advanced technology components and subsystems. Possibilities for consolidating and coordinating experiments are identified in the comments column.

TABLE IV-10. SELECTION OF EXPERIMENTS FOR ENERGY SYSTEMS AND THERMAL MANAGEMENT RT&E FACILITY

SUBTHEME/PROJECTS	COUNT	PATH-FINDER	CSTI	OAST	COMMENTS	SELECTED EXPERIMENTS
Advanced Thermal Control						
Liquid Droplet Radiators	4				Coordinate with fluid behavior research	EP-6, EP-8
Radiator Panel Technology	3		√	√	Coordinate into thermal control test bed.	TDMX2132
Thermal Design/Interfacing	2					TDMX2565
Two-Phase Systems	4					
Energy Conversion						
Dynamic Conversion	5	√	√		Demonstrate as SS or platform supplemental power source.	TDMX2153
Laser Systems	3				Consider as evolutionary development.	
Photovoltaic Systems	5				Demonstrate as SS or platform supplemental power source.	TDMX2152
Solar Furnace Technology	2				Consider as evolutionary development.	
Power Management and Distribution						
Environmental Interaction	4		√		Combine with photovoltaic/dynamic conversion experiments.	SE-001
Megawatt Systems	1				Consider as evolutionary development.	
Propulsion						
Advanced Propulsion Concepts	3	√			Consider as evolutionary development or demonstrate/verify in application context.	
Contamination Effects	4				Coordinate with low thrust experiments.	AFEN-001
Low Thrust	6	√			Use SS for characterization and free-flyer for lifetime tests.	TDMX2321
	46					

Missions selected for the strawman complement are broadly representative of theme in-space research objectives. Top-level payload characteristics and accommodation requirements are presented in Table IV-11. Mission equipment is intended for either attached payload or coorbiting platform accommodation. No internal equipment is identified.

An implementation scenario for the selected missions is depicted in Figure IV-5. The solar power and radiator test experiments all require solar-inertial pointing. For the solar dynamic test bed this is achieved by placing the payload outboard of the alpha joint on the transverse boom to accommodate it as a growth power system element. The radiator test bed is shown as an attached payload, and a two-axis solar pointing mount would be required to maintain the radiator edge toward the sun. The photovoltaic test bed is shown accommodated on a coorbiting platform, and it is assumed that one- or two-axis gimballing would be built into the payload as required. However, a coorbiting platform may not be available during the early stages of the Space Station program, so configuration of this payload as a free-flyer is identified as an alternative.

TABLE IV-11. ACCOMMODATION REQUIREMENTS FOR ENERGY SYSTEMS AND THERMAL MANAGEMENT EXPERIMENTS

PROJECT/EXPERIMENTS	MISSION CODE	START YEAR	EXPT TYPE	DEFN CODE	DBL RACKS	ATTACH PORTS	WEIGHT (lb) EXPT	WEIGHT (lb) LOG	PWR (kW)	OTHER CONSIDERATIONS
Liquid Droplet Radiators										
LDR Orifice and Jet Behavior	EP-6	2	T/D	1		1				Equipment characteristics TBD.
Evaporation Loss Determinarion for LDRs	EP-8	2	T	1		Sh				Use same equipment as EP-6.
Radiator Panel Technology										
Advanced Radiator Concepts	TDMX2132	5	T	4		1	397		0.75	
Thermal Design/Interfacing										
Thermal Interface Technology	TDMX2565	1	D	2		1	1760		2.5	
Dynamic Conversion										
Solar Dynamic Power Tests	TDMX2153	1	D	4		1	2735	220/?	1	MRDB defines 20 kW_e system.
Photovoltaic Systems										
Large Space Power Systems Technology	TDMX2152	2	T	2		1	1335	220/yr	*	*Generates own power. May be configured as a free-flyer.
Environmental Interaction (Elec.)										
Environmental Interactions	SE-001	1	R/T	1		TBD			1	Consolidate with TDMX2152.
Contamination Effects (Propulsion)										
Space-Based Contamination and Flow-Field Experiments	AFEN-001	1	R	1						Equipment characteristics TBD.
Low Thrust (Propulsion)										
Low Acceleration Propulsion Technology	TDMX2321	2	R/T	2		1	55		1.5-5	

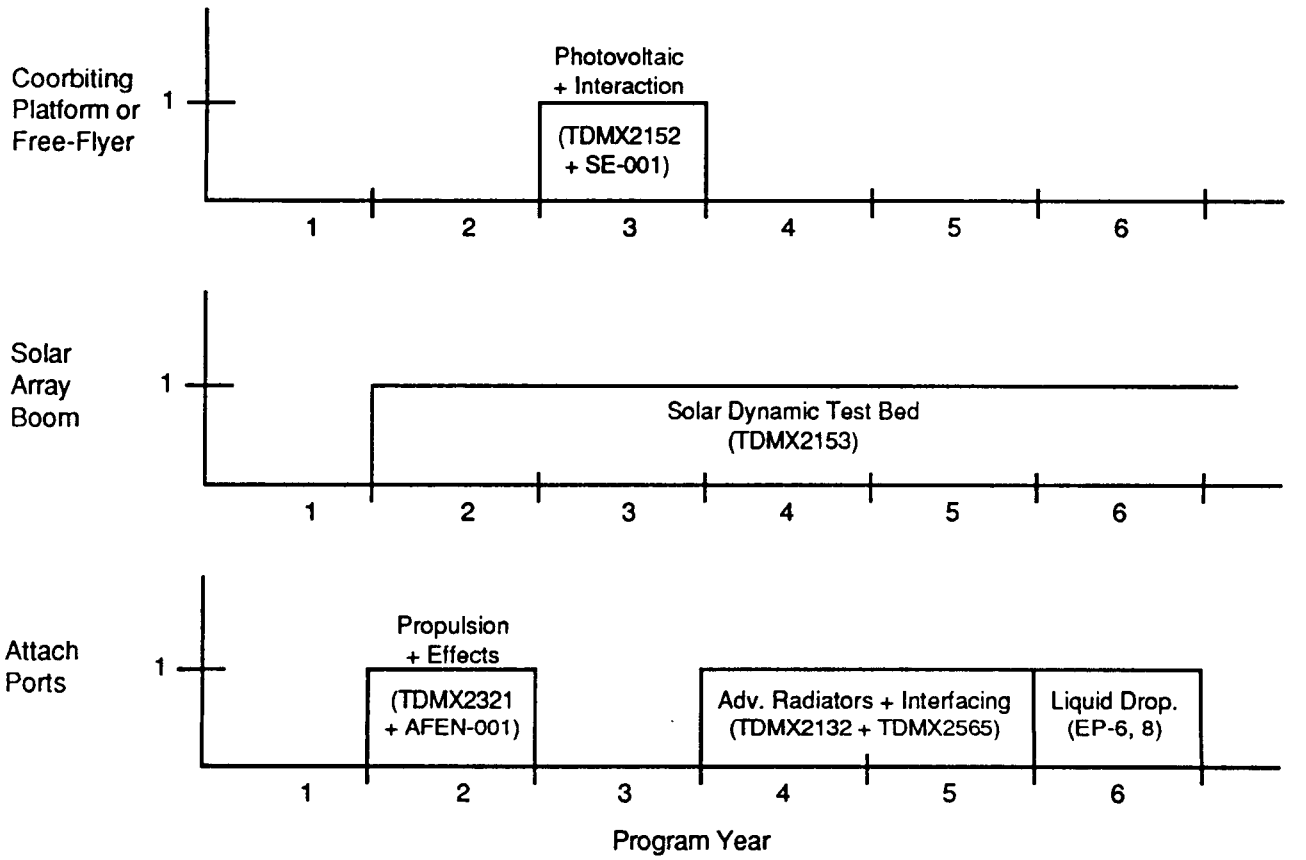


FIGURE IV-5. MISSION SCENARIO FOR ENERGY SYSTEMS AND THERMAL MANAGEMENT THEME

Potential outfitting needs for the initial years of the scenario are presented in Table IV-12. The equipment lists for both the low thrust and photovoltaic systems experiments contain several plasma diagnostic items. Also, it appears that an imaging radiometer may be useful for a number of applications such as observing exhaust plumes, monitoring temperature profiles of radiator panels, and monitoring photovoltaic arrays for hot spots.

TABLE IV-12. OUTFITTING NEEDS FOR EARLY-YEAR ENERGY SYSTEMS AND THERMAL MANAGEMENT MISSIONS

	PROGRAM YEAR 2				PROGRAM YEAR 3	
	LOW THRUST AND CONTAMINATION EFFECTS		DYNAMIC CONVERSION		PHOTOVOLTIC SYSTEMS AND ENVIRONMENTAL INTERACTION	
STATUS	ITEM	CAT	ITEM	CAT	ITEM	CAT
Planned	Microscope system	LSE	Contamination monitor	PAE	Contamination monitor	PAE
	Acceleration monitor, lab	LSS	Data recorder, digital	Std	Data recorder, digital	Std
	Contamination monitor	PAE	Hand tools, EVA general purpose	Std	Hand tools, EVA general purpose	Std
	Data recorder, digital	Std				
	Mobile Servicing Center (MSC)	Std	Video recorder	Std	Video recorder	Std
	Video recorder	Std	Video, external	Std		
Common-Use Potential	Accelerometer package, external		Camera, 35 mm (EVA)		Exposure tray	
	Imaging radiometer		Gas storage/transfer facility		Imaging radiometer	
	Mass spectrometer		Imaging radiometer		Magnetometer	
	Plasma diagnostic package		Pointing mount, two-axis solar		Mass spectrometer	
	Plasma ground		Storage, unpressurized		Plasma diagnostic package	
	Potential probe				Sun sensor	
	Reflectometer				Video, low light (external)	
	Sample containers					

F. Automation and Robotics

The mission classification scheme for the Automation and Robotics theme is presented in Table IV-13. After a review of experiment objectives only robotics missions were selected for the theme strawman complement. The evaluation of automation technologies in an operational context characteristically involves a host system, and it was felt that the primary outfitting impacts would be associated with the host systems and not the automation technologies per se. Top-level payload characteristics and accommodation requirements for the selected missions are presented in Table IV-14.

An implementation scenario is depicted in Figure IV-6. Little information was available on the lab robot. However, two double racks were assumed to be a reasonable allocation for storage and support for the lab robot during the first operational year. The Space Robotics Research Laboratory (SRRL) would be installed in the second operational year (delayed one year to minimize the rack space envelope) and require a double rack for a telerobotic workstation and one attachment port. The SRRL will serve as a host facility for a number of robotics experiments. Also in the second year, the OMV with the Flight Telerobotic Servicer would be used to accomplish the Materials Resupply mission.

Potential outfitting needs for the initial years of the scenario are presented in Table IV-15. It was assumed that the lab robot will be a largely self contained system. Also, a number of support items for external robotics may be provided as part of the SRRL.

TABLE IV-13. SELECTION OF EXPERIMENTS FOR AUTOMATION AND ROBOTICS RT&E FACILITY

SUBTHEME/PROJECTS	COUNT	PATH-FINDER	CSTI	OAST	COMMENTS	SELECTED EXPERIMENTS
Automation						
Autonomous Control	2	√	√		Verify in application context using other test beds or operational systems as host.	
Rendezvous/Docking	5	√			Verify with Shuttle, OMV, or ELVs as available.	
Robotics						
Advanced Concepts	1	√			Long-term. Needs definition.	
Free-Flight Dynamics	2	√			Verify with OMV and FTS.	
Remote Maintenance/ Servicing	2		√		Important capability for microgravity, astronomy, and remote sensing operations.	TDMX2563
Teleoperation	6	√	√	√*	Significant productivity/operations implications	AR-008, TDMX2473, TDMX2461
TOTAL	18					

*Preliminary manifesting

TABLE IV-14. ACCOMMODATION REQUIREMENTS FOR AUTOMATION AND ROBOTICS EXPERIMENTS

PROJECT/EXPERIMENTS	MISSION CODE	START YEAR	EXPT TYPE	DEFN CODE	DBL RACKS	ATTACH PORTS	WEIGHT (lb) EXPT	WEIGHT (lb) LOG	PWR (kW)	OTHER CONSIDERATIONS
Remote Maintenance/Servicing										
Materials Resupply	TDMX2563	2	D	2			TBD	TBD		Uses OMV with FTS for remote changeout of material samples.
Teleoperation										
Robot for Science Laboratories	AR-008	0	T	1	TBD		275		0.1	
Space Robotics Research Laboratory (SRRL)	TDMX2473	1	N/A	2	1	1	7000	770/ yr	1.2	SRRL facility hardware supports a number
Teleoperated Structure Assembly	TDMX2461	2	D	3		Shared	5510		2.8	Uses SRRL telerobotic workstation. External hardware mounts on SRRL carrier deck. Coordinates with Mobile Servicing Center (MSC).

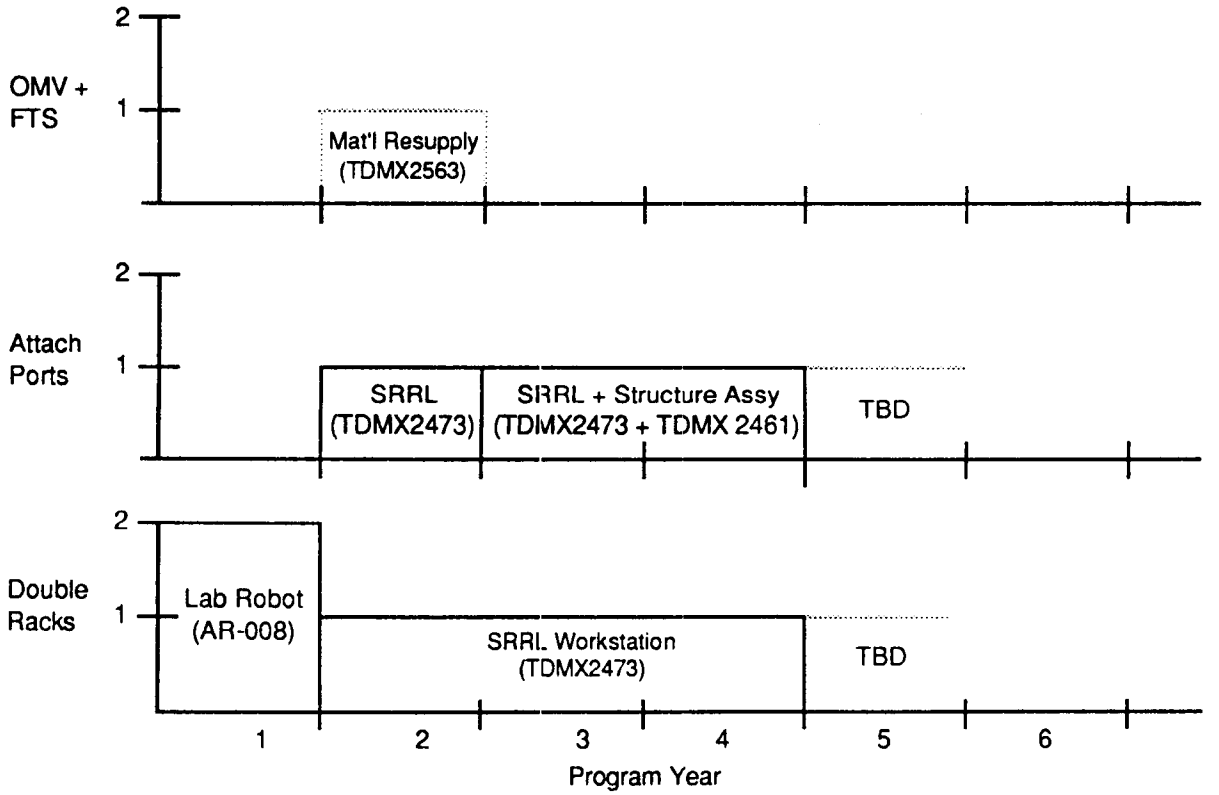


FIGURE IV-6. MISSION SCENARIO FOR AUTOMATION AND ROBOTICS EXPERIMENTS

TABLE IV-15. OUTFITTING NEEDS FOR EARLY-YEAR AUTOMATION AND ROBOTICS MISSIONS

	PROGRAM YEAR 1		PROGRAM YEAR 2			
	TELEOPERATION (LAB ROBOT)		REMOTE MAINTENANCE/SERVICING		TELEOPERATION (SRRL)	
STATUS	ITEM	CAT	ITEM	CAT	ITEM	CAT
Planned	Video Video recorder	Std Std	Data recorder, digital Video recorder	Std Std	Camera locker Camera, 35 mm Film locker Data recorder, digital Hand tools, EVA general purpose Mobile Servicing Center (MSC) Video recorder Video, external	LSE LSE LSE Std Std Std Std Std
Common-Use Potential	Workstation, telerobotic		OMV (with Smart Front End) OMV support systems Storage, unpressurized Workstation, teleoperations		(Accelerometer package, external) (Lighting, external) (Storage, unpressurized) (Video, external (SRRL)) Window, optical (Workstation, telerobotic) ( ) Provided by SRRL	

With regard to additional comments, the robotic activities will obviously be video intensive, and there is some concern about demands on the Space Station video system. Moreover, the question is raised as to whether some of the in-space objectives might be achieved by instrumenting the Flight Telerobotic Servicer and the robotic arm of the Mobile Servicing Center.

G. Information Systems

The mission classification scheme for Information Systems is presented in Table IV-16. This theme contained several one-of-a-kind missions as indicated by the project mission counts. Missions selected for the theme straw complement are broadly representative of theme objectives and include a mixture of internal, attached, and platform payloads. Top-level payload characteristics and accommodation requirements for the selected missions are presented in Table IV-17. While most of the numbers are reasonable, TDMX2264, a microwave radiometer, contains a major driver in the form of a 118 m antenna dish.

TABLE IV-16. SELECTION OF EXPERIMENTS FOR INFORMATION SYSTEMS RT&E FACILITY

SUBTHEME/PROJECTS	COUNT	PATH-FINDER	CSTI	OAST	COMMENTS	SELECTED EXPERIMENTS
Communication and Tracking						
Antenna Performance	2				Complementary experiments to large antenna deployment	TDMX2211
Component Technologies	1				Verify in application context	
Propagation	1				Potential experiments of opportunity	SE-009
Time Standards	1			√	Verify in application context	
Tracking -- Deep Space	3				Extend current laser satellite communications capability	TDMX2224
Tracking -- Proximity	2					
Data Systems						
Controls/Displays	4		√		Potential productivity benefits. Combine with human factor experiments.	CH-1, CH-2
Sensors						
Defense	1				Combine into sensor technology research facility	
Electro-Optical Sensors	4			√*		TDMX2262
Lidars	1		√			
Radars/Radiometers	3			√		TDMX2265, TDMX2264
Radio Astronomy	1				Assume operational system on platform/free-flyer	
TOTAL	24					

*Preliminary manifesting

TABLE IV-17. ACCOMMODATION REQUIREMENTS FOR INFORMATION SYSTEMS EXPERIMENTS

PROJECTS/EXPERIMENTS	MISSION CODE	START YEAR	EXPT TYPE	DEFN CODE	DBL RACKS	ATTACH PORTS	WEIGHT (lb) EXPT	WEIGHT (lb) LOG	PWR (kW)	OTHER CONSIDERATIONS
Antenna Performance										
Multi-Ftn Space Antenna Ring Tech	TDMX2211	2	T	3	0.5	1	860	TBD	0.7	Uses OMV as mobility platform for RF illuminator
Propagation										
40-105 GHz Propagation Experiments	SE-009	3	R	1		1	880		0.5	Earth pointing
Tracking -- Deep Space										
Space-Based Optical DSN Terminal	TDMX2224	2	T	3		1	440	TBD	1.0	Uses OMV and Payload Pointing System
Controls/Displays										
Physiological Control Systems in Low-g	CH-1	2	D	1	TBD		TBD			
Adv. Control/Display Concepts in Low-g	CH-2	7	D	1	TBD		TBD			
Electro-Optical Sensors										
Manned Observations Techniques	TDMX2262	1	T/D	2	TBD	1	TBD	130/	TBD	Uses Payload Pointing System (PPS)
Radars/Radiometers										
Satellite Doppler Meteorological Radar	TDMX2265	1	D	4		PP	4940		1.5	Downscaled TDMX2265. Flies on Polar Platform.
Microwave Remote Sensing - Passive	TDMX2264	6	D	4		COP	9040		0.5	118m diameter antenna flies on co-orbiting platform

An implementation scenario for the selected missions is depicted in Figure IV-7, and potential outfitting needs for the first two years of the scenario are presented in Table IV-18. The Electro-optical Sensors mission (Manned Observations) involves photographic activities using a hand-held camera as well as the control of pointed payloads mounted externally. For the Controls/Displays mission a set of support equipment was identified that would provide a programmed stimulus to the operator and would monitor operator response and physiological state for comparison with Earth-based experiments. It was assumed that the control unit would be a user-provided item. The deep space network (DSN) terminal experiment uses the OMV as a cooperative target.

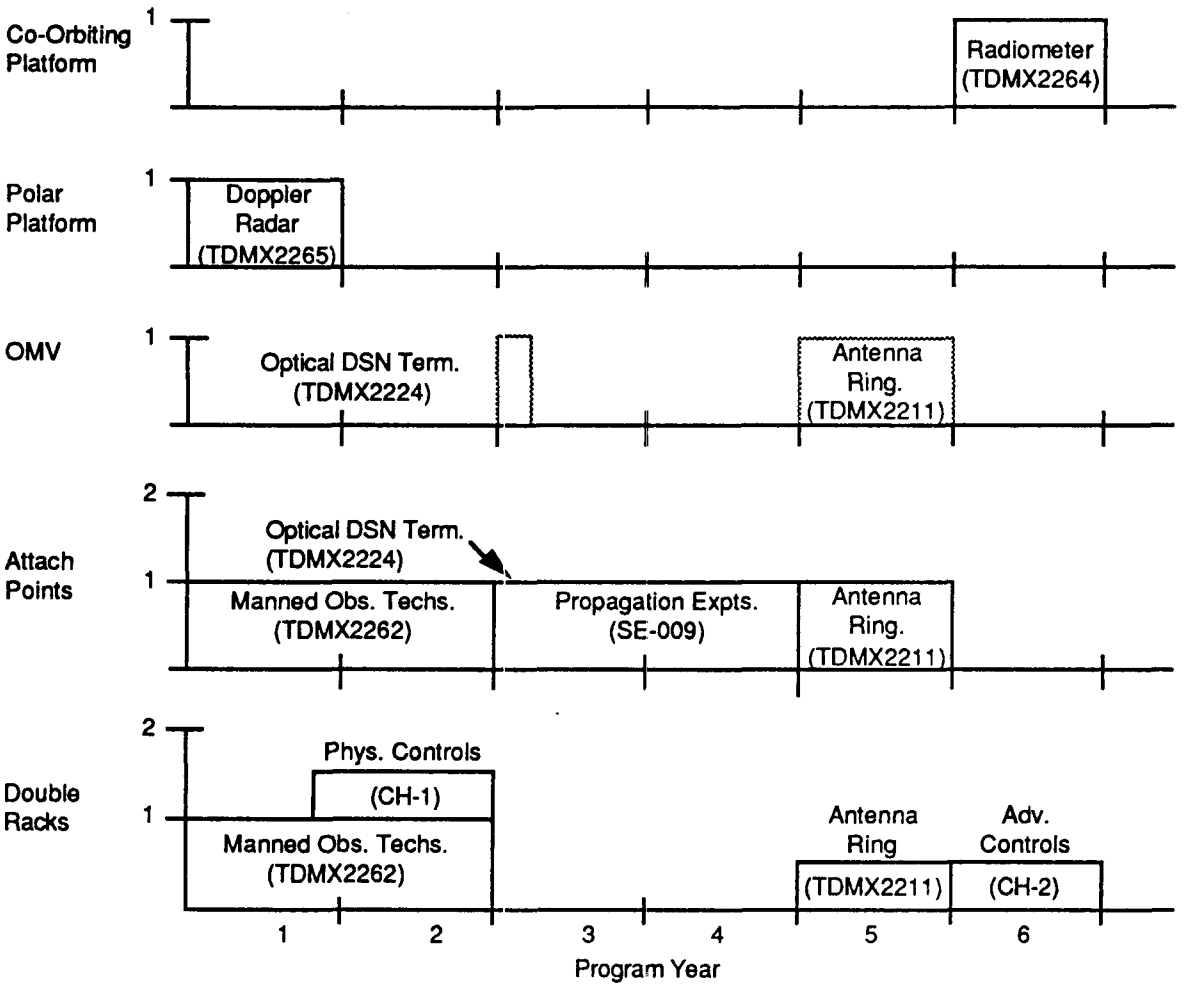


FIGURE IV-7. MISSION SCENARIO FOR INFORMATION SYSTEMS THEME

TABLE IV-8. OUTFITTING NEEDS FOR EARLY-YEAR INFORMATION SYSTEMS MISSIONS

	PROGRAM YEAR 1		PROGRAM YEAR 2			
	ELECTRO-OPTICAL SENSORS		CONTROLS/DISPLAYS		TRACKING -- DEEP SPACE	
STATUS	ITEM	CAT	ITEM	CAT	ITEM	CAT
Planned	Film locker	LSE	Storage locker, EM-shielded	LSE	Storage locker, EM-shielded	LSE
	Attitude Determination System (ADS)	PAE	Data recorder, digital	Std	Attitude Determination System	PAE
			Video	Std	Contamination monitor	PAE
	Contamination monitor	PAE	Video recorder	Std	Payload Pointing System	PAE
	Payload Pointing System (PPS)	PAE			Data recorder, digital	Std
	Data recorder, digital	Std				
	Video	Std				
Common-Use Potential	Battery storage		Computer, graphics/experiment control		Accelerometer package, external	
	Window, high-quality optical		Computer-video generator		OMV	
			Data recorder, audio		OMV support systems	
			Graphics display, high resolution		Storage, unpressurized	
			Physiological monitor			
			Speech generator			
			Tape recorder, audio			
			Visual task generator			

H. In-Space Operations

The In-Space Operations theme encompasses a highly diverse set of technologies as indicated by the mission classification scheme presented in Table IV-19. The missions selected for the strawman complement are representative of specific areas of the theme and, as it turned out, they consist entirely of pressurized volume (internal) payloads. Top-level payload characteristics and accommodation requirements for the selected missions are presented in Table IV-20.

An implementation scenario for the selected missions is depicted in Figure IV-8. Start years have been stretched in some cases to keep the experiment equipment within a four-rack envelope. Additional rack space would be required for support equipment.

Potential outfitting needs for the initial years of the scenario are presented in Table IV-21. Equipment sets representative of the other missions can be found in Appendix D. The semiconductor growth experiment overlaps microgravity research activities sponsored by other NASA organizations, and its outfitting needs are well covered by current outfitting plans. Likewise, the crew health experiment may need equipment that is a part of the Health Maintenance Facility, but the degree to which such equipment will be available for experiment use is not clear.

Table IV-21 illustrates very well the situation uncovered throughout the seven themes. Within focused areas of research (such as crew health, human factors, etc.) needs were identified for items that could be provided as common support equipment. In general, however, the need for such items is not widely shared either within the broad scope of the total mission set or within the more limited scope of the individual themes.

TABLE IV-19. SELECTION OF EXPERIMENTS FOR IN-SPACE OPERATIONS RT&E FACILITY

SUBTHEME/PROJECTS	COUNT	PATH-FINDER	CSTI	OAST	COMMENTS	SELECTED EXPERIMENTS
Biomedical						
Bends Avoidance/ Therapy	3	√			Include in flight crew health research facility	
Diagnosis/Treatment	1	√			Improved capability for emergency treatment and long-duration health maintenance	TDMX2531
Physiological Effects of Low-g	4	√		√	Include in flight crew health research facility	SO-007a
Human Factors						
Cognition	4	√			Consolidate into human factors research facility	CH-6
Crew Productivity	1	√				
Interaction	4	√	√			CH-3
Maintenance, Repair, and Test Test						
Cleaning/Refurbishment	3				Do as checkout of operational maintenance/servicing systems	
Inspection/Test	1					
Satellite Servicing	4	√				
Material Processing						
Composites	2				Include in microgravity facility	AFSO-005
Crystal Growth	2					TDMX2022
Fluids	4					TDMX2024
Materials Characterization	1				Accomplish under individual experiments	
Process Technology	4	√			Re-examine need for in-space experiments	
Sample Handling/Storage	1	√			Do as checkout of operational system	
Solid Propellants	2				Safety Concerns	
Systems/Facilities						
CELSS	4				Explore selected aspect of closed cycle	SS-1
Manned Systems	1	√			Involves checkout of manned Mars capsule	
OTV	3				Consider as evolutionary development	
Reentry Systems	2	√	√		May better be done from Shuttle/ELVs	
Technology Evaluation	1				Accomplish within individual experiments	
Tethers	5	√			Significant accommodation impacts	
TOTAL	57					

TABLE IV-20. ACCOMMODATION REQUIREMENTS FOR IN-SPACE OPERATIONS EXPERIMENTS

PROJECT/EXPERIMENTS	MISSION CODE	START YEAR	EXPT TYPE	DEFN CODE	DBL RACKS	ATTACH PORTS	WEIGHT (lbl EXPT	LOG	PWR (kW)	OTHER CONSIDERATIONS
Diagnosis/Treatment										
Surgery Technology Development	TDMX2531	3	T/D	2	2		220	TBD	0.3	
Physiological Effects of Low-g										
Flight Crew Health	SO-007a	1	R	1	3		980	TBD	0.36	
Cognition										
Visual Space Perception	CH-6	1	R	1	1		TBD		<0.5	
Interaction										
Eval. of Human Fine Motor Performance	CH-3	1	R	1	1		TBD		<0.5	
Composites										
Space Fiber Production	AFSO-005	4	T	1	TBD		TBD			Microgravity environment
Crystal Growth										
Growth of Comp. Semicond. Crystals	TDMX2022	1	D	2	1		440	150/m	2.5	Microgravity environment
Fluids										
Electrophoresis Separation Technology	TDMX2024	1	T/D	4	1.5		990	550/6m	1.0	Microgravity environment
CELSS										
Plant Growth Chamber	SS-1	1	D	1	2-3		TBD	TBD	1-5	

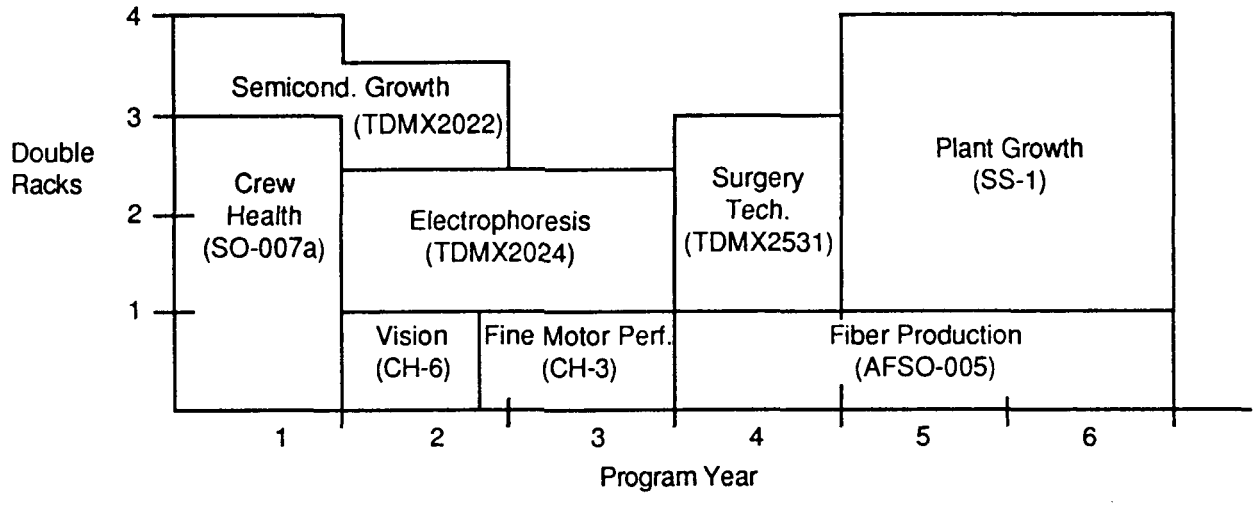


FIGURE IV-8. MISSION SCENARIO FOR IN-SPACE OPERATIONS

TABLE IV-21. OUTFITTING NEEDS FOR EARLY-YEAR IN-SPACE OPERATIONS MISSIONS

	PROGRAM YEAR 1		PROGRAM YEAR 2			
	CREW HEALTH		SEMICONDUCTOR GROWTH		HUMAN FACTORS	
STATUS	ITEM	CAT	ITEM	CAT	ITEM	CAT
Planned	Freezer	LSE	Cleaning equipment	LSE	Storage locker, EM-shielded	LSE
	Refrigerator	LSE	Cutting/polishing system	LSE	Data recorder, digital	Std
	Data recorder, digital	Std	Etching equipment	LSE	Video	Std
			Fluid handling tools	LSE	Video recorder	Std
			Hand tools, general purpose	LSE		
			Mass measurement device, small	LSE		
			Microscope system	LSE		
			Multimeter, digital	LSE		
			X-ray system	LSE		
			Glovebox, materials processing	LSF		
			Workbench, laboratory sciences	LSF		
			Acceleration monitor, lab	LSS		
			Chemical storage facility	LSS		
			Waste disposal system	LSS		
Common-Use Potential	Amplifiers		Hall probe		Anechoic chamber	
	Blood sample kit		Optical pyrometer		Computer-video generator	
	Centrifuge		Video, high resolution		Data recorder, audio	
	Dynamometer				Electrode impedance meter	
	Electrode impedance meter				Graphics display, high resolution	
	Ergometer				Joystick	
	Plethysmograph				Physiological monitor	
	Tape recorder, audio				Speech generator	
	Treadmill				Visual pulse generator	
	Urine sample kit				Visual task generator	

I. Cross-Theme Relationships in the Mission Set

The previous sections addressed theme-oriented mission groups as the basis for in-space laboratory facilities. However, there are complementary relationships among project-level technology thrusts that cut across theme boundaries, and the potential exists for defining coordinated RT&E facilities that accommodate multiple objectives. The more significant relationships as they pertain to the set of 241 missions in the study set are presented in Table IV-22.

TABLE IV-22. COMPLEMENTARY PROJECT OBJECTIVES MAY PROVIDE A BASIS FOR COORDINATED RT&E FACILITIES

COORDINATED RT&E FACILITY	RELATED PROJECT GROUPS	THEME
Large Structures	Large Structures (General)	Space Structure (Dynamics and Control)
	Thermal Design	Space Structure (Dynamics and Control)
	Sensors/Actuators	Space Structure (Dynamics and Control)
	Assembly	Space Structure (Dynamics and Control)
	Teleoperations	Automation and Robotics
	Structural Materials	Space Environmental Effects
Large Antennas	Antennas/Reflectors	Space Structure (Dynamics and Control)
	Sensors/Actuators	Space Structure (Dynamics and Control)
	Thermal Design	Space Structure (Dynamics and Control)
	Antennas Performance	Information Systems
	Radars/Radiometers	Information Systems
	Radio Astronomy	Information Systems
Segmented Optics	Segmented Optics	Space Structure (Dynamics and Control)
	Antennas/Reflectors	Space Structure (Dynamics and Control)
	Assembly	Space Structure (Dynamics and Control)
	Thermal Design	Space Structure (Dynamics and Control)
	Pointing/Isolation	Space Structure (Dynamics and Control)
	Cryogens-Helium	Fluid Management
Solar Thermal	Antennas/Reflectors	Space Structure (Dynamics and Control)
	Dynamic Conversion	Energy Systems and Thermal Management
	Solar Furnace Technology	Energy Systems and Thermal Management
Controls and Human Factors	Controls/Displays	Information Systems
	Cognition	In-Space Operations
	Interaction	In-Space Operations
	Physiological Effects of Low-g	In-Space Operations
	Autonomous Control	Automation and Robotics
Thermal Control	Radiator Panel Technology	Energy Systems and Thermal Management
	Thermal Design/Interfacing	Energy Systems and Thermal Management
	Two-Phase Systems	Energy Systems and Thermal Management
Spacecraft Systems	Assembly	Space Structure (Dynamics and Control)
	Attitude Control	Space Structure (Dynamics and Control)
	Satellite Servicing	In-Space Operations
	Photovoltaic Systems	Energy Systems and Thermal Management
	Low Thrust	Energy Systems and Thermal Management
Electric Power/ Propulsion	Photovoltaic Systems	Energy Systems and Thermal Management
	Environmental Interaction	Energy Systems and Thermal Management
	Low Thrust	Energy Systems and Thermal Management
	Contamination Effects	Energy Systems and Thermal Management

V. CONCLUSIONS

Descriptive materials on a set of 241 mission concepts have been reviewed to establish preliminary Space Station outfitting requirements for technology development. These missions cover, in a representative way, the full range of in-space technology development activities envisioned for the early years of Space Station operations and include both pressurized-volume and attached payloads. Identified requirements were compared with outfitting plans for the life sciences and microgravity user communities and the following conclusions were drawn:

- The great majority of accommodation requirements for technology payloads are captured by Space Station standard accommodations and current outfitting plans.
- A number of potential outfitting additions were identified; however, inputs from technology PIs are essential to refine and validate these findings and to establish priorities and performance specifications for equipment development.
- While the Space Station must support all types of technology missions, technology payload planning should emphasize research- and development-phase missions and de-emphasize demonstration-phase missions. The latter can be sponsored by major system projects as part of advanced development and operational checkout activities.
- Some experiment objectives may be achieved by taking advantage of the Space Station itself as a test article of opportunity. If suitably instrumented, it could be an important source of data on structural dynamics. Likewise, the MSC and fluid systems (including the logistics module) may provide useful data points on robotics and fluid management technologies.
- The mission set contains several distributed experiment systems, and a recommended approach for accommodating such payloads needs to be developed. Several other accommodation issues were raised relating to exposure samples, solar-pointed payloads (solar arrays, radiator test panels, etc.), and robotics.
- A number of research interests could benefit from the consolidation of objectives around special-purpose research facilities (e.g., Space Station LDEF, a Human Factors Research Facility, etc.)
- The scope of the technology mission set overlaps microgravity and life sciences (especially health maintenance) research interests.
- Some experiment concepts are becoming outdated due to continued progress in NASA and DOD technology programs.

In response to these conclusions several recommendations are made for follow-up actions in support of NASA planning for technology payload development and Space Station utilization.

- Develop and maintain a technology mission model that reflects a realistic and appropriate role for in-space research, test, and evaluation. Such a mission model can play an important role as a point of reference for a variety of study and planning activities. Toward this end it is

recommended that the technology thrusts be focused and prioritized taking into account future system needs, DOD and commercially sponsored developments, and NASA organizational charters. Likewise, it is recommended that applied research and component technology missions be emphasized and that mission start years reflect a supportable time phasing.

- Update and refine individual mission concepts to provide the necessary definition data for accommodation studies. This effort should consolidate experiment objectives as appropriate, identify needed support equipment, consider opportunities to use the Space Station itself as a test object, and address conceptually the packaging of payload equipment for delivery to orbit.

- Perform accommodation studies to identify, explore, and resolve mission accommodation issues. Such studies should address the complete mission cycle.

- Involve technology PIs in validating and refining the outfitting equipment needs identified in the current study.

APPENDIX A. Reference Documents for Mission Requirements

A set of 37 government-furnished report volumes constituted the primary source of descriptive information on technology development mission characteristics and requirements. Each volume was assigned a log number that was used for reference purposes during the course of the study. Reports printed in multiple volumes such as the proceedings of the Williamsburg workshop were assigned multiple log numbers to facilitate requirements traceability. The volumes are listed here in log-number sequence.

1. Space Station Experiment Definition; Liquid Droplet Radiator Test Bed, Sverdrup Technology Inc. for NASA/Lewis Research Center, Task order No. 5405-03, Revised January 24, 1986.

2. Concept Definition for Space Station Technology Development Experiments, Experiment Definition, NASA CR-178153, Research Triangle Institute for NASA/Langley Research Center, Contract NAS1-17639, April 1986.

3. Conceptual Definition of a Technology Development Mission for Advanced Solar Dynamic Power Systems, NASA CR-179482, Sverdrup Technology, Inc. for NASA/Lewis Research Center, Contract NAS3-24105, July 1986.

4. Concept Definition for Space Station Technology Development Experiments, Preliminary Mission Concept Development, RTI/3042/08-01F, Research Triangle Institute for NASA/ Langley Research Center, Contract NAS1-17639, September 1986.

5. Mission Requirements Data Base Data Diagnostic Report, JSC- 20798, NASA/Johnson Space Center, March 1987.

6. Planning Guide for In-Space Technology Experiments Using the National Space Station Complex, Executive Summary, General Research Corporation for NASA/Office of Aeronautics and Space Technology (Code RS), Contract NASW-4138, First Edition 1986.

7. Planning Guide for In-Space Technology Experiments Using the National Space Station Complex, General Research Corporation for NASA/Office of Aeronautics and Space Technology (Code RS), Contract NASW-4138, First Edition 1986.

8. Space Station Technology Development Mission Analysis, Battelle, Columbus Division for NASA/Lewis Research Center, Contract NAS3- 23895, August 15, 1986.

9. Space Station Technology Development Mission Experiment Definition Study, Final Report, JPL D-2395, NASA/Jet Propulsion Laboratory, October 1985.

10. Space Station Structural Performance Experiment, Task 5 Final Report, Boeing Aerospace Company for NASA/Langley Research Center, Contract NAS1-18224, August 29, 1986.

11. IOC Model Technology Experiments Evaluation, Task 4 Final Report, NASA TM-100656, Boeing Aerospace Company for NASA/Langley Research Center, Contract NAS1-18224, January 30, 1987.

12. In-Space Research, Technology and Engineering (RT&E) Workshop, Volume 1: Executive Summary, NASA/Langley Research Center and NASA/Office of Aeronautics and Space Technology, October 1985.

13. In-Space Research, Technology and Engineering (RT&E) Workshop, Volume 2: Space Structure (Dynamics and Control), NASA/Langley Research Center and NASA/Office of Aeronautics and Space Technology, October 1985.

14. In-Space Research, Technology and Engineering (RT&E) Workshop, Volume 3: Fluid Management, NASA/Langley Research Center and NASA/Office of Aeronautics and Space Technology, October 1985.

15. In-Space Research, Technology and Engineering (RT&E) Workshop, Volume 4: Space Environmental Effects, NASA/Langley Research Center and NASA/Office of Aeronautics and Space Technology, October 1985.

16. In-Space Research, Technology and Engineering (RT&E) Workshop, Volume 5: Energy Systems and Thermal Management, NASA/Langley Research Center and NASA/Office of Aeronautics and Space Technology, October 1985.

17. In-Space Research, Technology and Engineering (RT&E) Workshop, Volume 6: Information Systems, NASA/Langley Research Center and NASA/Office of Aeronautics and Space Technology, October 1985.

18. In-Space Research, Technology and Engineering (RT&E) Workshop, Volume 7: Automation and Robotics, NASA/Langley Research Center and NASA/Office of Aeronautics and Space Technology, October 1985.

19. In-Space Research, Technology and Engineering (RT&E) Workshop, Volume 8: In-Space Operations, NASA/Langley Research Center and NASA/Office of Aeronautics and Space Technology, October 1985.

20. TDMX2066 Large Inflatable/Rigidized Structures, Final Review, Wyle Laboratories for NASA/Marshall Space Flight Center, Contract NAS8-36410, August 22, 1986.

21. Conceptual Definition On-Orbit Generic Maintenance Test-Bed, Phase V Summary Report Presentation, Rockwell International for NASA/Kennedy Space Center, Contract NAS10-11095, January 9, 1987.

22. Space Transportation System Maintenance Technology Study, Phase IV Summary Report, KLO-86-004, Rockwell International for NASA/Kennedy Space Center, Contract NAS10-11095, May 30, 1986.

23. Advanced Photovoltaic Test Bed Study, Technical Presentation to NASA's Technology Development Advocacy Group (TAG), Ford Aerospace & Communications Corporation for NASA/Lewis Research Center, Contract NAS3-24664, July 14, 1986.

24. LDR Structural Experiment Definition, Task 6 Final Report, NASA TM-10018, Boeing Aerospace Company for NASA/Langley Research Center, Contract NAS1-18224, January 30, 1987.

25. Concept Definition Study of High Voltage in Space Plasma, Final Report Draft, SSS-R-86-7615, S-Cubed for NASA/Johnson Space Center, Contract NAS9-17421, November 1985.

26. Space Station Manned Earth Observations Technique Development, Results of Recent Literature Review of Interface Requirements for Earth Viewing Remote Sensors, LEMSCO-22020, Lockheed Engineering and Management Services Co., Inc. for NASA/Johnson Space Center, Contract NAS9-15800, September 1985.

27. Definition of Technology Development Mission for Early Space Station - TDMX2066 Large Inflatable/Rigidized Structures, Final Report, Wyle Laboratories for NASA/Marshall Space Flight Center, Contract NAS8-36410, June 1987.

28. Electrophoresis Technology Development Mission Study, Preliminary Draft, McDonnell Douglas Astronautics Company for The University of Texas Health Science Center, March 23, 1987.

29. Mankins, J. C., and Marzwell, N. I., Space Station Technology Development Experiment Definition Study, Volume 2: Automation & Robotics Technology Theme, Final Report Draft, NASA/Jet Propulsion Laboratory, December 1986.

30. Pollard, H. E. and Neff, R. E., Space Station Experiment Definition: Advanced Power System Test Bed, Final Report, NASA CR-179502, Ford Aerospace & Communications Corporation for NASA/Lewis Research Center, Contract NAS3-24664, December 15, 1986.

31. Air Force Space Station Working Group Summary Report - Identification of Potential R&D Needs, Volume II: Appendixes, Aerospace Report No. TOR-0086 (6911-04)-1, The Aerospace Corporation for Space Division Air Force Systems Command, Contract No. FO4701-85-C-0086, December 16, 1985.

32. On-Orbit Technology Experiment Accommodation, Task 9 Final Report, NASA TM-100614, Boeing Aerospace Company for NASA/Langley Research Center, Contract NAS1-18224, July 17, 1987.

33. Laboratory Services for RT&E and Microgravity Science and Applications Experiments on the Space Station Complex, General Research Corporation for NASA/Office of Aeronautics and Space Technology, June 1987.

34. Jetley, R. L. and Scarlotti, R. D., Space Station Experiment Definition: Long-Term Cryogenic Fluid Storage, NASA CR-4072, Beech Aircraft Corporation for NASA/Lewis Research Center, Contract NAS3-24661, June 1987.

35. Definition of Technology Development Mission for Early Space Station - TDMX 2131 Radiator Technology, Executive Summary, Wyle Laboratories for NASA/Marshall Space Flight Center, Contract NAS8-36410.

36. Definition of Technology Development Mission for Early Space Station - TDMX 2131 Radiator Technology, Final Report, Wyle Laboratories for NASA/Marshall Space Flight Center, Contract NAS8-36410.

37. Space Station Mission Requirements Data Base, JSC-32072, NASA/Johnson Space Center, January 1987.

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APPENDIX B. TECHNOLOGY MISSION SET

The technology mission set is presented here grouped by theme, subtheme, and project according to the classification scheme described in Section II.C. Missions included in the January 1987 edition of the Mission Requirements Data Base (MRDB) are identified by an asterisk.

Each mission was assigned a code that served as a key entry in the computerized data base. Codes from the MRDB, the Battelle report, and other sources were used where available. Otherwise one was invented. The invented codes are recognizable by a three-digit numerical string and include an alphabetic prefix that, in general, identifies the theme. Air Force missions were assigned codes that begin with 'AF'. A lower case alphabetic suffix was used to indicate either multiple phases of a mission or subsidiary experiments. These additional entries were not included in the total mission count.

With regard to the other columns, TDMX mission names were entered exactly as they appear in the MRDB. Other mission/experiment names were abbreviated to fit within the selected character count (40 characters). The research, development, and demonstration mission types described in Section II.D are represented by R, T, and D, respectively. Where the type identifier appears in parentheses, a mission type was inferred based on the system description presented. Finally, the year is the requested start year relative to Space Station initial operation. Year 0 signifies a possible shuttle/Spacelab flight in advance of Space Station.

SPACE STRUCTURE (DYNAMICS AND CONTROL)

SUBTHEME: Advanced Structures

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Assembly				
SS-008	EVA Large Structure Assembly	MDAC-HB	D	0
* TDMX2061	Large Space Structures	NASA/MSFC	D	1
* TDMX2062	Space Station Modifications	NASA/MSFC	D	1
* TDMX2063	On Orbit Spacecraft Assy/Test	NASA/MSFC	T/D	2
SS-012	Large Deployable Reflector SS Impact	LMSC/ARC	D	6
Segmented Optics				
* TDMX2421	Active Optic Technology	NASA/ARC	T/D	1
SS-004	Precision Optical System Assembly	BAC-Seattle	D	3
SS-013	TDM for Large Deployable Reflector	Kodak/ARC	D	4
Thin Film/Inflatable Structures				
AFSO-004	Thin Film Deployment Feasibility Expt.	AFRPL/XRX	T	2
AFSO-006	Bubble Structure Technology	AFRPL/XRX	R/T	2
MS-13	Injection Molding of Structural Elements	Battelle	T	3
SS-014	Structural Concepts Research Facility	MIT	T	3
* TDMX2066	Inflatable/Rigidizable Struc. Ele	NASA/MSFC	D	4
Trusses				
MS-12	Space Frame Pyramid Stiffening	Battelle	D	3
Welding				
SO-006	On-Orbit Welding	MM-Michoud Aero.	D	0
* TDMX2065	Ion Beam Cold Welding	NASA/LeRC	D	1
TDMX2581c	Electron Beam Welding Experiment	NASA/KSC	D	4

SPACE STRUCTURE (DYNAMICS AND CONTROL)

SUBTHEME: Mechanisms/Controls

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Attitude Control				
SS-005	Attitude Control and Energy Experiment	NASA/GSFC	T	1
• TDMX2431	Advanced Control Device Tech	NASA/LaRC	D	3
Pointing/Isolation				
• TDMX2432	Pointing and Isolation Devices	NASA/LaRC	D	1
AR-002	Astrometric Telescope Auto. Operation	NASA/ARC	(D)	3
SS-6	Acceleration Reduction Chamber	Battelle	T/D	4
Sensors/Actuators				
SS-001	Fiber Optic Sensors in Space Appl.	MDAC-HB	D	1
• TDMX2072	S/C Strain and Acoustic Sensors	NASA/LaRC	D	1
AFSS-001	Sensor/Actuator Interactions	AFRPL/XRX	T	2
MS-11	Adv. Mechanisms and Control System Comp.	Battelle	T	4
MS-15	Appl. of AI/Expert Sys. for Struc. Mon.	Battelle	D	4
Tribological Effects				
EP-3	Solid Film Lubri. of Bearings and Joints	Battelle	T	1
EP-4	Dyn. of Rotating Mach. During Maneuvers	Battelle	T	1
EP-5	Oil Lubrication of Bearings and Joints	Battelle	T	1
SS-016	Polymeric Materials for Space Mechanisms	NASA/LeRC	R	1
SS-011	Environ. Influence on Struc. Dynamics	MIT	R	3

SPACE STRUCTURE (DYNAMICS AND CONTROL)

SUBTHEME: Structural Dynamics

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Antennas/Reflectors				
SS-002	Control of Flexible Structures	NASA/LaRC	T	0
* TDMX2071	Flight Dynamics Identification	NASA/JPL	R/T	1
* TDMX2111	Deploy Large Solar Concentrator	NASA/LaRC	D	1
SS-009	Large Space Reflectors Flt Expts on SS	NASA/JPL	T	2
SS-018	Large Space Antenna (Reflectors)		T	2
* TDMX2411	Advanced Adaptive Control	NASA/JPL	T	2
* TDMX2412	Distributed Control Experiment	NASA/JPL	T/D	2
SS-015	Large Space Structures Disturb. Supress.	NASA/JPL	T/D	3
* TDMX2413	Dynamic Disturbance Experiment	NASA/JPL	T/D	3
EP-10	Shape Control for Solar Concentrator	Battelle	T/D	4
* TDMX2064	Advanced Antenna Assy/Perform.	NASA/MSFC	D	6
Large Structures (General)				
MS-8	Dynamic Behavior of Structures in Space	Battelle	T	1
SS-007	In-Space Actively Controlled Structures	NASA/GSFC	T	1
MS-5	Damping Response of Struc. Element Matls	Battelle	T	4
Space Station Dynamics				
SS-017	SS Structural Characterization Expt.	NASA/LaRC	D	1
* TDMX2073	Adv. Struct. Dyn/Controls	NASA/LaRC	T/D	1
TDMX2414	Advanced Controls	NASA/LaRC	T	1
Thermal Design				
MS-9	Thermal Response of Structures in Space	Battelle	T	1
* TDMX2422	Thermal Shape Control	NASA/LaRC	T	1
MS-14	Therm. Design of Composite Antenna Dish	Battelle	D	5

FLUID MANAGEMENT

SUBTHEME: Fluid Behavior

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Helium				
FM-009	Quantized Vortex Structure in SfHe	NASA/JPL	R	1
Liquid Streams				
FM-004	Liquid Stream Space Technology Facility	Univ. So. Cal.	R/T	TBD
Two-Phase Fluids				
AFFM-001	Two-Phase Fluids for Heat Transport Sys.	AFWAL/POOC	R	0
FM-010	Liquid-Vapor Flow in Microgravity	GDC/JSC	R	0
EP-1	Evaporation and Condensation Phenomena	Battelle	R	1
AFEN-002	Two-Phase Fluid Heat Transfer Correl.	AFWAL/FI	R	2
FM-003	Two-Phase Fluid Behavior and Management	NASA/LeRC	R/T	2

SUBTHEME: Fluid Storage/Transfer

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Cryogens				
FM-005	Cryogenic Fluid Management Facility	NASA/LeRC	T/D	0
AFFM-003	Sorption Compressor Refrigeration Sys.	AFWAL/FI	D	2
FM-001	Long-Term Cryo. Storage Facility Demo.	GDC/MSFC	D	2
• TDMX2311	Long-Term Cryogenic Fluid Storage	NASA/LeRC	D	2
• TDMX2572	Cryo Prop Transfer/Stor/Reliq	NASA/MSFC	D	2
AFFM-004	Magnetic Refrig. Space Flight Validation	AFWAL/FI	D	3
AFFM-002	Passive/Active Cooling for Cryo.	AFRPL/XRX	D	4
Cryogens -- Helium				
FM-002	Helium Transfer in Space	NASA/ARC	R/D	5
Sensors/Gauges				
FM-008	Ultrasonic Fluid Measurement	Worcester Poly.	T	0

SUBTHEME: Spacecraft Fire Safety

Flame Spread Mechanisms				
FM-007	Spacecraft Fire Safety Technology	NASA/LeRC	R/T	1

SPACE ENVIRONMENTAL EFFECTS

SUBTHEME: Environment Characterization

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
External Environment				
AFSE-006	Gas Chromatograph	AFGL/XO	R	1
SE-017	Environmental Contam Characteristics Exp	NASA/GSFC	R	1
SS-5	Real-Time Monitoring of SS Environment	Battelle	R	1
SE-004	Collision-Free Plasma Experiment	NASA/LeRC	R	4
AFSE-007	Gaseous Environment Monitor (GEM)	AFGL/XO	R	TBD
Internal Environment				
AFSE-001	Radiation Measurements Experiment (RME)	AFTAC	R	0
AFSE-002	Heavy Ion & Neutron Environments in S/C	USAF/AMD	R	1
SE-005	In-Situ Trace Contaminant Analysis	NASA/LaRC	T	1
* TDMX2521	Acoustics Control Technology	NASA/LaRC	T/D	1

SUBTHEME: Environmental Effects

Coatings/Surface Effects				
SE-006	Adv. Solar Concentrator Materials Expt.	NASA/LeRC	R/T	0
SE-008	Atomic Oxygen Effects Experiment	NASA/JSC	R	0
SE-002	Spacecraft Glow and Erosion	Vanderbilt U.	R	1
* TDMX2011	Spacecraft Materials & Coatings	NASA/LaRC	R/T	1
SE-003	Effects of Space Exposure on Materials	NASA/LeRC	R	2
AFSE-003	Contamination Effects and Control Expt.	AFWAL/ML/P	R/T	TBD
AFSE-004	Space Environmental Effects	AFWAL/ML/P	R	TBD
Data System Effects				
* TDMX2441	Microelectronics Data Syst Expt	NASA/JPL	T	1
* TDMX2442	Transient Upset Phenomena - VLSI	NASA/LaRC	T	1
* TDMX2443	VHSIC Fault Tolerant Processor	NASA/LaRC	T	1
Facilities				
SE-014	Space Ultra-Vacuum Facility: Wake Shield	UAH	D	1
SE-019	Variable Gravity Experiment Facility	NASA/JSC	N/A[1]	6
Micro-meteoroid Impacts				
MS-2	Effects of Hypervelocity Impact	Battelle	R	2
SS-010	Micro-Meteorite Protection	MIT	R/T	4
Solid Rocket Motors				
AFSO-010	Solid Propellant Reliability in Space	AFRPL/XRX	R	1
AFSO-011	Solid Propellant Motor Exposure Study	AFRPL/XRX	T	1
Structural Materials				
AFSE-005	Composite Durability in Space	AFRPL/XRX	R	1
MS-10	Environmental Exposure Data Collection	Battelle	R	1
MS-1	Service Life Estimation	Battelle	R	3
TDMX2581b	Strut NDT Baseline Evaluation	NASA/KSC	R	3

1. Not appropriate as a TDM

ENERGY SYSTEMS AND THERMAL MANAGEMENT

SUBTHEME: Advanced Thermal Control

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Liquid Droplet Radiators				
EP-6	LDR Orifice and Jet Behavior	Battelle	T/D	2
EP-7	LDR Jet Trajectory and Collection System	Battelle	T	2
EP-8	Evaporation Loss Determination For LDR's	Battelle	T	2
EP-9	Radiation Effectiveness of LDR's	Battelle	T	2
Radiator Panel Technology				
AFEN-004	Survivable Lightweight Radiator Panel	AFWAL/FI	T/D	2
* TDMX2132	Advanced Radiator Concepts	NASA/LeRC	T	5
* TDMX2131	Radiator Technology	NASA/MSFC	D	7
Thermal Design/Interfacing				
MS-4	Therm. Design of Space System Components	Battelle	T	1
* TDMX2565	Thermal Interface Technology	NASA/MSFC	D	1
Two-Phase Systems				
EN-001	Thermal Management	NASA/LeRC	R/T	0
EN-013	Flow Boiling Thermal Management		R/T	1
EP-11	Heat Pipe Perf. and Reliability in Low-G	Battelle	T	1
EP-2	Perf. of Two-Phase Thermodynamic Systems	Battelle	D	4

SUBTHEME: Energy Conversion

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Dynamic Conversion				
AFEN-003	Thermal Energy Storage (TES) Flight Test	AFWAL/POOC	T/D	0
SE-026	Adv. Power Sys. Thermal Energy Storage	NASA/LeRC	T	0
SE-027	Energy Storage for Solar Dyn. Power Sys.	Sunstrand	T	0
* TDMX2153	Solar Dynamic Power Tests	NASA/LeRC	D	1
FM-006	Two-Phase Fluid Mgt. for Liquid Metals	NASA/LeRC	T	TBD
Laser Systems				
EN-006	Nuclear Pumped Lasers	U of Illinois	R	1
* TDMX2121	Test Solar Pumped Lasers	NASA/LaRC	T	1
* TDMX2122	Laser-to-Electric Conversion	NASA/LaRC	D	2
Photovoltaic Systems				
EN-002	Large Photovoltaic Power System Demo.	NASA/LeRC	T	2
EN-005	Solar Array Blanket Zero-G Foldup Expt.	LMSC	T	2
SE-028	Advanced Power System Test Bed	Ford Aerospace	T	2
* TDMX2151	Solar Array/Energy Storage Tech.	NASA/MSFC	T	2
* TDMX2152	Large Space Power Systems Tech	NASA/LeRC	T	2
Solar Furnace Technology				
EN-004	Direct Solar Thermal Furnace Technology	NASA/LeRC	T	4
SS-7	Solar Furnace For Metals Refining	Battelle	D	4

ENERGY SYSTEMS AND THERMAL MANAGEMENT

SUBTHEME: Power Management and Distribution

	MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Environmental Interaction					
	SE-012	Voltage Op. Limit Tests Shuttle Expt.	NASA/LeRC	R	0
	EN-014	Environmental Interaction Experiment		R/T	1
	SE-001	Environmental Interactions	NASA/LeRC	R/T	1
*	TDMX2512	High Voltage in Space Plasma	NASA/JSC	T/D	1
Megawatt Systems					
*	TDMX2154	Megawatt Power Distribution	NASA/LeRC	T	3

SUBTHEME: Propulsion

Advanced Propulsion Concepts					
*	TDMX2322	Laser Propulsion	NASA-LaRC/ MSFC	T	2
	AFSO-012	High Area Ratio Nozzle Tests in Space	AFRPL/XRX	T	3
	AFEN-005	High Performance Space Booster	AFRPL/XRX	D	4
Contamination Effects					
	AFEN-001	Space-Based Contam. and Flowfield Expts.	AFRPL/XRX	R	1
	SE-011	Plume Properties Measurements Experiment	NASA/LeRC	R	1
*	TDMX2511	Space Power System Environ. Int.	NASA/LeRC	T	2
	SE-015	Radiation from Attitude Control Jets	UAH	R	TBD
Low Thrust					
	SO-005	Ion Auxiliary Propulsion System	NASA/LeRC	D	0
	AFSO-017	Low Thrust Propulsion Experiment	AFSD/YEZ	D	1
	SO-001	Controlled Thrust Propulsion Technology	NASA/LeRC	T	1
*	TDMX2321	Low Acceleration Propulsion Technology	NASA/LeRC	R/T	2
	AFSO-014	Electric Prop. Test Platform	AFRPL/XRX	T	3
	AFSO-015	Solar Thermal Propulsion System	AFRPL/XRX	D	4

AUTOMATION AND ROBOTICS

SUBTHEME: Automation

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Autonomous Control				
• TDMX2472	Advanced Automation Technology	NASA/GSFC	D	1
AR-009	Space Power Systems A&R Space Expts.	NASA/LeRC	D	6
Rendezvous/Docking				
AR-001	Advanced Autopilot for Spacecraft	Draper Lab	D	0
AR-007	Near-Term Teleoperator Maneuvering Expt.	MIT	T	0
SS-006	Berthing and Docking Sensor	NASA/JSC	D	0
AFAR-001	Autonomous Rendezvous and Docking System	AFRPL/XRX	D	4
AR-003	Berthing/Docking Mechanisms and Control	NASA/JPL	D	4

SUBTHEME: Robotics

Advanced Concepts				
AR-010	Space Spider Crane	NASA/LaRC	D	19
Free-Flight Dynamics				
AR-004	Dyn. of Retargeting/Maneuvering Large SS	NASA/JPL	D	2
• TDMX2433	Dynamic Stabilization FF Robot	NASA/JPL	T	6
Remote Maintenance/Servicing				
• TDMX2563	Materials Resupply	NASA/MSFC	D	2
• TDMX2464	Autonomous Servicing Robot	NASA/JPL	D	5
Teleoperation				
AR-005	Flt vs. Gnd Command of Service Robot	GE	T	0
AR-008	Robot for Science Laboratories	NASA/GSFC	T	0
• TDMX2462	Dextrous Teleoperator Technology	NASA/JPL	D	1
• TDMX2473	Space Robotics Research Laboratory	NASA/JPL	N/A	1
• TDMX2461	Teleoperated Structure Assembly	NASA/JPL	D	2
• TDMX2463	Autonomous Robotic Maint Demo	NASA/JPL	D	3

INFORMATION SYSTEMS

SUBTHEME: Communication and Tracking

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Antenna Performance				
* TDMX2211	Multi-Ftn Space Antenna Rng Tech	NASA/JPL	T	2
* TDMX2212	Multi Antenna Beam Patterns	NASA/JPL	T	3
Component Technologies				
IS-001	High-Voltage Traveling Wave Tube Amp.	NASA/LeRC	D	3
Propagation				
SE-009	40-105 GHz Propagation Experiments	NASA/LeRC	R	3
Time Standards				
* TDMX2223	Maser Precision Time Generation	NASA/JPL	D	2
Tracking -- Deep Space				
* TDMX2224	Space-Based Optical DSN Terminal	NASA/JPL	T	2
* TDMX2266	Spacecraft Optical Rng Determin.	NASA/JPL	D	4
* TDMX2267	Optical Spatial Tracking S/Craft	NASA/JPL	D	4
Tracking -- Proximity				
AFIS-003	Proximity Traffic Control Studies	AFWAL/FI	R	2
* TDMX2221	Laser Comm & Tracking Develop.	NASA/JPL	D	3

SUBTHEME: Data Systems

Controls/Displays				
AFIS-002	Visually-Coupled Remote Control System	USAF/AMD	D	2
CH-1	Physiological Control Systems in Low-g	Battelle	D	2
CH-2	Adv. Control/Display Concepts in Low-g	Battelle	D	7
CH-7	Eval. of 3-D Holographic Control System	Battelle	D	7

INFORMATION SYSTEMS

SUBTHEME: Sensors

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Defense				
AFIS-001	W-Sensor Trial Experiment	AFSD/YEZ	D	0
Electro-Optical Sensors				
AFIS-005	Ultraviolet Remote Sensor	AFGL/XO	R	1
• TDMX2262	Manned Observations Techniques	NASA/JSC	T/D	1
AFIS-006	Plume Observables Optical Laboratory	AFRPL/XRX	R	2
• TDMX2261	Sensor Systems Technology Exp'mt	NASA/LaRC	N/A[1]	3
Lidars				
• TDMX2263	CO2 Doppler Lidar Wind Sensor	NASA/LaRC	D	2
Radars/Radiometers				
AFIS-004	Space Based Radar (SBR)	RADC/OCSA	D	1
• TDMX2265	Satellite Doppler Meteorol Radar	NASA/LaRC	D	1
• TDMX2264	Microwave Remote Sensing-Passive	NASA/LaRC	D	6
Radio Astronomy				
IS-002	Advanced Orbiting VLBI Technology on SS	NASA/JPL	D	5

1. Not appropriate as a TDM

IN-SPACE OPERATIONS

SUBTHEME: Biomedical

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Bends Avoidance/Therapy				
AFSO-018	Zero-G Denitrogenation Study	USAF/AMD	R	0
AFSO-020	Spaceflight Bends Therapy	USAF/AMD	T	TBD
AFSO-021	Bends Warning Device	USAF/AMD	TBD	TBD
Diagnosis/Treatment				
• TDMX2531	Surgery Technology Development	NASA/JSC	T/D	3
Physiological Effects of Low-G				
AFSO-019	Body Segmental Fluid Shifts in Low-g	USAF/AMD	R	0
AFSO-022	Foot Forces and Press. Patterns	USAF/AMD	R	0
SO-007a	Flight Crew Health	LMSC	R	1
• TDMX2532	Medical Experiments Technology	NASA/JSC	R	1
CH-8	Metabolic Workload Measurements in Low-g	Battelle	R	3

SUBTHEME: Human Factors

Cognition				
CH-6	Visual Space Perception	Battelle	R	1
AFSO-023	Military Crew Cognition/Decision Making	USAF/AMD	R	2
CH-4	Time Perception and Estimation	Battelle	R	3
AFSO-025	Long-Term Visual Performance in Space	USAF/AMD	R	TBD
Crew Productivity				
SO-007	Manned System Experiments	LMSC	R/D	1
SO-007b	IVA Crew Operations Productivity	LMSC	D	1
SO-007c	EVA Operations Demonstration	LMSC	D	2
Interaction				
CH-3	Eval. of Human Fine Motor Performance	Battelle	R	1
CH-5	Human Orientation Perception	Battelle	R	1
• TDMX2471	Human/Machine Interface Workload	NASA/JPL	R	2
AFSO-024	Target Acquisition and Tracking	USAF/AMD	R	TBD

IN-SPACE OPERATIONS

SUBTHEME: Maintenance, Repair, and Test

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Cleaning/Refurbishment				
SE-007	On-Orbit Contamination Control	GE-Space Div.	D	0
• TDMX2564	Coatings Maintenance Technology	NASA/MSFC	D	1
MS-3	Development and Refurb. of Adv. Coatings	Battelle	T	4
TDMX2581g	Laser Cleaning Demonstration Experiment	NASA/KSC	D	TBD
Inspection/Test				
TDMX2581	Systems Operational Maint. Tech.	NASA/KSC	D	2
TDMX2581a	Video Probe Experiment	NASA/KSC	D	4
TDMX2581d	On-Orbit Checkout Equipment	NASA/KSC	D	4
TDMX2581e	Gas Leak Detection Experiment	NASA/KSC	D	4
TDMX2581f	Real-Time Digital Radiography Experiment	NASA/KSC	D	TBD
Satellite Servicing				
SO-003	Automatic Satellite Checkout Equipment	Rockwell Int'l	D	0
AFSO-013	Verif. Testing of Resupply Components	AFRPL/XRX	T/D	1
• TDMX2561	Satellite Servicing and Refurb.	NASA/MSFC	D	1
• TDMX2562	Satellite Maintenance and Repair	NASA/MSFC	D	2

IN-SPACE OPERATIONS

SUBTHEME: Material Processing

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
Composites				
AFSO-005	Space Fiber Production	AFRPL/XRX	T	4
AFSO-007	Space Wound Composite Manufacturing	AFRPL/XRX	T	TBD
Crystal Growth				
* TDMX2022	Growth of Comp Semicond Crystals	NASA/LaRC	D	1
* TDMX2023	Growth of Thin Single Crys Wafer	NASA/LaRC	R	1
Fluids				
MS-7	Containerless Processing of Liquids	Battelle	T	1
SE-010	Electrophoresis in Space	NASA/JSC	D	1
SO-011	Bioreactor Technology in Space	NASA/JSC	D	1
* TDMX2024	Electrophoresis Separation Tech.	NASA/JSC	T/D	1
Materials Characterization				
* TDMX2021	Man/Machine Mix Investigations	NASA/JSC	D	1
Process Technology				
MS-6	Spent Materials Utilization	Battelle	D	7
SS-10	Processing Systems for Lunar Materials	Battelle	D	10
SE-013	High Temp Controlled Reactions in S.E.M.	Mcrscpy Res. Labs	R	TBD
SO-009	Fluidized Bed Behavior in Low-G	Carbotek, Inc.	R	TBD
Sample Handling/Storage				
SS-3	Isolation of Extraterrestrial Materials	Battelle	D	7
Solid Propellants				
AFSO-009	Synthesis of Novel Solid Propellants	AFRPL/XRX	R	3
AFSO-008	Space-based Solid Propellant Motor Mfg.	AFRPL/XRX	T	7

IN-SPACE OPERATIONS

SUBTHEME: Systems/Facilities

MSN CODE	MISSION NAME	ORG	MSN TYPE	YR
CELSS				
SS-1	Plant Growth Chamber	Battelle	D	1
SS-2	Aerobic Digestor	Battelle	D	7
SS-4	Algae-Based Food Production System	Battelle	T	7
SS-8	Microbial/Chemosynthetic Food Sources	Battelle	D	7
Manned Systems				
SS-9	Manned Mars Capsule Prototype	Battelle	D	10
OTV				
* TDMX2571	OTV/Payload Interfacing/Transfer	NASA/MSFC	D	3
* TDMX2573	OTV Docking and Berthing	NASA/MSFC	D	3
* TDMX2574	OTV Maintenance Technology	NASA/MSFC	D	3
Reentry Systems				
AFSO-002	Maneuverable Reentry Research Vehicle	AFWAL/FI	T/D	2
AFSO-001	Escape and Recovery Experiments on SS	AFWAL/FIER	D	4
Technology Evaluation				
SO-004	Space Test and Evaluation Facility	Wyle Labs.	N/A[1]	
Tethers				
* TDMX2541	Tethered Electrodynamic Power Gn	NASA/MSFC	(D)	3
* TDMX2542	Tethered Constellation	NASA/MSFC	(D)	3
* TDMX2544	Tethered Fluid Storage/Transfer	NASA/MSFC	(D)	3
SO-010	Shuttle Deorbit/OTV Boost Using a Tether	NASA/MSFC	(D)	6
* TDMX2543	Tethered Transportation	NASA/MSFC	(D)	6

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APPENDIX C. OUTFITTING NEEDS CONSOLIDATED BY TECHNOLOGY THEME

This section contains a list of support equipment items for each of the seven technology themes. The count is a tally of the number of missions in the theme that were identified as needing an item. It is presented as an indicator user demand. The categories of items currently in planning are identified in Table III-2.

OUTFITTING NEEDS FOR SPACE STRUCTURE (DYNAMICS AND CONTROL) THEME (Sheet 1 of 2)

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Camera locker	LSE	4
Camera, 35 mm	LSE	3
Cleaning equipment	LSE	5
Film locker	LSE	8
Hand tools, general purpose	LSE	3
Microscope system	LSE	2
Oscilloscope, digital recording	LSE	1
Storage locker, EM-shielded	LSE	8
Glovebox, materials processing	LSF	2
Workbench, laboratory sciences	LSF	3
Acceleration monitor, lab	LSS	3
Chemical storage facility	LSS	3
Gas storage/supply, lab	LSS	2
Storage, sample	LSS	2
Vacuum vent	LSS	6
Waste disposal system	LSS	5
Attitude Determination System (ADS)	PAE	6
Contamination monitor	PAE	9
Payload Pointing System (PPS)	PAE	3
Data recorder, digital	Std	36
Hand tools, EVA general purpose	Std	20
Mobile Servicing Center (MSC)	Std	16
Storage, pressurized	Std	5
Video	Std	6
Video recorder	Std	16
Video, external	Std	20
Workstation, maintenance	Std	1
Accelerometer package, external		15
Antenna positioner, medium		1
Assembly platform		3
Battery charger, external		2
Camera locker, cinema		3
Camera, 35 mm (EVA)		2
Camera, high speed cinema		3
Cleaning materials, EVA		4
Computer		4
Cryogen storage/transfer facility		1
Cryogen storage/transfer facility, LHe		2
Film magazines		3
Frequency analyzer		1
Gas storage/transfer facility		1
Imaging radiometer		2
Inertial reference unit		1
Laser measurement unit		5
Lighting, external		8
Mass spectrometer		1
OMV		3
OMV support systems		3
Orbit transfer vehicle, low thrust		1
Pointing mount, two-axis solar		1
Propellant storage/transfer facility		1
Proximity sensor		4
Radiometer		2
Reflectometer		1

OUTFITTING NEEDS FOR SPACE STRUCTURE (DYNAMICS AND CONTROL) THEME (Sheet 2 of 2)

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Retroreflective targets		3
Sample containers		1
Space Station Construction Platform		1
Storage, unpressurized		19
Stress test machine		2
Sun sensor		3
Transmitter/receiver, RF		1
Truss extension arm		1
Vacuum chamber		3

		310

OUTFITTING NEEDS FOR FLUID MANAGEMENT THEME

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Camera locker	LSE	3
Camera, 35 mm	LSE	2
Cleaning equipment	LSE	1
Film locker	LSE	3
Fluid handling tools	LSE	4
Storage locker, EM-shielded	LSE	5
Acceleration monitor, lab	LSS	4
Chemical storage facility	LSS	4
Gas storage/supply, lab	LSS	1
Storage, sample	LSS	1
Vacuum vent	LSS	6
Waste disposal system	LSS	1
Contamination monitor	PAE	3
Data recorder, digital	Std	5
Data terminal, graphics	Std	1
Film locker, cinema	Std	1
Hand tools, EVA general purpose	Std	1
Video	Std	6
Video recorder	Std	6
Video, external	Std	1
Camera, cinema		3
Camera, high speed cinema		3
Cryo storage/transfer facility, lab LHe		1
Film locker, cinema		4
Film magazines		2
Gas chromatograph/mass spectrometer		1
Gas sampling bottles		1
Image intensifier		1
Interferometer, holographic		1
Laser Doppler anemometer		1
Leak detector, He		1
Leak detector, propellant		3
Photo processor unit		1
Sample containers		1
		83

OUTFITTING NEEDS FOR SPACE ENVIRONMENTAL EFFECTS THEME

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Battery charger	LSE	2
Camera locker	LSE	6
Camera, 35 mm	LSE	7
Dosimeter, passive	LSE	1
Film locker	LSE	6
Hand tools, general purpose	LSE	2
Microscope system	LSE	7
Multimeter, digital	LSE	1
Storage locker, EM-shielded	LSE	1
Workbench, laboratory sciences	LSF	6
Acceleration monitor, lab	LSS	1
Storage, sample	LSS	2
Vacuum vent	LSS	1
Attitude Determination System (ADS)	PAE	1
Contamination monitor	PAE	10
Data recorder, digital	Std	19
Hand tools, EVA general purpose	Std	7
Mobile Servicing Center (MSC)	Std	6
MRMS	Std	1
Storage, pressurized	Std	5
Accelerometer package, external		1
Audiometer		1
Battery charger, external		1
Bi-directional reflectance instrument		1
Exposure tray		10
Imaging radiometer		1
Magnetometer		1
Mass spectrometer		8
Noise dosemeter		1
Noise monitor		1
Optical disk drive		1
Plasma diagnostic package		2
Power amplifier		1
Radiation monitor		2
Radiation monitor, EM		1
Radiation monitor, internal		2
Radiometer		4
Reflectometer		2
Retarding potential analyzer		1
Sample containers		8
Solid Rocket Motor Research Facility		2
Sound level meter		1
Spectrophotometer		2
Storage, unpressurized		2
Stress test machine		2
Sun sensor		1
Tape recorder, audio		1
Transmitter/receiver, RF		2
Ultrasonic test unit		2
Video, low light (external)		1
Workstation, teleoperator		1
X-ray unit		1
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OUTFITTING NEEDS FOR ENERGY SYSTEMS AND THERMAL MANAGEMENT THEME

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Camera locker	LSE	3
Camera, 35 mm	LSE	3
Film locker	LSE	3
Fluid handling tools	LSE	1
Hand tools, general purpose	LSE	1
Microscope system	LSE	2
Storage locker, EM-shielded	LSE	6
Acceleration monitor, lab	LSS	2
Chemical storage facility	LSS	1
Storage, sample	LSS	2
Vacuum vent	LSS	1
Attitude Determination System (ADS)	PAE	9
Contamination monitor	PAE	23
Data recorder, digital	Std	38
Hand tools, EVA general purpose	Std	14
Mobile Servicing Center (MSC)	Std	6
Storage, pressurized	Std	1
Video	Std	1
Video recorder	Std	15
Video, external	Std	12
Accelerometer package, external		3
Assembly platform		1
Camera, 35 mm (EVA)		2
Camera, high speed cinema		1
Computer, experimemt control		1
Data recorder, digital		1
Exposure tray		1
Film locker, cinema		1
Film magazines		1
Gas storage/transfer facility		1
Imaging radiometer		8
Lighting, external		1
Magnetometer		1
Mass spectrometer		5
Plasma diagnostic package		6
Plasma diagnostic probe		1
Plasma ground		11
Pointing mount, two-axis solar		10
Potential probe		5
Propellant storage/transfer facility		3
Radiometer		3
Reflectometer		1
Sample containers		1
Spectrophotometer, imaging (external)		1
Storage, unpressurized		9
Sun sensor		4
Tether system		1
Transmitter/receiver, RF		1
Video, low light (external)		6
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OUTFITTING NEEDS FOR AUTOMATION AND ROBOTICS THEME

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Camera locker	LSE	6
Camera, 35 mm	LSE	6
Film locker	LSE	7
Storage locker, EM-shielded	LSE	13
Data recorder, digital	Std	12
Data terminal	Std	1
Hand tools, EVA general purpose	Std	6
Mobile Servicing Center (MSC)	Std	2
Video	Std	2
Video recorder	Std	14
Video, external	Std	6
Accelerometer package, external		2
Assembly bay		1
Camera, cinema		1
Computer, AI		1
Docking assembly		1
Lighting, external		4
Manned Maneuvering Unit (MMU) with FSS		1
OMV		4
OMV (with Smart Front End)		1
OMV support systems		5
Pointing mount, two-axis solar		1
Propellant storage/transfer facility		2
Range sensor, laser		1
Range sensor, radar		1
Rendezvous radar		1
Shroud, cover		1
Storage, unpressurized		19
Video, external (SRRL)		5
Window, viewing		6
Workstation, teleoperator		5
Workstation, telerobotic		8
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OUTFITTING NEEDS FOR INFORMATION SYSTEMS THEME

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Film locker	LSE	1
Storage locker, EM-shielded	LSE	8
Chemical storage facility	LSS	1
Vacuum vent	LSS	1
Attitude Determination System (ADS)	PAE	10
Contamination monitor	PAE	10
Payload Pointing System (PPS)	PAE	6
Data recorder, digital	Std	18
Hand tools, EVA general purpose	Std	3
Mobile Servicing Center (MSC)	Std	2
Storage, pressurized	Std	6
Video	Std	9
Video recorder	Std	5
Video, external	Std	3
Accelerometer package, external		8
Airlock, scientific		1
Antenna positioner, large		3
Antenna positioner, medium		1
Battery storage		1
Calibration/servicing		1
Cleaning equipment, optics		1
Computer, graphics/experiment control		3
Computer-video generator		3
Cryogen storage/transfer facility		2
Data recorder, digital		3
Frequency standard, hydrogen maser		1
Global Positioning System (GPS)		2
Graphics display, high resolution		3
Isolator, mechanical		3
OMV		6
OMV support systems		6
Physiological monitor		4
Range sensor, laser		2
Speech generator		4
Storage, unpressurized		3
Tape recorder, audio		4
Test instruments, electronic		1
Tools, optical alignment		1
Visual task generator		3
Window, high-quality optical		2
Workbench, optical		1
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OUTFITTING NEEDS FOR IN-SPACE OPERATIONS THEME
(Sheet 1 of 3)

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Autoclave	LSE	6
Battery charger	LSE	3
Camera locker	LSE	9
Camera, 35 mm	LSE	10
Cleaning equipment	LSE	14
Cutting/polishing system	LSE	3
Dosimeter, passive	LSE	1
Electrical conductivity probe	LSE	1
Etching equipment	LSE	5
Film locker	LSE	10
Fluid handling tools	LSE	13
Freeze dryer	LSE	1
Freezer	LSE	11
Freezer, cryogenic	LSE	2
Hand tools, general purpose	LSE	14
Incubator	LSE	4
Mass measurement device, small	LSE	7
Microscope system	LSE	15
Multimeter, digital	LSE	5
pH meter	LSE	8
Refrigerator	LSE	11
Storage locker, EM-shielded	LSE	16
Surgery/dissecting tools	LSE	1
Thermometer, digital	LSE	2
Ultraviolet sterilization unit	LSE	3
Washer/sanitizer, equipment	LSE	5
X-ray system	LSE	3
Glovebox, materials processing	LSF	13
Workbench, laboratory sciences	LSF	14
Acceleration monitor, lab	LSS	7
Chemical storage facility	LSS	16
Cleanup/decontamination equipment	LSS	2
Gas storage/supply, lab	LSS	7
Materials transport system	LSS	1
Storage, process materials	LSS	5
Storage, sample	LSS	4
Vacuum vent	LSS	2
Waste disposal system	LSS	20
Water service, lab grade	LSS	10
Contamination monitor	PAE	4
Airlock, hyperbaric	Std	1
Data recorder, digital	Std	33
Docking port	Std	2
Hand tools, EVA general purpose	Std	8
Mobile Servicing Center (MSC)	Std	7
Storage, pressurized	Std	17
Storage, unpressurized	Std	3
Video	Std	22
Video recorder	Std	21
Video, external	Std	14
Workstation, maintenance	Std	2
Workstation, MSC telerobotic	Std	5
Airlock, scientific		1
Amplifiers		2

OUTFITTING NEEDS FOR IN-SPACE OPERATIONS THEME
(Sheet 2 of 3)

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Anechoic chamber		4
Animal holding facility		2
Battery charger, external		1
Berthing system, OTV		3
Blood sample kit		2
Centrifuge		4
Centrifuge, refrigerated		3
Cleaning equipment, optics		1
Computer, parallel processor		1
Computer, process control		2
Computer-video generator		4
Counter		1
Cryogen storage/transfer facility, LHe		1
Digital word generator		1
Docking system		2
Dummy payload		1
Dynamometer		2
Electrical stimulation pulse generator		1
Electrical test/checkout equipment		1
Electrode impedance meter		9
EMU		2
Ergometer		2
Exposure tray		2
Gas chromatograph/mass spectrometer		4
Gas storage/transfer facility		1
Graphics display, high resolution		6
Hall probe		2
Hand tools, laboratory		2
Hand wash facility		1
Joystick		1
Leak detector, propellant		4
Lighting, external		7
Logic analyzer		1
Manned Maneuvering Unit (MMU)		1
Mixing facilities		1
OMV		5
OMV support systems		5
Optical pyrometer		1
OTV		1
Physiological monitor		8
Plethysmograph		1
Power supply, programmable		1
Propellant storage/transfer facility		3
Reflectometer		1
Respiratory monitoring system		1
RF power meter		1
Sample containers		8
Satellite Servicing Facility		3
Scanning electron microscope system		3
Servicing/maintenance hangar		3
Solid Rocket Motor Research Facility		2
Spectrum analyzer		1
Speech generator		6
Spirometer		1
Sterilization facility		1

OUTFITTING NEEDS FOR IN-SPACE OPERATIONS THEME
(Sheet 3 of 3)

EQUIPMENT ITEM	EQUIP CAT	MISSION COUNT
Storage, isolation		1
Storage, pressurized		1
Storage, unpressurized		9
Tape recorder, audio		12
Temperature monitor, ambient		1
Tether alignment system		2
Tether tracking system		5
Tethered pointing system		1
Transmitter/receiver		1
Transmitter/receiver, RF		1
Treadmill		1
Urine sample kit		2
Video, high resolution		4
Visual pulse generator		2
Visual task generator		6
Waveform digitizer		1
Workstation, teleoperator		2
Workstation, telerobotic		1

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APPENDIX D. OUTFITTING NEEDS CONSOLIDATED AT THE PROJECT LEVEL

This section contains a list of support equipment items grouped by project for each of the seven technology themes. Within the classification scheme used to organize the mission data, a project group contains one or more missions that address a single technology development issue or technology application. Multiple missions within a project group are closely related in their objectives and in most cases could benefit from the same set of support equipment. As stated previously, the mission count for each item is interpreted as a measure of user demand.

SPACE STRUCTURE (DYNAMICS AND CONTROL)
Equipment Count by Project

SUBTHEME: Advanced Structures

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Assembly		
Storage locker, EM-shielded	LSE	4
Contamination monitor	PAE	2
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	5
Mobile Servicing Center (MSC)	Std	5
Video recorder	Std	5
Video, external	Std	5
Accelerometer package, external		1
Assembly platform		1
Cryogen storage/transfer facility, LHe		1
Gas storage/transfer facility		1
Lighting, external		5
OMV		1
OMV support systems		1
Propellant storage/transfer facility		1
Storage, unpressurized		5
Segmented Optics		
Attitude Determination System (ADS)	PAE	2
Contamination monitor	PAE	3
Payload Pointing System (PPS)	PAE	2
Data recorder, digital	Std	1
Hand tools, EVA general purpose	Std	3
Mobile Servicing Center (MSC)	Std	2
Video	Std	1
Video recorder	Std	1
Video, external	Std	1
Accelerometer package, external		2
Assembly platform		1
Cryogen storage/transfer facility		1
Cryogen storage/transfer facility, LHe		1
Imaging radiometer		1
Lighting, external		1
Storage, unpressurized		3

SUBTHEME: Advanced Structures (cont'd)

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Thin Film/Inflatable Structures		
Camera locker	LSE	2
Camera, 35 mm	LSE	2
Cleaning equipment	LSE	3
Film locker	LSE	2
Microscope system	LSE	2
Storage locker, EM-shielded	LSE	3
Glovebox, materials processing	LSF	2
Chemical storage facility	LSS	3
Gas storage/supply, lab	LSS	2
Storage, sample	LSS	2
Vacuum vent	LSS	3
Waste disposal system	LSS	3
Data recorder, digital	Std	1
Hand tools, EVA general purpose	Std	1
Mobile Servicing Center (MSC)	Std	1
Storage, pressurized	Std	1
Video	Std	1
Video recorder	Std	4
Video, external	Std	3
OMV		1
OMV support systems		1
Reflectometer		1
Sample containers		1
Storage, unpressurized		3
Stress test machine		2
Trusses		
Data recorder, digital	Std	1
Hand tools, EVA general purpose	Std	1
Mobile Servicing Center (MSC)	Std	1
Video, external	Std	1
Accelerometer package, external		1
Storage, unpressurized		1
Welding		
Camera locker	LSE	1
Film locker	LSE	2
Storage locker, EM-shielded	LSE	1
Contamination monitor	PAE	1
Storage, pressurized	Std	1
Video recorder	Std	2
Video, external	Std	2
Battery charger, external		1
Camera, 35 mm (EVA)		2
Storage, unpressurized		2

SPACE STRUCTURE (DYNAMICS AND CONTROL)
Equipment Count by Project

SUBTHEME: Mechanisms/Controls

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Attitude Control		
Acceleration monitor, lab	LSS	1
Attitude Determination System (ADS)	PAE	1
Data recorder, digital	Std	2
Pointing/Isolation		
Acceleration monitor, lab	LSS	1
Attitude Determination System (ADS)	PAE	1
Contamination monitor	PAE	1
Payload Pointing System (PPS)	PAE	1
Data recorder, digital	Std	3
Video	Std	1
Accelerometer package, external		2
Sensors/Actuators		
Camera locker	LSE	1
Camera, 35 mm	LSE	1
Film locker	LSE	1
Hand tools, general purpose	LSE	1
Oscilloscope, digital recording	LSE	1
Data recorder, digital	Std	5
Hand tools, EVA general purpose	Std	1
Mobile Servicing Center (MSC)	Std	1
Workstation, maintenance	Std	1
Frequency analyzer		1
Sun sensor		1
Tribological Effects		
Cleaning equipment	LSE	2
Film locker	LSE	3
Hand tools, general purpose	LSE	2
Workbench, laboratory sciences	LSF	3
Acceleration monitor, lab	LSS	1
Vacuum vent	LSS	3
Waste disposal system	LSS	2
Contamination monitor	PAE	1
Data recorder, digital	Std	5
Storage, pressurized	Std	3
Video	Std	3
Accelerometer package, external		1
Camera locker, cinema		3
Camera, high speed cinema		3
Film magazines		3
Mass spectrometer		1
Radiometer		1
Vacuum chamber		3

SUBTHEME: Structural Dynamics

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Antennas/Reflectors		
Attitude Determination System (ADS)	PAE	2
Contamination monitor	PAE	1
Data recorder, digital	Std	8
Hand tools, EVA general purpose	Std	7
Mobile Servicing Center (MSC)	Std	3
Video recorder	Std	3
Video, external	Std	7
Accelerometer package, external		5
Assembly platform		1
Cleaning materials, EVA		4
Computer		4
Laser measurement unit		4
Lighting, external		2
OMV		1
OMV support systems		1
Orbit transfer vehicle, low thrust		1
Pointing mount, two-axis solar		1
Proximity sensor		4
Space Station Construction Platform		1
Storage, unpressurized		3
Truss extension arm		1
Large Structures (General)		
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	1
Mobile Servicing Center (MSC)	Std	1
Accelerometer package, external		1
Radiometer		1
Storage, unpressurized		1
Space Station Dynamics		
Data recorder, digital	Std	3
Mobile Servicing Center (MSC)	Std	2
Video recorder	Std	1
Video, external	Std	1
Accelerometer package, external		2
Battery charger, external		1
Inertial reference unit		1
Laser measurement unit		1
Retroreflective targets		3
Storage, unpressurized		1
Transmitter/receiver, RF		1
Thermal Design		
Data recorder, digital	Std	3
Hand tools, EVA general purpose	Std	1
Antenna positioner, medium		1
Imaging radiometer		1
Sun sensor		2

FLUID MANAGEMENT
Equipment Count by Project

SUBTHEME: Fluid Behavior

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Helium		
Storage locker, EM-shielded	LSE	1
Vacuum vent	LSS	1
Video	Std	1
Video recorder	Std	1
Camera, cinema		1
Cryo storage/transfer facility, lab LHe		1
Liquid Streams		
Storage locker, EM-shielded	LSE	1
Video	Std	1
Video recorder	Std	1
Two-Phase Fluids		
Camera locker	LSE	2
Camera, 35 mm	LSE	2
Film locker	LSE	3
Fluid handling tools	LSE	4
Storage locker, EM-shielded	LSE	2
Acceleration monitor, lab	LSS	3
Chemical storage facility	LSS	4
Vacuum vent	LSS	4
Data recorder, digital	Std	2
Film locker, cinema	Std	1
Video	Std	3
Video recorder	Std	3
Camera, cinema		2
Camera, high speed cinema		2
Film locker, cinema		3
Film magazines		2

SUBTHEME: Fluid Storage/Transfer

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Cryogens		
Contamination monitor	PAE	3
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	1
Video, external	Std	1
Leak detector, propellant		3
Cryogens -- Helium		
Leak detector, He		1
Sensors/Gauges		
Acceleration monitor, lab	LSS	1

SUBTHEME: Spacecraft Fire Safety

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Flame Spread Mechanisms		
Camera locker	LSE	1
Cleaning equipment	LSE	1
Storage locker, EM-shielded	LSE	1
Gas storage/supply, lab	LSS	1
Storage, sample	LSS	1
Vacuum vent	LSS	1
Waste disposal system	LSS	1
Data recorder, digital	Std	1
Data terminal, graphics	Std	1
Video	Std	1
Video recorder	Std	1
Camera, high speed cinema		1
Film locker, cinema		1
Gas chromatograph/mass spectrometer		1
Gas sampling bottles		1
Image intensifier		1
Interferometer, holographic		1
Laser Doppler anemometer		1
Photo processor unit		1
Sample containers		1

SPACE ENVIRONMENTAL EFFECTS
Equipment Count by Project

SUBTHEME: Environment Characterization

EQUIPMENT ITEM	EQP CAT	MSN COUNT
External Environment		
Acceleration monitor, lab	LSS	1
Attitude Determination System (ADS)	PAE	1
Contamination monitor	PAE	2
Data recorder, digital	Std	4
Mobile Servicing Center (MSC)	Std	3
Accelerometer package, external		1
Exposure tray		2
Imaging radiometer		1
Magnetometer		1
Mass spectrometer		2
Radiation monitor		1
Radiation monitor, EM		1
Retarding potential analyzer		1
Sample containers		1
Sun sensor		1
Video, low light (external)		1
Internal Environment		
Battery charger	LSE	2
Dosimeter, passive	LSE	1
Storage locker, EM-shielded	LSE	1
Data recorder, digital	Std	2
Storage, pressurized	Std	2
Audiometer		1
Noise dosemeter		1
Noise monitor		1
Power amplifier		1
Radiation monitor		1
Radiation monitor, internal		1
Sample containers		1
Sound level meter		1
Tape recorder, audio		1

SUBTHEME: Environmental Effects

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Coatings/Surface Effects		
Camera locker	LSE	2
Camera, 35 mm	LSE	2
Film locker	LSE	2
Microscope system	LSE	2
Multimeter, digital	LSE	1
Workbench, laboratory sciences	LSF	3
Storage, sample	LSS	1
Vacuum vent	LSS	1
Contamination monitor	PAE	5
Data recorder, digital	Std	5
Hand tools, EVA general purpose	Std	3
Mobile Servicing Center (MSC)	Std	1
Bi-directional reflectance instrument		1
Exposure tray		3
Mass spectrometer		5
Radiometer		1
Reflectometer		2
Sample containers		4
Spectrophotometer		2
Stress test machine		1
Transmitter/receiver, RF		1
Ultrasonic test unit		1
Data System Effects		
Data recorder, digital	Std	3
Hand tools, EVA general purpose	Std	1
Mobile Servicing Center (MSC)	Std	1
Storage, pressurized	Std	2
Optical disk drive		1
Radiation monitor, internal		1
Storage, unpressurized		1
Facilities		
Data recorder, digital	Std	1
Hand tools, EVA general purpose	Std	1
Battery charger, external		1
Transmitter/receiver, RF		1

SPACE ENVIRONMENTAL EFFECTS
Equipment Count by Project

SUBTHEME: Environmental Effects (cont'd)

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Micro-meteoroid Impacts		
Camera locker	LSE	2
Camera, 35 mm	LSE	2
Film locker	LSE	2
Hand tools, general purpose	LSE	1
Microscope system	LSE	2
Workbench, laboratory sciences	LSF	1
Storage, sample	LSS	1
Exposure tray		2
Solid Rocket Motors		
Contamination monitor	PAE	2
Data recorder, digital	Std	2
Solid Rocket Motor Research Facility		2
Plasma diagnostic package		2
Radiometer		2
Ultrasonic test unit		1
Workstation, teleoperator		1
X-ray unit		1
Structural Materials		
Camera locker	LSE	2
Camera, 35 mm	LSE	3
Film locker	LSE	2
Hand tools, general purpose	LSE	1
Microscope system	LSE	3
Workbench, laboratory sciences	LSF	2
Contamination monitor	PAE	1
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	2
Mobile Servicing Center (MSC)	Std	1
MRMS	Std	1
Storage, pressurized	Std	1
Exposure tray		3
Mass spectrometer		1
Radiometer		1
Sample containers		2
Storage, unpressurized		1
Stress test machine		1

ENERGY SYSTEMS AND THERMAL MANAGEMENT
Equipment Count by Project

SUBTHEME: Advanced Thermal Control

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Liquid Droplet Radiators		
Storage locker, EM-shielded	LSE	2
Attitude Determination System (ADS)	PAE	3
Contamination monitor	PAE	4
Data recorder, digital	Std	4
Video recorder	Std	2
Video, external	Std	2
Plasma ground		4
Pointing mount, two-axis solar		4
Radiometer		2
Radiator Panel Technology		
Storage locker, EM-shielded	LSE	2
Attitude Determination System (ADS)	PAE	2
Contamination monitor	PAE	2
Data recorder, digital	Std	3
Hand tools, EVA general purpose	Std	2
Mobile Servicing Center (MSC)	Std	1
Video recorder	Std	2
Video, external	Std	2
Plasma ground		1
Pointing mount, two-axis solar		2
Radiometer		1
Storage, unpressurized		1
Thermal Design/Interfacing		
Hand tools, general purpose	LSE	1
Contamination monitor	PAE	1
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	2
Storage, pressurized	Std	1
Video recorder	Std	1
Video, external	Std	1
Storage, unpressurized		2
Two-Phase Systems		
Camera locker	LSE	1
Camera, 35 mm	LSE	1
Film locker	LSE	1
Fluid handling tools	LSE	1
Storage locker, EM-shielded	LSE	1
Acceleration monitor, lab	LSS	1
Chemical storage facility	LSS	1
Vacuum vent	LSS	1
Data recorder, digital	Std	2
Video	Std	1
Video recorder	Std	1
Camera, high speed cinema		1
Film locker, cinema		1
Film magazines		1
Imaging radiometer		1

SUBTHEME: Energy Conversion

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Dynamic Conversion		
Camera locker	LSE	1
Film locker	LSE	1
Contamination monitor	PAE	1
Data recorder, digital	Std	5
Hand tools, EVA general purpose	Std	1
Video recorder	Std	1
Video, external	Std	1
Camera, 35 mm (EVA)		1
Gas storage/transfer facility		1
Imaging radiometer		1
Pointing mount, two-axis solar		1
Storage, unpressurized		1
Laser Systems		
Contamination monitor	PAE	2
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	1
Video, external	Std	2
Camera, 35 mm (EVA)		1
Storage, unpressurized		2
Photovoltaic Systems		
Contamination monitor	PAE	1
Data recorder, digital	Std	3
Hand tools, EVA general purpose	Std	2
Video recorder	Std	2
Video, external	Std	1
Imaging radiometer		1
Pointing mount, two-axis solar		1
Sun sensor		1
Video, low light (external)		1
Solar Furnace Technology		
Storage, sample	LSS	2
Attitude Determination System (ADS)	PAE	2
Contamination monitor	PAE	2
Data recorder, digital	Std	2
Imaging radiometer		2
Pointing mount, two-axis solar		2

ENERGY SYSTEMS AND THERMAL MANAGEMENT
Equipment Count by Project

SUBTHEME: Power Management and Distribution

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Environmental Interaction		
Camera locker	LSE	1
Camera, 35 mm	LSE	1
Film locker	LSE	1
Microscope system	LSE	1
Attitude determination system (ADS)	PAE	2
Contamination monitor	PAE	2
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	1
Mobile Servicing Center (MSC)	Std	1
Video recorder	Std	1
Computer, experiment control		1
Data recorder, digital		1
Exposure tray		1
Magnetometer		1
Mass spectrometer		1
Plasma diagnostic package		3
Plasma ground		1
Storage, unpressurized		1
Sun sensor		2
Video, low light (external)		2
Megawatt Systems		
Contamination monitor	PAE	1
Data recorder, digital	Std	1
Video recorder	Std	1
Plasma diagnostic probe		1
Video, low light (external)		1

SUBTHEME: Propulsion

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Advanced Propulsion Concepts		
Camera, 35 mm	LSE	1
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	2
Video, external	Std	1
Accelerometer package, external		1
Propellant storage/transfer facility		1
Spectrophotometer, imaging (external)		1
Storage, unpressurized		1
Contamination Effects		
Microscope system	LSE	1
Storage locker, EM-shielded	LSE	1
Contamination monitor	PAE	2
Data recorder, digital	Std	4
Hand tools, EVA general purpose	Std	1
Mobile Servicing Center (MSC)	Std	2
Video recorder	Std	3
Imaging radiometer		2
Mass spectrometer		2
Reflectometer		1
Sample containers		1
Sun sensor		1
Video, low light (external)		2
Low Thrust		
Acceleration monitor, lab	LSS	1
Contamination monitor	PAE	5
Data recorder, digital	Std	6
Hand tools, EVA general purpose	Std	2
Mobile Servicing Center (MSC)	Std	2
Video recorder	Std	1
Video, external	Std	2
Accelerometer package, external		2
Assembly platform		1
Imaging radiometer		1
Lighting, external		1
Mass spectrometer		2
Plasma diagnostic package		3
Plasma ground		5
Potential probe		5
Propellant storage/transfer facility		2
Storage, unpressurized		1
Tether system		1
Transmitter/receiver, RF		1

AUTOMATION AND ROBOTICS
Equipment Count by Project

SUBTHEME: Automation

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Autonomous Control		
Data recorder, digital	Std	1
Data terminal	Std	1
Mobile Servicing Center (MSC)	Std	1
Computer, AI		1
Pointing mount, two-axis solar		1
Storage, unpressurized		1
Rendezvous/Docking		
Film locker	LSE	1
Storage locker, EM-shielded	LSE	2
Data recorder, digital	Std	2
Video recorder	Std	3
Video, external	Std	3
Accelerometer package, external		1
Camera, cinema		1
Manned Maneuvering Unit (MMU) with FSS		1
OMV		1
OMV support systems		1
Propellant storage/transfer facility		1
Range sensor, laser		1
Range sensor, radar		1
Rendezvous radar		1
Storage, unpressurized		2
Workstation, teleoperator		2

SUBTHEME: Robotics

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Advanced Concepts		
Storage locker, EM-shielded	LSE	1
Data recorder, digital	Std	1
Video recorder	Std	1
Video, external	Std	1
Storage, unpressurized		1
Workstation, telerobotic		1
Free-Flight Dynamics		
Camera locker	LSE	1
Camera, 35 mm	LSE	1
Film locker	LSE	1
Storage locker, EM-shielded	LSE	2
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	1
Video recorder	Std	2
Video, external	Std	1
Assembly bay		1
Docking assembly		1
Lighting, external		1
OMV		1
OMV support systems		1
Propellant storage/transfer facility		1
Storage, unpressurized		3
Video, external (SRRL)		1
Window, viewing		1
Workstation, teleoperator		1
Workstation, telerobotic		1
Remote Maintenance/Servicing		
Camera locker	LSE	1
Camera, 35 mm	LSE	1
Film locker	LSE	1
Storage locker, EM-shielded	LSE	2
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	1
Video recorder	Std	2
Lighting, external		1
OMV		1
OMV (with Smart Front End)		1
OMV support systems		2
Storage, unpressurized		3
Video, external (SRRL)		1
Window, viewing		1
Workstation, teleoperator		1
Workstation, telerobotic		1

AUTOMATION AND ROBOTICS
Equipment Count by Project

SUBTHEME: Robotics (continued)

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Teleoperation		
Camera locker	LSE	4
Camera, 35 mm	LSE	4
Film locker	LSE	4
Storage locker, EM-shielded	LSE	6
Data recorder, digital	Std	4
Hand tools, EVA general purpose	Std	4
Mobile Servicing Center (MSC)	Std	1
Video	Std	2
Video recorder	Std	6
Video, external	Std	1
Accelerometer package, external		1
Lighting, external		2
OMV		1
OMV support systems		1
Shroud, cover		1
Storage, unpressurized		9
Video, external (SRRL)		3
Window, viewing		4
Workstation, teleoperator		1
Workstation, telerobotic		5

INFORMATION SYSTEMS
Equipment Count by Project

SUBTHEME: Communication and Tracking

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Antenna Performance		
Storage locker, EM-shielded	LSE	2
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	2
Mobile Servicing Center (MSC)	Std	1
Video, external	Std	2
Accelerometer package, external		2
Antenna positioner, large		2
Isolator, mechanical		2
OMV		2
OMV support systems		2
Range sensor, laser		2
Storage, unpressurized		2
Component Technologies		
Contamination monitor	PAE	1
Data recorder, digital	Std	1
Video, external	Std	1
Propagation		
Antenna positioner, medium		1
Time Standards		
Data recorder, digital	Std	1
Tracking -- Deep Space		
Storage locker, EM-shielded	LSE	3
Attitude Determination System (ADS)	PAE	3
Contamination monitor	PAE	3
Payload Pointing System (PPS)	PAE	2
Data recorder, digital	Std	3
Accelerometer package, external		3
Global Positioning System (GPS)		2
OMV		3
OMV support systems		3
Storage, unpressurized		1
Tracking -- Proximity		
Storage locker, EM-shielded	LSE	1
Contamination monitor	PAE	1
Data recorder, digital	Std	1
Hand tools, EVA general purpose	Std	1
OMV		1
OMV support systems		1

SUBTHEME: Data Systems

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Controls/Displays		
Data recorder, digital	Std	4
Storage, pressurized	Std	3
Video	Std	4
Video recorder	Std	4
Computer, graphics/experiment control		3
Computer-video generator		3
Graphics display, high resolution		3
Physiological monitor		4
Speech generator		4
Tape recorder, audio		4
Visual task generator		3

INFORMATION SYSTEMS
Equipment Count by Project

SUBTHEME: Sensors

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Defense		
(Requirements TBD)		
Electro-Optical Sensors		
Film locker	LSE	1
Storage locker, EM-shielded	LSE	1
Chemical storage facility	LSS	1
Vacuum vent	LSS	1
Attitude Determination System (ADS)	PAE	4
Contamination monitor	PAE	4
Payload Pointing System (PPS)	PAE	4
Data recorder, digital	Std	4
Storage, pressurized	Std	2
Video	Std	4
Video recorder	Std	1
Accelerometer package, external		1
Airlock, scientific		1
Battery storage		1
Calibration/servicing		1
Cleaning equipment, optics		1
Cryogen storage/transfer facility		1
Window, high-quality optical		2
Workbench, optical		1
Lidars		
Storage locker, EM-shielded	LSE	1
Attitude Determination System (ADS)	PAE	1
Contamination monitor	PAE	1
Data recorder, digital	Std	1
Storage, pressurized	Std	1
Video	Std	1
Accelerometer package, external		1
Cryogen storage/transfer facility		1
Test instruments, electronic		1
Tools, optical alignment		1
Radars/Radiometers		
Attitude Determination System (ADS)	PAE	1
Data recorder, digital	Std	1
Mobile Servicing Center (MSC)	Std	1
Data recorder, digital		2
Radio Astronomy		
Attitude Determination System (ADS)	PAE	1
Accelerometer package, external		1
Antenna positioner, large		1
Data recorder, digital		1
Frequency standard, hydrogen maser		1
Isolator, mechanical		1

IN-SPACE OPERATIONS
Equipment Count by Project

SUBTHEME: Biomedical

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Bends Avoidance/Therapy		
Gas storage/supply, lab	LSS	2
Airlock, hyperbaric	Std	1
Data recorder, digital	Std	1
EMU		1
Gas chromatograph/mass spectrometer		1
Spirometer		1
Sterilization facility		1
Storage, pressurized		1
Diagnosis/Treatment		
Autoclave	LSE	1
Cleaning equipment	LSE	1
Surgery/dissecting tools	LSE	1
Ultraviolet sterilization unit	LSE	1
Washer/sanitizer, equipment	LSE	1
Waste disposal system	LSS	1
Data recorder, digital	Std	1
Video	Std	1
Video recorder	Std	1
Animal holding facility		1
Hand wash facility		1
Physiological Effects of Low-G		
Battery charger	LSE	2
Dosimeter, passive	LSE	1
Freezer	LSE	2
Hand tools, general purpose	LSE	1
Refrigerator	LSE	2
Storage locker, EM-shielded	LSE	1
Chemical storage facility	LSS	1
Waste disposal system	LSS	1
Data recorder, digital	Std	3
Storage, pressurized	Std	3
Video	Std	1
Video recorder	Std	1
Amplifiers		2
Animal holding facility		1
Blood sample kit		2
Centrifuge		2
Dynamometer		2
Electrode impedance meter		2
Ergometer		2
Gas chromatograph/mass spectrometer		1
Plethysmograph		1
Respiratory monitoring system		1
Tape recorder, audio		3
Temperature monitor, ambient		1
Treadmill		1
Urine sample kit		2

SUBTHEME: Human Factors

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Cognition		
Storage locker, EM-shielded	LSE	4
Data recorder, digital	Std	4
Storage, pressurized	Std	1
Video	Std	4
Video recorder	Std	4
Anechoic chamber		2
Computer-video generator		1
Electrical stimulation pulse generator		1
Electrode impedance meter		4
Graphics display, high resolution		3
Physiological monitor		4
Speech generator		3
Tape recorder, audio		4
Visual pulse generator		2
Visual task generator		3
Crew Productivity		
Cleanup/decontamination equipment	LSS	1
Waste disposal system	LSS	1
Storage, pressurized	Std	1
Video	Std	1
Video, external	Std	1
Lighting, external		1
Storage, unpressurized		1
Interaction		
Storage locker, EM-shielded	LSE	3
Data recorder, digital	Std	4
Storage, pressurized	Std	3
Video	Std	3
Video recorder	Std	3
Anechoic chamber		2
Computer, parallel processor		1
Computer-video generator		3
Electrode impedance meter		3
Graphics display, high resolution		3
Joystick		1
Physiological monitor		3
Speech generator		3
Tape recorder, audio		3
Visual task generator		3
Workstation, telerobotic		1

IN-SPACE OPERATIONS
Equipment Count by Project

SUBTHEME: Maintenance, Repair, and Test

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Cleaning/Refurbishment		
Camera locker	LSE	2
Camera, 35 mm	LSE	2
Film locker	LSE	2
Microscope system	LSE	2
Storage locker, EM-shielded	LSE	2
Workbench, laboratory sciences	LSF	1
Chemical Storage Facility	LSS	1
Storage, process materials	LSS	1
Waste disposal system	LSS	1
Contamination monitor	PAE	1
Data recorder, digital	Std	1
Mobile Servicing Center (MSC)	Std	2
Video recorder	Std	2
Video, external	Std	3
Airlock, scientific		1
Battery charger, external		1
Exposure tray		2
Gas storage/transfer facility		1
Reflectometer		1
Sample containers		1
Storage, unpressurized		2
Workstation, teleoperator		1
Inspection/Test		
Battery charger	LSE	1
Multimeter, digital	LSE	1
Storage locker, EM-shielded	LSE	3
Data recorder, digital	Std	2
Storage, pressurized	Std	3
Storage, unpressurized	Std	1
Video	Std	2
Video recorder	Std	2
Counter		1
Digital word generator		1
Logic analyzer		1
Power supply, programmable		1
RF power meter		1
Spectrum analyzer		1
Storage, unpressurized		1
Transmitter/receiver, RF		1
Waveform digitizer		1

SUBTHEME: Maintenance, Repair, and Test (continued)

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Satellite Servicing		
Contamination monitor	PAE	2
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	3
Mobile Servicing Center (MSC)	Std	2
Storage, pressurized	Std	1
Storage, unpressurized	Std	1
Video, external	Std	2
Workstation, MSC telerobotic	Std	2
Docking system		1
EMU		1
Leak detector, propellant		2
Lighting, external		2
Manned Maneuvering Unit (MMU)		1
OMV		2
OMV support systems		2
Propellant storage/transfer facility		2
Satellite Servicing Facility		2
Storage, unpressurized		1

IN-SPACE OPERATIONS
Equipment Count by Project

SUBTHEME: Material Processing

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Composites		
Autoclave	LSE	1
Camera locker	LSE	1
Camera, 35 mm	LSE	1
Cleaning equipment	LSE	2
Film locker	LSE	1
Hand tools, general purpose	LSE	2
Mass measurement device, small	LSE	1
Microscope system	LSE	2
Glovebox, materials processing	LSF	1
Workbench, laboratory sciences	LSF	2
Acceleration monitor, lab	LSS	1
Chemical storage facility	LSS	2
Materials transport system	LSS	1
Storage, process materials	LSS	2
Waste disposal system	LSS	2
Video	Std	2
Mixing facilities		1
Scanning electron microscope system		1
Crystal Growth		
Cleaning equipment	LSE	2
Cutting/polishing system	LSE	1
Etching equipment	LSE	2
Fluid handling tools	LSE	2
Hand tools, general purpose	LSE	2
Mass measurement device, small	LSE	2
Microscope system	LSE	2
Multimeter, digital	LSE	2
X-ray system	LSE	2
Glovebox, materials processing	LSF	2
Workbench, laboratory sciences	LSF	2
Acceleration monitor, lab	LSS	2
Chemical storage facility	LSS	2
Storage, sample	LSS	2
Waste disposal system	LSS	2
Data recorder, digital	Std	1
Storage, pressurized	Std	1
Hall probe		2
Optical pyrometer		1
Video, high resolution		2

SUBTHEME: Material Processing (cont'd)

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Fluids		
Autoclave	LSE	3
Camera locker	LSE	3
Camera, 35 mm	LSE	3
Cleaning equipment	LSE	4
Film locker	LSE	3
Fluid handling tools	LSE	4
Freezer	LSE	4
Freezer, cryogenic	LSE	2
Hand tools, general purpose	LSE	4
Incubator	LSE	3
Microscope system	LSE	1
Multimeter, digital	LSE	2
pH meter	LSE	3
Refrigerator	LSE	4
Storage locker, EM-shielded	LSE	1
Thermometer, digital	LSE	2
Ultraviolet sterilization unit	LSE	1
Glovebox, materials processing	LSF	5
Workbench, laboratory sciences	LSF	4
Acceleration monitor, lab	LSS	3
Chemical storage facility	LSS	4
Waste disposal system	LSS	4
Water service, lab grade	LSS	5
Data recorder, digital	Std	1
Storage, pressurized	Std	3
Video	Std	2
Video recorder	Std	3
Workstation, maintenance	Std	2
Centrifuge		2
Centrifuge, refrigerated		1
Computer, process control		2
Hand tools, laboratory		2
Sample containers		1
Tape recorder, audio		2
Video, high resolution		1

IN-SPACE OPERATIONS
Equipment Count by Project

SUBTHEME: Material Processing (cont'd)

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Materials Characterization		
Cleaning equipment	LSE	1
Cutting/polishing system	LSE	1
Electrical conductivity probe	LSE	1
Etching equipment	LSE	1
Fluid handling tools	LSE	1
Hand tools, general purpose	LSE	1
Mass measurement device, small	LSE	1
Microscope system	LSE	1
X-ray system	LSE	1
Glovebox, materials processing	LSF	1
Workbench, laboratory sciences	LSF	1
Acceleration monitor, lab	LSS	1
Chemical storage facility	LSS	1
Cleanup/decontamination equipment	LSS	1
Gas storage/supply, lab	LSS	1
Waste disposal system	LSS	1
Scanning electron microscope system		1
Video, high resolution		1
Process Technology		
Camera locker	LSE	1
Camera, 35 mm	LSE	2
Cleaning equipment	LSE	2
Cutting/polishing system	LSE	1
Etching equipment	LSE	1
Film locker	LSE	2
Fluid handling tools	LSE	1
Hand tools, general purpose	LSE	2
Incubator	LSE	1
Mass measurement device, small	LSE	1
Microscope system	LSE	1
Storage locker, EM-shielded	LSE	2
Glovebox, materials processing	LSF	2
Workbench, laboratory sciences	LSF	3
Chemical storage facility	LSS	1
Storage, process materials	LSS	2
Storage, sample	LSS	2
Vacuum vent	LSS	1
Waste disposal system	LSS	2
Data recorder, digital	Std	2
Video	Std	3
Video recorder	Std	2
Sample containers		1
Scanning electron microscope system		1
Storage, isolation		1

SUBTHEME: Material Processing (cont'd)

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Sample Handling/Storage		
Autoclave	LSE	1
Camera locker	LSE	1
Camera, 35 mm	LSE	1
Cleaning equipment	LSE	1
Etching equipment	LSE	1
Film locker	LSE	1
Fluid handling tools	LSE	1
Freeze dryer	LSE	1
Freezer	LSE	1
Hand tools, general purpose	LSE	1
Microscope system	LSE	1
pH meter	LSE	1
Refrigerator	LSE	1
Ultraviolet sterilization unit	LSE	1
Glovebox, materials processing	LSF	1
Workbench, laboratory sciences	LSF	1
Chemical storage facility	LSS	1
Vacuum vent	LSS	1
Waste disposal system	LSS	1
Water service, lab grade	LSS	1
Data recorder, digital	Std	1
Centrifuge, refrigerated		1
Gas chromatograph/mass spectrometer		1
Sample containers		1
Solid Propellants		
Camera locker	LSE	1
Camera, 35 mm	LSE	1
Film locker	LSE	1
Microscope system	LSE	1
Data recorder, digital	Std	1
Video	Std	1
Video recorder	Std	1
Solid Rocket Motor Research Facility		2
Sample containers		1
Workstation, teleoperator		1

IN-SPACE OPERATIONS
Equipment Count by Project

SUBTHEME: Systems/Facilities

EQUIPMENT ITEM	EQP CAT	MSN COUNT
CELSS		
Cleaning equipment	LSE	1
Fluid handling tools	LSE	4
Freezer	LSE	4
Mass measurement device, small	LSE	2
Microscope system	LSE	4
pH meter	LSE	4
Refrigerator	LSE	4
Washer/sanitizer, equipment	LSE	4
Glovebox, materials processing	LSF	1
Chemical storage facility	LSS	3
Gas storage/supply, lab	LSS	4
Waste disposal system	LSS	4
Water service, lab grade	LSS	4
Data recorder, digital	Std	4
Centrifuge, refrigerated		1
Gas chromatograph/mass spectrometer		1
Sample containers		3
Manned Systems		
Hand tools, general purpose	LSE	1
Data recorder, digital	Std	1
Docking port	Std	1
Video	Std	1
Video recorder	Std	1
Electrical test/checkout equipment		1
Physiological monitor		1
OTV		
Data recorder, digital	Std	2
Hand tools, EVA general purpose	Std	2
Mobile Servicing Center (MSC)	Std	3
Video, external	Std	3
Workstation, MSC telerobotic	Std	3
Berthing system, OTV		2
Dummy payload		1
Leak detector, propellant		2
Lighting, external		2
OMV		1
OMV support systems		1
Propellant storage/transfer facility		1
Servicing/maintenance hangar		1
Storage, unpressurized		2

SUBTHEME: Systems/Facilities (cont'd)

EQUIPMENT ITEM	EQP CAT	MSN COUNT
Reentry Systems		
Data recorder, digital	Std	1
Docking port	Std	1
Docking system		1
OMV		1
OMV support systems		1
Servicing/maintenance hangar		2
Storage, unpressurized		2
Technology Evaluation		
(Requirements TBD)		
Tethers		
Contamination monitor	PAE	1
Data recorder, digital	Std	1
Hand tools, EVA general purpose	Std	3
Storage, pressurized	Std	1
Storage, unpressurized	Std	1
Video	Std	1
Video recorder	Std	1
Video, external	Std	5
Berthing system, OTV		1
Cleaning equipment, optics		1
Cryogen storage/transfer facility, LHe		1
Lighting, external		2
OMV		1
OMV support systems		1
OTV		1
Satellite Servicing Facility		1
Tether alignment system		2
Tether tracking system		5
Tethered pointing system		1
Transmitter/receiver		1

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APPENDIX E. New Development Candidates for TDM Outfitting

This section contains two versions of a list of potential outfitting items -- one sorted by mission count and the other sorted alphabetically. For each mission a list of outfitting equipment needs was generated that included outfitting items requested in the mission descriptions, support items thought to be of benefit where none were identified, key items of Space Station accommodation equipment, and items of experiment equipment thought to have multi- use potential. These mission-level equipment lists were consolidated into a master list. The list presented here is what is left after subtracting from the master list those items known to be in planning. As such, it represents outfitting needs for technology development missions that are not already being met.

EQUIPMENT ITEMS WITH COMMON-USE POTENTIAL BY DESCENDING COUNT (Sheet 1 of 2)

ITEM	MISSION COUNT
Storage, unpressurized	61
Accelerometer package, external	29
Lighting, external	20
OMV support systems	19
Sample containers	19
OMV	18
Tape recorder, audio	17
Mass spectrometer	14
Exposure tray	13
Physiological monitor	12
Pointing mount, two-axis solar	12
Imaging radiometer	11
Plasma ground	11
Speech generator	10
Electrode impedance meter	9
Graphics display, high resolution	9
Propellant storage/transfer facility	9
Radiometer	9
Visual task generator	9
Workstation, telerobotic	9
Plasma diagnostic package	8
Sun sensor	8
Workstation, teleoperator	8
Camera, high speed cinema	7
Computer-video generator	7
Leak detector, propellant	7
Video, low light (external)	7
Film magazines	6
Window, viewing	6
Film locker, cinema	5
Gas chromatograph/mass spectrometer	5
Laser measurement unit	5
Potential probe	5
Reflectometer	5
Tether tracking system	5
Transmitter/receiver, RF	5
Video, external (SRRL)	5
Anechoic chamber	4
Assembly platform	4
Battery charger, external	4
Camera, 35 mm (EVA)	4
Camera, cinema	4
Centrifuge	4
Cleaning materials, EVA	4
Computer (VAX 11/780 or equivalent)	4
Data recorder, digital	4
Proximity sensor	4
Solid Rocket Motor Research Facility	4
Stress test machine	4
Video, high resolution	4
Antenna positioner, large	3
Berthing system, OTV	3

ITEM	MISSION COUNT
Camera locker, cinema	3
Centrifuge, refrigerated	3
Computer, graphics/experiment control	3
Cryogen storage/transfer facility	3
Cryogen storage/transfer facility, LHe	3
Gas storage/transfer facility	3
Isolator, mechanical	3
Range sensor, laser	3
Retroreflective targets	3
Satellite Servicing Facility	3
Scanning electron microscope system	3
Servicing/maintenance hangar	3
Vacuum chamber	3
Airlock, scientific	2
Amplifiers	2
Animal holding facility	2
Antenna positioner, medium	2
Blood sample kit	2
Cleaning equipment, optics	2
Computer, process control	2
Docking system	2
Dynamometer	2
EMU	2
Ergometer	2
Global Positioning System (GPS)	2
Hall probe	2
Hand tools, laboratory	2
Magnetometer	2
Radiation monitor	2
Radiation monitor, internal	2
Spectrophotometer	2
Tether alignment system	2
Ultrasonic test unit	2
Urine sample kit	2
Visual pulse generator	2
Window, high-quality optical	2
Assembly bay	1
Audiometer	1
Battery storage	1
Bi-directional reflectance instrument	1
Calibration/servicing equipment--optical	1
Computer, AI	1
Computer, experimemt control	1
Computer, parallel processor	1
Counter	1
Cryo storage/transfer facility, lab LHe	1
Digital word generator	1
Docking assembly	1
Dummy payload	1
Electrical stimulation pulse generator	1
Electrical test/checkout equipment	1
Frequency analyzer	1

EQUIPMENT ITEMS WITH COMMON-USE POTENTIAL BY DESCENDING COUNT (Sheet 2 of 2)

ITEM	MISSION COUNT
Frequency standard, hydrogen maser	1
Gas sampling bottles	1
Hand wash facility	1
Image intensifier	1
Inertial reference unit	1
Interferometer, holographic	1
Joystick	1
Laser Doppler anemometer	1
Leak detector, He	1
Logic analyzer	1
Manned Maneuvering Unit (MMU)	1
Manned Maneuvering Unit (MMU) with FSS	1
Mixing facilities	1
Noise dosemeter	1
Noise monitor	1
OMV (with Smart Front End)	1
Optical disk drive	1
Optical pyrometer	1
Orbit transfer vehicle, low thrust	1
OTV	1
Photo processor unit	1
Plasma diagnostic probe	1
Plethysmograph	1
Power amplifier	1
Power supply, programmable	1

ITEM	MISSION COUNT
Radiation monitor, EM	1
Range sensor, radar	1
Rendezvous radar	1
Respiratory monitoring system	1
Retarding potential analyzer	1
RF power meter	1
Shroud, cover	1
Sound level meter	1
Space Station Construction Platform	1
Spectrophotometer, imaging (external)	1
Spectrum analyzer	1
Spirometer	1
Sterilization facility	1
Storage, isolation	1
Storage, pressurized	1
Temperature monitor, ambient	1
Test instruments, electronic	1
Tether system	1
Tethered pointing system	1
Tools, optical alignment	1
Transmitter/receiver	1
Treadmill	1
Truss extension arm	1
Waveform digitizer	1
Workbench, optical	1
X-ray unit	1

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ALPHABETIC LISTING OF EQUIPMENT ITEMS WITH COMMON-USE POTENTIAL (Sheet 1 of 2)

ITEM	MISSION COUNT
Accelerometer package, external	29
Airlock, scientific	2
Amplifiers	2
Anechoic chamber	4
Animal holding facility	2
Antenna positioner, large	3
Antenna positioner, medium	2
Assembly bay	1
Assembly platform	4
Audiometer	1
Battery charger, external	4
Battery storage	1
Berthing system, OTV	3
Bi-directional reflectance instrument	1
Blood sample kit	2
Calibration/servicing	1
Camera locker, cinema	3
Camera, 35 mm (EVA)	4
Camera, cinema	4
Camera, high speed cinema	7
Centrifuge	4
Centrifuge, refrigerated	3
Cleaning equipment, optics	2
Cleaning materials, EVA	4
Computer (VAX 11/780 or equivalent)	4
Computer, AI	1
Computer, experiment control	1
Computer, graphics/experiment control	3
Computer, parallel processor	1
Computer, process control	2
Computer-video generator	7
Counter	1
Cryo storage/transfer facility, lab LHe	1
Cryogen storage/transfer facility	3
Cryogen storage/transfer facility, LHe	3
Data recorder, digital	4
Digital word generator	1
Docking assembly	1
Docking system	2
Dummy payload	1
Dynamometer	2
Electrical stimulation pulse generator	1
Electrical test/checkout equipment	1
Electrode impedance meter	9
EMU	2
Ergometer	2
Exposure tray	13
Film locker, cinema	5
Film magazines	6
Frequency analyzer	1
Frequency standard, hydrogen maser	1
Gas chromatograph/mass spectrometer	5
Gas sampling bottles	1

ITEM	MISSION COUNT
Gas storage/transfer facility	3
Global Positioning System (GPS)	2
Graphics display, high resolution	9
Hall probe	2
Hand tools, laboratory	2
Hand wash facility	1
Image intensifier	1
Imaging radiometer	11
Inertial reference unit	1
Interferometer, holographic	1
Isolator, mechanical	3
Joystick	1
Laser Doppler anemometer	1
Laser measurement unit	5
Leak detector, He	1
Leak detector, propellant	7
Lighting, external	20
Logic analyzer	1
Magnetometer	2
Manned Maneuvering Unit (MMU)	1
Manned Maneuvering Unit (MMU) with FSS	1
Mass spectrometer	14
Mixing facilities	1
Noise dosemeter	1
Noise monitor	1
OMV	18
OMV (with Smart Front End)	1
OMV support systems	19
Optical disk drive	1
Optical pyrometer	1
Orbit transfer vehicle, low thrust	1
OTV	1
Photo processor unit	1
Physiological monitor	12
Plasma diagnostic package	8
Plasma diagnostic probe	1
Plasma ground	11
Plethysmograph	1
Pointing mount, two-axis solar	12
Potential probe	5
Power amplifier	1
Power supply, programmable	1
Propellant storage/transfer facility	9
Proximity sensor	4
Radiation monitor	2
Radiation monitor, EM	1
Radiation monitor, internal	2
Radiometer	9
Range sensor, laser	3
Range sensor, radar	1
Reflectometer	5
Rendezvous radar	1

ALPHABETIC LISTING OF EQUIPMENT ITEMS WITH COMMON-USE POTENTIAL (Sheet 2 of 2)

ITEM	MISSION COUNT
Respiratory monitoring system	1
Retarding potential analyzer	1
Retroreflective targets	3
RF power meter	1
Sample containers	19
Satellite Servicing Facility	3
Scanning electron microscope system	3
Servicing/maintenance hangar	3
Shroud, cover	1
Solid Rocket Motor Research Facility	4
Sound level meter	1
Space Station Construction Platform	1
Spectrophotometer	2
Spectrophotometer, imaging (external)	1
Spectrum analyzer	1
Speech generator	10
Spirometer	1
Sterilization facility	1
Storage, isolation	1
Storage, pressurized	1
Storage, unpressurized	61
Stress test machine	4
Sun sensor	8
Tape recorder, audio	17
Temperature monitor, ambient	1

ITEM	MISSION COUNT
Test instruments, electronic	1
Tether alignment system	2
Tether system	1
Tether tracking system	5
Tethered pointing system	1
Tools, optical alignment	1
Transmitter/receiver	1
Transmitter/receiver, RF	5
Treadmill	1
Truss extension arm	1
Ultrasonic test unit	2
Urine sample kit	2
Vacuum chamber	3
Video, external (SRRL)	5
Video, high resolution	4
Video, low light (external)	7
Visual pulse generator	2
Visual task generator	9
Waveform digitizer	1
Window, high-quality optical	2
Window, viewing	6
Workbench, optical	1
Workstation, teleoperator	8
Workstation, telerobotic	9
X-ray unit	1

NASA National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-181707		

4. Title and Subtitle	5. Report Date
Space Station RT&E Utilization Study	September 1989
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
P. K. Wunsch and P. H. Anderson	
	10. Work Unit No. 480-51-23-03

9. Performing Organization Name and Address	11. Contract or Grant No.
Teledyne Brown Engineering Cummings Research Park Huntsville, AL 35807	NAS1-18228
	13. Type of Report and Period Covered: Contractor Report

12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeroanutics and Space Administration Langley Research Center Hampton, VA 23665-5225	

15. Supplementary Notes

Langley Technical Monitor: Lenwood G. Clark
Final Report - Task 4

16. Abstract

Descriptive materials on a set of 241 mission concepts were reviewed to establish preliminary Space Station outfitting needs for technology development missions. The missions studied cover the full range of in-space technology development activities envisioned for early Space Station operations and included both pressurized volume and attached payload requirements. Equipment needs were compared with outfitting plans for the life sciences and microgravity user communities, and a number of potential outfitting additions were identified. Outfitting implementation was addressed by selecting a strawman mission complement for each of seven technical themes, by organizing the missions into flight scenarios, and by assessing the associated outfitting buildup for planning impacts.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Space Station Outfitting Technology Development Experiments	Unclassified - Unlimited Subject Category 15

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	108	A06